

**Sleep, Memory, Cognition and Wellbeing in Participants with Vascular Dementia and in
Healthy Older and Younger Adults.**

Submitted to Swansea University in fulfilment of the requirements for the
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by

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Summary

Vascular Cognitive Impairment (VCI) is the second most common form of dementia and may be the most prevalent due to evolving diagnostic criteria. However, the relationship between sleep disturbances, cognitive decline, and wellbeing in VCI remains poorly understood. While evidence highlights the role of sleep in cognitive health, most research has focused on Alzheimer's disease, overlooking how sleep disturbances uniquely affect VCI. This thesis addresses this gap through studies aimed at understanding and improving sleep and wellbeing in VCI populations.

Chapter 1 utilised the National Alzheimer's Coordinating Center Uniform Data Set to show that individuals with Vascular Dementia (VaD) and sleep disturbances had significantly poorer performance in orientation, memory, executive function, and global cognition compared to those without sleep disturbances, highlighting the importance of considering sleep disturbances in VCI diagnosis and management.

Chapter 2 develops and validates a narrative-based emotional memory task in healthy young adults to assess sleep-dependent memory consolidation designed for future use in VCI populations. Findings show enhanced declarative memory following sleep compared to wakefulness; however, the expected preferential consolidation of emotional over neutral content was not observed. To support future research in clinical populations, including VCI, an automatic scoring tool was developed to improve narrative analysis efficiency and reliability.

Chapter 3 evaluates a bedtime fiction reading intervention, showing improved subjective sleep quality and objective Total Sleep Time in healthy older adults and those with subjective cognitive decline, with differing effects on wellbeing. A feasibility study with VaD participants confirmed its applicability in VCI.

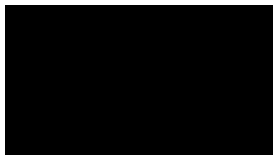
Chapter 4 explores online recruitment and retention challenges in older adults, offering recommendations to enhance participant retention and study design.

Collectively, this thesis advances understanding of how sleep disturbances contribute to cognitive and wellbeing outcomes in VCI and highlights the potential of non-pharmacological interventions to improve sleep and wellbeing in this under-researched population.

Keywords: Sleep, Cognition, Memory, Vascular Cognitive Impairment, Vascular Dementia, Mild Cognitive Impairment, Subjective Cognitive Decline, Sleep-Intervention, Fiction, Reading, Emotional Memory Consolidation, Wellbeing, Mild Cognitive Impairment

Declarations

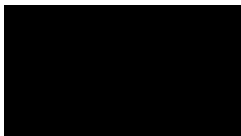
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Statement 1

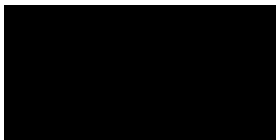
This thesis is the result of my own investigations, except where otherwise stated. Where correction services have been used, the extent and nature of the correction is clearly marked in a footnote(s). Other sources are acknowledged by footnotes giving explicit references. A bibliography is appended.

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Contents Page

Summary	2
Keywords: Sleep, Cognition, Memory, Vascular Cognitive Impairment, Vascular Dementia, Mild Cognitive Impairment, Subjective Cognitive Decline, Sleep-Intervention, Fiction, Reading, Emotional Memory Consolidation	3
Declarations	4
Contents Page.....	6
Acknowledgements.....	13
List of Tables.....	14
List of Figures	18
Abbreviations.....	21
List of Publications, Conferences, Presentation and Awards During Candidature	23
Chapter 1. General Introduction	25
1.1 Overview	25
1.2 Overview of Sleep.....	29
1.2.1 Sleep Architecture	29
1.2.2 Circadian Rhythms.....	30
1.2.3 The Neurobiology of Sleep and of Sleep-Wake Regulation	32
1.2.4 Measurement of Sleep.....	33
1.2.5 Defining Sleep Health: The SATED Model.....	36
1.3 Sleep Changes in Aging	39
1.3.1 Macro Changes in Sleep Architecture with Aging.....	39
1.3.2 Micro Changes in Sleep Architecture with Aging	41
1.3.3 Potential Mechanisms Underlying Sleep Changes with Aging	43
1.3.4 Individual Variability in Sleep Changes with Aging.....	44
1.3.5 The Relationship Between Sleep and Cognition in Healthy Ageing	45
1.3.6 Healthy Older Adults and Cognition.....	46
1.3.7 Summary of Sleep and Cognition in Healthy Ageing.....	49

1.4	Sleep and Dementia	50
1.4.1	Sleep and Vascular Cognitive Impairment (VCI)	53
Chapter 2. The Effect of Sleep Disturbances on Cognitive Performance in Vascular Cognitive Impairment: Findings from the National Alzheimer's Coordinating Center Uniform Dataset		59
2.1	Abstract	59
2.2	Introduction	60
2.2.1	Conceptual Advantages and Disadvantages of VCI	61
2.2.2	Cognitive Symptoms in VCI	62
2.2.3	Importance of cognitive characterisation in VCI	63
2.2.4	Potential Sleep-Related Mechanisms in VCI	66
2.2.5	The Importance of Understanding the Effects of Sleep on Cognitive Symptoms in VCI	66
2.3	Aims of The Study	68
2.3.1	Aims:	69
2.3.2	Hypotheses	70
2.4	Method	71
2.4.1	The National Alzheimer's Coordinating Center Uniform Data Set	71
2.4.2	Participants	71
2.4.3	Materials	74
2.5	Analysis	81
2.6	Results	82
2.6.1	Global Cognition	83
2.6.2	Orientation	90
2.6.3	MoCA Orientation	92
2.6.4	Visuospatial	94
2.6.5	Executive Function	98
2.6.6	Attention	101
2.6.7	Memory	103
2.6.8	Language	116
2.6.9	Summary of Findings	118

2.7	Discussion	121
2.7.1	VaD Group Findings	122
2.7.2	MCI and SCD	127
2.7.3	Limitations	129
2.7.4	Future Research and Implications.....	130
Chapter 3. Sleep-Dependent Emotional Memory Consolidation: Development of a Narrative Task, Preliminary Findings in Young and Older Adults, and Implications for Future Research for Individuals with Vascular Cognitive Impairment		132
3.1	Abstract	132
3.2	Introduction.....	133
3.2.1	Sleep and Memory Overview	134
3.2.2	Sleep, Memory and Dementia.....	136
3.2.3	Emotional Memory Overview	138
3.2.4	Aims of the Chapter	145
3.3	Pilot Study 1.....	147
3.3.1	Method	147
3.3.2	Analysis.....	153
3.3.3	Results.....	154
3.3.4	Discussion	156
3.4	Pilot Study 2.....	158
3.4.1	Introduction.....	158
3.4.2	Method	159
3.4.3	Analysis.....	161
3.4.4	Results.....	162
3.4.5	Discussion	170
3.5	Study 3: Examining the Effect of Sleep-Dependent Memory Consolidation on Emotional Memory Performance Using Narratives in Young Adults.....	172
3.5.1	Method	172
3.5.2	Analysis.....	177
3.5.3	Results.....	178
3.5.4	Discussion	185
3.6	Study 4: Automatic Narrative Scoring Tool.....	188

3.6.1	Introduction.....	188
3.6.2	Development.....	191
3.6.3	Designing the tool.....	195
3.6.4	Implementation and Functional Testing.....	196
3.6.5	Functionalities and Features	203
3.6.6	Initial testing and Iterations	203
3.6.7	Final code.....	432
3.6.8	Validation	207
3.6.9	Error Analysis Post Count.....	212
3.6.10	Discussion.....	215
3.7	Study 5: Examining the Effect of Sleep-Dependent Memory Consolidation on Emotional Memory Performance Using Narratives in Older Adults: A Case Study of 5 Older Adults.....	217
3.7.1	Method.....	217
3.7.2	Results.....	220
3.7.3	Discussion.....	222
3.8	Chapter 5: General Discussion.....	224
Chapter 4. The Impact of Bedtime Fiction Reading on Sleep, Wellbeing, and Mood in Healthy Older Adults and Individuals with Vascular Dementia		228
4.1	Abstract.....	228
4.2	Introduction.....	229
4.3	Aims.....	235
4.4	Objectives	235
4.5	Research Questions.....	236
4.5.1	Additional research questions:.....	236
4.6	Hypotheses:.....	236
4.7	Study 1: Healthy Older Adults and Adults with Self-Reported Subjective Cognitive Decline.....	238
4.7.1	Method.....	238
4.7.2	Materials	242
4.7.3	<i>Mood Disturbances</i>	247

4.7.4	Procedure	249
4.7.5	Analysis.....	254
4.7.6	Wellbeing	257
4.7.7	Wellbeing and Sleep.....	257
4.7.8	Mood	258
4.7.9	Reading	258
4.7.10	Covariates	258
4.7.11	Participants Analysis.....	259
4.7.12	Results.....	261
4.7.13	Main Effects.....	266
4.7.14	Discussion	284
4.8	Vascular Dementia and Fiction Reading.....	293
4.8.1	Method	293
4.8.2	Design, Materials, and Procedure	293
4.8.3	Presentation of Findings	294
4.8.4	Results.....	295
4.8.5	Discussion.....	305
Chapter 5. Addressing the Challenges of Online Research Recruitment and Participation Among Older Adults: Insights and Recommendations Based on Reflections from Studies in This Thesis		307
5.1	Abstract.....	307
5.2	Introduction.....	308
5.2.1	Medical	309
5.2.2	Cognition.....	309
5.2.3	Commitment	310
5.2.4	Gatekeepers.....	310
5.2.5	Access to Research Sites.....	311
5.2.6	Online Research.....	311
5.3	Aim and Objectives.....	312
5.4	Method.....	314
5.4.1	Design and Analysis.....	314
5.4.2	Ethical approval, Data management and Security	314

5.4.3	Participants.....	314
5.4.4	Procedure	318
5.5	Results.....	319
5.5.1	Study 1: Emotional Memory Study with Healthy Older Adults	319
5.5.2	Study 2: 8-week Fiction reading study with Older Adults and Adults living with VaD and their Study Partners.....	320
5.5.3	Researcher Engagement.....	322
5.5.4	Correspondences for those enrolled in the study	322
5.5.5	Methodological Challenges	325
5.5.6	Technological Challenges	325
5.5.7	Protocol Adherence and Scheduling	326
5.5.8	Environmental and Personal Factors	327
5.5.9	Communication and Trust Issues with Researchers.....	328
5.5.10	Data Quality and Integrity Concerns	329
5.5.11	Cognitive Capacity and Study Comprehension	329
5.6	Discussion.....	331
5.6.1	Technological challenges	332
5.6.2	Protocol Adherence and Scheduling	333
5.6.3	Communication and Trust Issues with Researchers.....	334
5.6.4	Data Quality and Integrity Concerns	335
5.6.5	Cognition.....	335
5.6.6	Conclusion	336
Chapter 6.	General Discussion.....	338
6.1	Overview.....	338
6.2	Chapter 2: The Effect of Sleep Disturbances on Cognitive Performance in Vascular Cognitive Impairment: Findings from the National Alzheimer’s Coordinating Center Uniform Dataset.....	340
6.3	Chapter 3: Sleep-Dependent Emotional Memory Consolidation: Development of a Narrative Task, Preliminary Findings in Young and Older Adults, and Implications for Future Research for Individuals with Vascular Cognitive Impairment.....	341
6.4	Chapter 4: The Effect of Bedtime Fiction Reading on Sleep, Wellbeing, and Mood in Healthy Older Adults and Individuals with Subjective Cognitive Decline.	343

6.5	Chapter 5: Addressing the Challenges of Online Recruitment and Participation in Research Among Older Adults: Insights and Recommendations Based on Reflections from Studies in This Thesis	345
6.6	Limitations	346
6.7	Future studies	349
6.8	Conclusion	350
References		352
Appendices		427
	Appendix A	428
	Appendix B	432
	Appendix C	531

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List of Tables

Table 1: SATED Dimensions with Recommendations for Achieving Good Sleep Health.....	37
Table 2: VCI Terminology (Bir et al., 2021).....	61
Table 3: Demographic Characteristics According to Group	73
Table 4: Summary of Measures According to Cognitive Domain, Measure and Corresponding Maximum Score.....	80
Table 5: Global MoCA Scores Adjusted for Years of Education.....	83
Table 6: Total MMSE Score (Using D-L-R-O-W Subdomains).....	86
Table 7: Mean Orientation scores according to MMSE (out of 10)	90
Table 8: MoCA Total Orientation Scores.....	92
Table 9: Mean Scores for Copy of Benson Figure.....	94
Table 10: Mean Total Score for Composite MoCA Visuospatial Items.....	96
Table 11: Total Number of Correct Lines for Part B of the Trail-Making Task.....	98
Table 12: Total Number of Commission Errors of the Trail-Making Task -Part B	100
Table 13: Mean and SD Scores for Composite MoCA Attention Subscale Tasks	102
Table 14: Total Number of Correct Trials in Digit Span-Forward.....	103
Table 15: Total Number of Correct Trials in Digit Span-Backwards	105
Table 16: Total Number of units recalled on the Immediate LM subtest of the WMS-R.....	107
Table 17: Total Number of units recalled on the Delayed LM subtest of the WMS-R.....	108
Table 18: Total Mean and SD Memory Index Score out of 15 per group.....	111
Table 19: Mean Verbatim Score on the Immediate Craft-21 Assessment.....	113
Table 20: Mean Verbatim Score on the Delayed Craft-21 Assessment	114
Table 21: Total Mean Category Fluency for Animals and Vegetables Out of 144	116
Table 22: Summary of Findings.....	118
Table 23: Stories Developed for Pilot Study 1 with Corresponding Authors	147

Table 24: Total Word Count, Number of Sentences, Scored content and Total Buffer Words Per Story.....	149
Table 25: Results of Repeated Measures 3x2 Factorial ANOVAs, Including Assumption Test Statistics and Post-hoc Comparisons	155
Table 26: Recall Means and Standard Error of the Total Score (%) for Each Story.....	162
Table 27: Recall means (SE) in Analysis 1, including all 12 stories, and recall means (SE) in Analysis 2.....	163
Table 28: Main effects and interactions of Evaluation ratings along with Sphericity checks and significant pairwise comparisons using a Bonferroni Correction.	165
Table 29: Eligibility and Exclusion Criteria	172
Table 30: Participant Randomisation and Counterbalancing	176
Table 31: Equivalency Statistics Including Assumption Checks	178
Table 32: Rating Matrices Results, Including Main Effects of Valece and Version and Interactions.....	181
Table 33: Descriptives (mean, SD, with measure of forgetting content words T2%-T1%) ..	182
Table 34: Sphericity Checks for Main Effects and Interactions of Main Analysis.....	183
Table 35: Examples of Modal and Copula Verbs.....	193
Table 36: New Word Count for Stories.....	194
Table 37: Manual Scoring Table Results	209
Table 38: Final Manual Count Versus Final Python Code Count.....	213
Table 39: Change Scores From T2% To T1% as a Percentage Of Correct Content Words...	220
Table 40: Inclusion and Exclusion Criteria for SCD and HOA groups	240
Table 41: Participant Demographics by Group Stratification.....	242
Table 42: Materials and Measures According to Domain of Interest	243
Table 43: DASS-21 Symptom Severity Scoring Thresholds	247
Table 44: Actigraphy Parameter Measurements	256

Table 45: Descriptive Statistics for Objective and Subjective Sleep Quality and Objective Sleep Variables.....	261
Table 46: Descriptive Statistics for Wellbeing Variables (PERMA-Profiler)	262
Table 47: Descriptive Statistics for Mood Variables (DASS-21 Item)	263
Table 48: Descriptive Statistics for Reading Variables	263
Table 49: Assumption Checks for Independent Samples T-Test conducted on Baseline Variables.....	265
Table 50: Assumption Statistics for Main Effects of 3x2 factorial ANOVAs.....	267
Table 51: Secondary Analysis Main Effects, Between-Subject Differences, and Interaction Statistics	268
Table 52: Post-Hoc Tests for Secondary Main Analysis using Bonferroni Correction	270
Table 53: Correlation Statistics between Changes in Sleep Quality from Baseline to the Intervention	280
Table 54: Correlation Statistics between Changes in Sleep Quality and Wellbeing Measures from Baseline to the Intervention	280
Table 55: Correlation Statistics between Changes in Sleep Quality and Mood Disturbances Measures from Baseline to the Intervention	281
Table 56: Correlation Statistics between Changes in Sleep Quality from Baseline to the End of the Intervention Phase and Measures of Narrative Engagement Taken at the End of the Reading Period.....	282
Table 57: Sleep quality (CSD, Actigraphy and PSQI) across an 8-week Study Period.....	295
Table 58: Inclusion/Exclusion Criteria for Older Adult Emotional Memory Study	316
Table 59: Inclusion/Exclusion Criteria for Fiction Reading Study.....	317
Table 60: Number of People for Outcome Measures for Each Study/Cohort	319
Table 61: Number of Correspondences with Participants in the Emotional Memory Study Involving Older Adults	323
Table 62: Number of Correspondences with Participants in the 8-Week Fiction Reading Study Involving Older Adults	323

Table 63: Combined Total Engagement (once showed interest).....	324
Table 64: Combined Total Recruitment effort (including invitations).....	325
Table 65: Descriptive Statistics for Objective and Subjective Sleep Quality and Objective Sleep Variables.....	531
Table 66: Descriptive Statistics for Wellbeing Variables Across 3 Study Phases.....	549

List of Figures

Figure 1: Sleep Architecture Changes Over the Lifespan (Ohayon et al., 2004).....	41
Figure 2: Global MoCA Score After Adjusting for Years of Education According to Group with and without Sleep Issues.....	85
Figure 3: Total MMSE Score Assessing D-L-O-W Subdomains	88
Figure 4: Mean Orientation scores according to MMSE (out of 10).....	90
Figure 5: Mean Total Scores for Copy of the Benson Figure (Visuospatial).....	94
Figure 6: Total Composite Score for MoCA Visuospatial Items	96
Figure 7: Total number of correct lines on the trail-making task, Part B.	98
Figure 8: Total Number of Commission Errors of the Trail-Making Task -Part B.....	100
Figure 9: MoCA Attention Composite.....	102
Figure 10: Total Number of Correct Trials in Digit Span-Forward	103
Figure 11: Total Number of Correct Trials in Digit Span-Backwards	105
Figure 12: Mean Number of units recalled on the Immediate LM subtest of the WMS-R ...	107
Figure 13: Mean Number of units recalled on the Delayed LM subtest of the WLM-R.....	109
Figure 14: Total MoCA Memory Index Score out of 15.....	111
Figure 15: Mean Verbatim Score on the Immediate Craft-21 Assessment.....	113
Figure 16: Mean Verbatim Score on the Delayed Craft-21 Assessment.....	115
Figure 17: Mean Category Fluency for Animals and Vegetables Out of 144.....	116
Figure 18: Rating Matrix Used to Evaluate Narrative Texts	152
Figure 19: Percentage of correct words recalled at initial recall for the sleep-first, wake- second group according to story valence (Positive, Neutral and Negative)	180
Figure 20: Forgetting (T2%-T1%) Across Sleep and Wake Conditions.....	184
Figure 21: A sample of The Dental Exam with class words automatically identified and coloured using OneNote Immersive Reader.	191

Figure 22: Sample Story Segmentation Entries	205
Figure 23: Output Of An Analysed Sample Story With Respective Counts, Highlighted Words And Counted Synonyms	206
Figure 24: Median Change in Recall Performance From Delayed Recall (T2%) Minus Initial Recall (T1%) Across Valence and Sleep and Wake Conditions	220
Figure 25: Median Change in Recall Performance From Delayed Recall (T2%) Minus Initial Recall (T1%) Across Sleep and Wake Conditions	221
Figure 26: Median Change in Recall Performance From Delayed Recall (T2%) Minus Initial Recall (T1%) Across Valence	221
Figure 27: A Schematic overview of the Study Procedure	254
Figure 28: CSD sleep diary quality across 3 study phases	296
Figure 29: PSQI Sleep Quality	297
Figure 30: Actigraphic Sleep Quality (Composite Z-Score).....	299
Figure 31: Global Mood Disturbances (DASS-21)	301
Figure 32: Global Wellbeing (PERMA-Profiler).....	302
Figure 33: Neuropsychiatric Symptoms- Participant 1	303
Figure 34: Neuropsychiatric Symptoms- Participant 2.....	303
Figure 35: Mean Reading Time (Minutes) Across 4-week Reading Period	304
Figure 36: Global PSQI Scores Across 3 Study Phases.....	538
Figure 37: CSD Sleep Diary Quality Across 3 Study Phases	539
Figure 38: Actigraphic Sleep Quality Composite Score Across 3 Study Phases	540
Figure 39: Mean Total Sleep Time (Seconds) Across 3 Study Phases.....	541
Figure 40: Mean Sleep Onset Latency (Seconds) Across 3 Study Phases.....	542
Figure 41: Mean Sleep Efficiency (%) Across 3 Study Phases	544
Figure 42: Mean Sleep Fragmentation Index Scores Across 3 Study Phases.....	545
Figure 43: PSQI Sleep Quality Versus CSD Sleep Diary Quality at Intervention Phase	546
Figure 44: Actigraphy Sleep Quality Versus CSD Sleep Quality at Intervention Phase	547

Figure 45: Actigraphy Sleep Quality Score Versus PSQI Sleep Quality Score at The	
Intervention Phase.....	548

Abbreviations

AD	Alzheimer's disease
aMCI	Amnesic Mild Cognitive Impairment
Aβ	Amyloid- β
CCI	Cognitive Change Index
CSD	Consensus Sleep Diary
CVD	Cerebrovascular Disease
DASS-21	Depression, Anxiety and Stress Scale-21 Item
EEG	Electroencephalogram
ESS	Epworth Sleepiness Scale
FFT	Fast Fourier Transform
HOA	Healthy Older Adult
MCI	Mild Cognitive Impairment
MMS	Mini Mental State Examination
MoCA	Montreal Cognitive Assessment
mPFC	Medial Prefrontal Cortex
MID	Multi-Infarct Dementia
naMACI	Non-Amnesic Mild Cognitive Impairment
NPI-Q	Neuropsychiatric Inventory Questionnaire
NPS	Neuropsychiatric Symptoms
NPT	Non-Pharmacological Treatment
OSA	Obstructive Sleep Apnoea
PFC	Prefrontal Cortex
PSG	Polysomnography
PSQI	Pittsburgh Sleep Quality Index
REM	Rapid Eye Movement
SCD	Subjective Cognitive Decline
SDB	Sleep Disordered Breathing
SE	Sleep Efficiency
SFI	Sleep Fragmentation Index
SOL	Sleep Onset Latency
SSS	Stanford Sleepiness Scale

SWA	Slow Wave Activity
SWAS	Story World Absorption Scale
SWS	Slow Wave Sleep
ToM	Theory of Mind
TST	Total Sleep Time
VaD	Vascular Dementia
VCI	Vascular Cognitive Impairment
vMCI:	Vascular Mild Cognitive Impairment
WASO	Wake After Sleep Onset

List of Publications, Conferences, Presentation and Awards During Candidature

Publications

Reid, A., Bloxham, A., Carr, M., Van Rijn, E., Basoudan, N., **Tulip, C.**, & Blagrove, M. (2022). Effects of sleep on positive, negative and neutral valenced story and image memory. *British Journal of Psychology*, 113(3), 777–797.
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Conference Presentations

Tulip, C. (2021, July). Keynote Speaker. Collaborative Partnerships in Wellbeing Research. Presentation at the Summer of Hope: Multidisciplinary Wellbeing Symposia, Swansea University, UK.

Tulip, C. (2022) Keynote Speaker. Together 4 Dementia, a conference held by BRACE, a dementia charity, UK.

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Tulip, C (2023) Speaker. Postgraduate Research Festival, Swansea University, UK.

Tulip, C. (2023) Keynote Speaker. Together 4 Dementia, a conference held by BRACE, a dementia charity, UK.

Presentations and Seminars

Tulip, C. (2020) Podcast. Finding Your PhD Feet. Dementia Researcher. National Institute of Health Research. UK. <https://www.dementiaresearcher.nihr.ac.uk/podcast-finding-your-phd-feet/>

Tulip, C (2020). Podcast. Looking Back and Learning from the PhD Years. Dementia Researcher. National Institute of Health Research. UK.
<https://www.dementiaresearcher.nihr.ac.uk/podcast-looking-back-and-learning-from-the-phd-years/>

Tulip, C (2022) 6-Week Workshop. Sleeping Well. Crisis, UK.

Tulip, C (2023). 6-Week Workshop. Sleeping Well. The Wallich, UK.

Tulip, C (2023). 6-Week Workshop. Sleeping Well. Faith In Families, UK.

Tulip, C (2023). Speaker. The Science of Sleeping Well. Bangor University, UK.

Tulip, C (2023) Keynote Speaker. Webinar. The Science of Sleep. The Food Medic.

Tulip, C (2024). 6-Week Workshop. Sleeping Well. Crisis, UK.

Awards

Tulip, C. (2022) Winner. The Big Pitch Award (£1500 prize). Award ceremony held at Swansea University.

Tulip, C (2022) Runner-up. Impactober Impact Excellence Award. A competition for research demonstrating real-world impact across the Faculty of Medicine.

Tulip, C (2023) Winner. Outstanding Contribution to the PGR Student Experience or Community. Postgraduate Research Festival, Swansea University

Tulip, C. (2024) Winner. Outstanding Contribution to Public Engagement. Postgraduate Research Festival, Swansea University.

Chapter 1. General Introduction

1.1 Overview

Dementia is an umbrella term for a group of clinical syndromes characterised by the development and progression of cognitive impairment that significantly interferes with daily function and is beyond what is expected for normal ageing (Arvanitakis et al., 2019; Bir et al., 2021). Cognitive impairment refers to objective deficits in various domains of thinking, such as memory, attention, language, reasoning, and problem-solving abilities (Morley, 2018; Ismail et al., 2021). As of 2019, the number of people living worldwide with dementia was 57.4 million and is projected to rise to 152.8 million cases in 2050 (Nichols et al., 2022). The rising prevalence and costs of dementia care highlight the need for an improved understanding of causal and contributing risk factors, early diagnosis, monitoring, and treatment strategies (Wimo et al., 2023).

Dementia encompasses a range of subtypes, each with distinct underlying pathologies and clinical presentations. Among these subtypes, Alzheimer's Disease (AD) is the most common form of dementia, accounting for approximately 60 to 80% of cases (Scheltens et al., 2016). AD is primarily characterised by the accumulation of amyloid-beta (amyloid- β) plaques and neurofibrillary tangles composed of hyperphosphorylated tau protein (Scheltens et al., 2016; Soria Lopez et al., 2019). These pathological changes lead to neuronal loss, synaptic dysfunction, and neuroinflammation, particularly in regions critical for memory and cognitive function, such as the medial temporal lobe, especially the hippocampus and entorhinal cortex (Reddy & Beal, 2008; Scheltens et al., 2016; Soria Lopez et al., 2019). This results in a progressive decline in cognitive abilities, typically affecting episodic memory first, followed by impairments in executive function, language, and visuospatial skills over time (Soria Lopez et al., 2019).

Vascular Dementia (VaD) is the second most prevalent form of dementia, contributing to about 15 to 20% of all cases (Plassman et al., 2007; Cipollini et al., 2020; Bir et al., 2021). VaD results from cerebrovascular disease (CVD), which refers to conditions that affect blood supply within the brain, such as haemorrhages and blood flow restrictions (Portegies et al., 2016; Berisha et al., 2024). VaD comprises several subtypes based on unique underlying

pathologies, broadly categorised into large vessel and small vessel disease (SVD). Large vessel disease typically affects major arteries and larger blood vessels in the brain, leading to strategic infarct or multi-infarct dementia (Bowler, 2002, 2005; Solans-Laqué et al., 2008). An infarct refers to an area of tissue death due to insufficient blood supply, often caused by the narrowing or occlusion of a cerebral blood vessel (Solans-Laqué et al., 2008). Small vessel disease, which is more common, affects the brain's smaller blood vessels and can lead to subcortical ischemic vascular dementia, characterised by lacunar infarcts and white matter lesions (Bowler, 2002; Kalaria, 2016). Multi-infarct dementia results from multiple infarcts, while strategic infarct dementia is caused by infarcts in brain regions critical for cognition and behaviour (Solans-Laqué et al., 2008). While each subtype has distinct pathology, causes, and manifestations, they all ultimately lead to cognitive impairment through disruption of cerebral blood flow and subsequent neuronal damage (Bowler, 2005).

Moreover, cerebral amyloid angiopathy, another subtype of VaD, includes the presence of amyloid deposition in blood vessels (Yamada, 2015), exemplifying how pathologies associated with AD can overlap with VaD (Bowler, 2002). Accordingly, research has shown that the boundaries between VaD and other forms of dementia are not clear-cut. It is increasingly recognised that 'pure' forms of VaD are relatively rare. For example, autopsy studies have revealed that approximately 80% of clinically diagnosed AD cases show evidence of CVD at post-mortem (Kling et al., 2013; Attems & Jellinger, 2014). Thus, the term mixed dementia refers to the concomitance of pathology owing to more than one type of dementia (Bowler, 2005; Custodio et al., 2017). As the understanding of these pathologies evolves, so too has the recognition of the importance of identifying cognitive changes across a spectrum of severity (Bowler, 2005).

In recent years, there has been growing recognition of earlier stages in the spectrum of cognitive impairment (Bowler, 2002, 2005; Calabrese et al., 2021). Mild Cognitive Impairment (MCI) represents an intermediate stage between normal cognitive ageing and dementia, characterised by objective cognitive decline without significant impairment in daily activities (Petersen, 2016). Whilst not everyone with MCI will go on to convert to dementia, it is considered a prodromal stage due to the increased risk of conversion (Petersen, 2016). For example, a meta-analysis found that around 1 in 4 (23.8%) individuals with MCI will go on to develop dementia (Petersen, 2016). More recently, it has been proposed that the spectrum of dementia may even precede MCI as it has been proposed that Subjective

Cognitive Decline (SCD) is perhaps the earliest prodromal stage of dementia (Jessen et al., 2014, 2020). SCD refers to self-reported cognitive decline in the absence of objective impairment on standardised neuropsychological tests (Jessen et al., 2020).

To encompass varying levels of severity of cognitive impairment for early detection and intervention and to include various subtypes of VaD, the term Vascular Cognitive Impairment (VCI) has gained preference over the term VaD in recent decades (P. Calabrese et al., 2021). Thus, the term VCI encompasses all levels of objective cognitive impairment that are caused by cerebrovascular factors. As such, this includes those with MCI ranging to those with dementia. This shift in terminology reflects the recognition that vascular contributions to cognitive impairment exist on a continuum and that intervention may be most effective in earlier stages.

Central to identifying and differentiating these stages of cognitive impairment are neuropsychological tests, which provide objective measures of cognitive function across various domains. These assessments are crucial for determining the severity of impairment, tracking progression over time, and distinguishing between different types of cognitive impairment based on particular cognitive symptoms. Cognition function is commonly assessed using standardised tests such as the Montreal Cognitive Assessment (MoCA; Nasreddine et al., 2005) and the Mini-Mental State Examination (MMSE; Folstein et al., 1975). These tools provide a global measure of cognitive function but also allow for the examination of specific cognitive domains. These assessments are used in connection with imaging evidence of cerebrovascular disease to provide definitive and probable diagnoses. Cut-off scores based on validated neuropsychological tests are then used to determine the severity of cognitive impairment.

Early detection of cognitive impairment is just as important as slowing cognitive decline for those with established dementia. Inclusive of this is the identification of risk factors that contribute to and exacerbate cognitive decline. For example, in VCI deleterious risk factors include hypertension, obesity, vascular disease, diabetes, heavy alcohol consumption and smoking (Bowler, 2005; P. Calabrese et al., 2021; Rundek et al., 2022). Indeed, risk factors are considered modifiable if the characteristics, behaviours or conditions can be changed or controlled through treatment or intervention to alter subsequent risk (Burt, 2001). For example, with regards to hypertension, considered a modifiable risk factor, studies examining

the use of antihypertensive medications have shown that for 2418 adults in a randomised controlled trial, after an average of 2-year follow-up, a 50% reduction in the incidence of dementia was found for those who had received treatment compared to those who did not (Forette, 2002). Similarly, another proposed modifiable risk factor in the pathogenesis and contribution of cognitive decline in dementia is sleep disturbances (Chang et al., 2013; T.-Z. Liu et al., 2017; Shi et al., 2018; Fernandez-Mendoza et al., 2020).

Indeed, sleep disturbances have been highlighted as a potential early marker of neurodegenerative processes (Chang et al., 2013; Guarnieri et al., 2012; Ju et al., 2014; Xu et al., 2020) but may also actively contribute to cognitive decline and disease progression (Mander et al., 2015; Xu et al., 2020), understanding the relationship between sleep and cognition is essential to develop effective strategies to mitigate the sleep-related cognitive decline and reduce the risk of conversion to dementia in preclinical stages (Rundek et al., 2022). As such, the following sections will provide an overview of sleep, including sleep architecture, the neurobiological regulation of sleep, the measurement and analysis of sleep and what constitutes sleep health. Additionally, this chapter will review how sleep patterns and quality change with healthy ageing and in dementia, how changes to sleep differ from healthy ageing in dementia, and the potential mechanisms through which sleep disturbances impact cognitive health. Moreover, this review will examine gaps in the literature relating to sleep and VCI, an understudied area with regard to sleep and cognition, highlighting the need for targeted research and interventions in this population (P. Calabrese et al., 2021; Rundek et al., 2022).

Thus, the following sections will provide:

1. An overview of sleep, including sleep architecture and the neurobiological regulation of sleep, the measurement and analysis of sleep and what constitutes sleep health
2. A review of how sleep changes with healthy ageing and in dementia
3. An examination of how changes to sleep differ from healthy ageing in dementia
4. The potential mechanisms through which sleep disturbances impact cognitive health in healthy ageing and dementia
5. An examination of gaps in the literature relating to sleep and VCI, an understudied area with regards to sleep and cognition,

1.2 Overview of Sleep

Sleep is a reversible state characterised by reduced responsiveness to external stimuli and a period of immobility (Jessen et al., 2014, 2020). The study of sleep has been revolutionised by the use of polysomnography (PSG), which combines three primary measures: electroencephalography (EEG) to record neuronal electrical activity, electrooculography (EOG) to monitor eye movements, and electromyography (EMG) to assess muscle tone, particularly in the chin (Rundo & Downey, 2019). Using PSG, researchers have identified distinct sleep stages, which are broadly categorised into non-rapid eye movement (NREM) and rapid eye movement (REM) sleep. NREM sleep is further divided into three stages: N1, N2, and slow-wave sleep (SWS; Fuller et al., 2006; Rundo & Downey, 2019).

1.2.1 Sleep Architecture

Stage 1 (N1) sleep marks the transition from wakefulness to sleep and is characterised by slow, rolling eye movements and the appearance of theta waves (4-7 Hz) on the EEG (Carskadon & Dement, 2005). This stage accounts for approximately 5-10% of total sleep time (TST) in healthy adults (Carskadon & Dement, 2005; Vysata et al., 2012). Stage 2 (N2) sleep, which constitutes about 50% of TST, is identified by the presence of K-complexes and sleep spindles on the EEG. K-complexes are brief, high-amplitude, low-frequency waveforms that last between 0.5 and 2 seconds. Sleep spindles are short bursts of electrical activity generated by interactions between neurons in the thalamic reticular nucleus and thalamocortical relay neurons (Andrillon et al., 2011). These features are suggested to play a role in sleep maintenance and sensory gating (Fernandez & Lüthi, 2020).

Slow-wave sleep (SWS), also known as N3, is the deepest stage of NREM sleep and is characterised by the presence of delta waves (0.5-2 Hz) on the EEG (Carskadon & Dement, 2005). In addition to delta waves, SWS is associated with the occurrence of sleep spindles and hippocampal sharp-wave ripples (SWRs), which are associated with rapid navigational planning and gradual memory consolidation (Roumis & Frank, 2015; Antony & Paller, 2017). The depth of sleep during SWS reflects the difficulty in arousing an individual to wakefulness, highlighting its role in sleep homeostasis and restorative processes (Dijk et al., 2010). REM sleep, which accounts for approximately 20-25% of TST in adults, is

characterised by rapid eye movements, muscle atonia, and EEG activity that closely resembles wakefulness (Carskadon & Dement, 2005). This stage is associated with dreaming and has been implicated in memory consolidation (Stickgold & Walker, 2005), emotional processing (Murkar & De Koninck, 2018; Mukai & Yamanaka, 2023), and developmental functions (Mukai & Yamanaka, 2023).

Sleep is not a static state but rather a dynamic process characterised by a predictable organisation of sleep stages throughout the night. This architecture follows a distinct pattern, with SWS predominating in the first half of the night, while REM sleep becomes more prevalent in the latter half (Morris et al., 2012). In healthy adults, sleep progresses through cycles of non-rapid eye movement (NREM; N1, N2, SWS) and REM sleep, each cycle lasting approximately 90-120 minutes. As the night progresses, these cycles tend to lengthen, with later cycles containing proportionally more REM sleep (Carskadon & Dement, 2005). These cycles repeat throughout the night, and their timing and propensity for each stage are governed by homeostatic sleep pressure and our internal biological clock, which is known as the circadian rhythm (Carskadon & Dement, 2005).

1.2.2 Circadian Rhythms

Humans and many other living organisms possess an internal timing system that synchronises behaviour and physiology with the light/dark cycle. These circadian rhythms (derived from the Latin words 'circa' meaning "around", and 'dies' meaning 'day') are essential for maintaining optimal health and performance by ensuring that various biological functions occur at the most appropriate times of the day (McFadden, 1988; Edery, 2000). The circadian system has two main functions: 1) maintaining an endogenous ~24-hour rhythm that operates independently of external time cues, or zeitgebers, and 2) adjusting its synchronised rhythm in response to zeitgebers, such as light and food (Edery, 2000).

Most cells in the body contain circadian clocks that dictate specific physiological activities based on the time of day (Edery, 2000). However, the suprachiasmatic nucleus (SCN), located in the anterior hypothalamus above the optic chiasm, acts as the master pacemaker, coordinating the timing of all circadian clocks throughout the body via neural, hormonal, and behavioural signals (Edery, 2000; Hastings et al., 2018). The process by which circadian

rhythms are synchronised to external time cues is called entrainment (Hannibal, 2002). Light is the primary and strongest zeitgeber for the SCN, with information about the light/dark cycle being transmitted from the retina to the SCN via the retinohypothalamic tract (Hannibal, 2002). Other non-photic zeitgebers, such as melatonin, exercise, and feeding schedules, can also influence circadian entrainment, although their effects are generally weaker than those of light (Hastings et al., 2018).

The SCN orchestrates circadian rhythms in behaviour and physiology, including the sleep-wake cycle, via endocrine and neural pathways (Carskadon & Dement, 2005). Hormonal systems under circadian control include melatonin, the hypothalamic-pituitary-adrenal axis (including cortisol), the hypothalamic-pituitary-thyroid axis, and epinephrine (Hannibal, 2002). While the circadian system plays a crucial role in regulating the sleep-wake cycle, the two-process model of sleep regulation, proposed by (Borbély, 1982), suggests that sleep is governed by the interaction of two distinct processes: Process S and Process C.

Process S represents the homeostatic sleep drive that accumulates during wakefulness and dissipates during sleep. Adenosine, an inhibitory neurotransmitter, is partly responsible for increasing the pressure to sleep as extracellular adenosine accumulates with time spent awake and decreases proportionately with the intensity of slow-wave activity during sleep (Borbély, 1982). The longer an individual stays awake, the higher the homeostatic sleep pressure becomes, leading to increased sleepiness and the need for sleep. Once sleep is initiated, Process S gradually declines, with the rate of decline being proportional to the intensity of sleep, particularly slow-wave sleep (SWS). Process C, on the other hand, represents the circadian influence on sleep propensity, which is independent of prior sleep and wake. This process is driven by the endogenous circadian clock and oscillates with a period of approximately 24 hours. Process C promotes wakefulness during the biological day and promotes sleep during the biological night, regardless of the amount of prior sleep or wakefulness (Borbély, 1982).

The independence of these two processes has been demonstrated through various experimental studies. For example, sleep deprivation leads to an increase in homeostatic sleep pressure (Process S), while the circadian drive for wakefulness (Process C) remains unaffected (Morris et al., 2012; Mander et al., 2017). Conversely, in forced desynchrony protocols, where individuals are exposed to non-24-hour sleep-wake schedules, the circadian

rhythm of sleep propensity (Process C) can be observed to free-run independently of the homeostatic sleep drive (Process S; Edery, 2000; Hastings et al., 2018). Under entrained conditions, the interaction of Process S and Process C promotes consolidated wakefulness during the day and consolidated sleep during the night (Borbély, 1982). The circadian drive for wakefulness counteracts the increasing homeostatic sleep pressure during the day, enabling alertness. During the night, the circadian drive for sleep works in conjunction with the high homeostatic sleep pressure to facilitate sleep initiation and maintenance.

1.2.3 The Neurobiology of Sleep and of Sleep-Wake Regulation

Building upon the two-process model of sleep regulation, Saper and colleagues (2005) offer a framework for understanding the neurobiological mechanisms that generate these processes, known as the flip-flop model. This model suggests that the regulation of sleep and wakefulness are controlled by reciprocal inhibition between two main neuronal populations: the sleep-promoting ventrolateral preoptic nucleus (VLPO) and the wake-promoting monoaminergic and cholinergic systems.

During wakefulness, the monoaminergic and cholinergic systems, which include the locus coeruleus (LC), dorsal raphe nucleus (DRN), and pedunculopontine and laterodorsal tegmental nuclei (PPT/LDT), are highly active (Alóe et al., 2005; Saper et al., 2005). These systems release neurotransmitters such as norepinephrine, serotonin, and acetylcholine, which promote cortical activation and maintain arousal (Saper & Fuller, 2017). The activity of these wake-promoting systems inhibits the sleep-promoting VLPO neurons (Saper et al., 2005). As sleep pressure builds during prolonged wakefulness, the activity of the wake-promoting systems gradually decreases, leading to a disinhibition of the VLPO. The VLPO neurons, which contain the inhibitory neurotransmitters GABA and galanin, become active and inhibit the wake-promoting systems, thus promoting the transition to sleep (Saper & Fuller, 2017). This reciprocal inhibition between the sleep-promoting VLPO and the wake-promoting systems creates a bistable flip-flop switch, ensuring rapid and stable transitions between sleep and wake states (Saper et al., 2005).

In addition to the flip-flop switch, other neuronal populations and neurotransmitters play essential roles in sleep-wake regulation. The hypothalamic hypocretin/orexin system, which

projects to various wake-promoting regions, helps stabilise the flip-flop switch and maintain wakefulness (Saper et al., 2005; Saper & Fuller, 2017). For example, the loss of hypocretin (orexin) neurons has been linked to narcolepsy, a disorder characterised by excessive daytime sleepiness, rapid sleep onset, and abnormal REM sleep (Taheri et al., 2002; Kornum et al., 2017). The circadian system, centred in the suprachiasmatic nucleus (SCN) of the hypothalamus, also influences sleep-wake regulation by providing a 24-hour oscillatory signal that synchronises sleep-wake cycles with the external light-dark cycle (Saper & Fuller, 2017). The SCN modulates the activity of the VLPO and wake-promoting systems through direct and indirect projections, ensuring that sleep occurs at the appropriate time of day (Saper & Fuller, 2017). Homeostatic sleep pressure, which increases with prolonged wakefulness and dissipates during sleep, is another critical factor in sleep-wake regulation. The accumulation of adenosine, a neuromodulator that builds up during wakefulness, has been proposed as a key mediator of homeostatic sleep pressure (Porkka-Heiskanen et al., 2002). Adenosine acts on specific receptors in the basal forebrain and other wake-promoting regions, inhibiting their activity and promoting the transition to sleep (Porkka-Heiskanen et al., 2002; Blanco-Centurion et al., 2006).

1.2.4 Measurement of Sleep

Assessing sleep in terms of architecture, timing, and quality involves a variety of measurement techniques. The ‘gold-standard’ approach for assessing sleep architecture and observing objective sleep quality involves using EEG (Signorino et al., 1995; Emmady & Anilkumar, 2024). The EEG measures neuronal electrical activity during sleep where signals are generated by the collective action potentials of neurons in the brain, with each neuron acting as a dipole due to the excitatory or inhibitory actions between the dendrites and the outer layers of the cortex (Kirschstein & Köhling, 2009; Chikhi et al., 2022). Electrodes placed on the scalp capture these neuronal action potentials, measuring electrical activity in terms of frequency and amplitude. Frequency refers to the number of oscillations per second and is measured in Hertz (Hz), while the amplitude of a waveform is measured in microvolts (μV ; Kirschstein & Köhling, 2009). Standard methods of using EEG data in sleep research is to quantify the length of sleep stages experienced throughout sleep in addition to gathering insights on general sleep quality using measures of Total Sleep Time (TST), sleep fragmentation, typically assessed using Wake After Sleep Onset (WASO), Sleep Efficiency

(SE), which is the percentage of TST divided by the time spent in bed multiplied by 100 and Sleep Onset Latency (SOL) the time taken to fall asleep (Emmady & Anilkumar, 2024).

Moreover, the spectral power of the EEG signal is used to provide insight into the strength of neural electrical signals within a specific frequency band. Spectral power is a quantitative measure of the intensity of brain activity within each frequency band. It is calculated by squaring the amplitude of the signal within the respective frequency range (Duhamel & Vetterli, 1990). To calculate the power, researchers employ spectral analysis techniques, such as the Fast Fourier Transform (FFT), which decomposes the EEG signal into its constituent frequency components (Duhamel & Vetterli, 1990). The FFT allows for the segmentation of the signal into distinct frequency bands, such as delta (0.5-4 Hz), theta (4-8 Hz), alpha (8-13 Hz), beta (13-30 Hz), and gamma (30-100 Hz; Klimesch, 1999). In essence, the power within a given frequency band reflects the cumulative intensity of brain activity represented by those frequencies. Higher spectral power in a specific frequency band indicates greater synchronisation of neuronal activity within that frequency range, which can be associated with various cognitive processes, brain states, or neurological conditions (Klimesch, 1999).

For example, delta power is typically associated with deep sleep, while alpha power is linked to relaxed wakefulness and is often observed during periods of eyes-closed rest (Cantero et al., 2002). Theta power has been implicated in memory processes and emotional regulation (Klimesch, 1999; Ertl et al., 2013; Herweg et al., 2020), while beta power is associated with active thinking, attention, and sensorimotor processing (Kilavik et al., 2013; Pavlidou et al., 2014; Barone & Rossiter, 2021; Attar, 2022). Gamma power, on the other hand, has been linked to higher-order cognitive processes, such as perception, attention, and memory (Sheth et al., 2009; Güntekin & Tülay, 2014; R. V. Zhang et al., 2019).

By examining the spectral power distribution across different frequency bands, researchers can gain insights into the underlying brain activity and its potential functional significance. Changes in spectral power can be used to investigate the effects of sleep deprivation, ageing, neurological disorders, and cognitive tasks on brain function (Signorino et al., 1995; Vysata et al., 2012; Rueda-Delgado et al., 2019). Moreover, spectral power analysis can be used to examine the role of specific frequency bands in sleep-dependent memory consolidation and to assess the impact of sleep disturbances on cognitive performance (Hogan et al., 2003; Zheng et al., 2007; Kjaerby et al., 2022).

Whilst PSG and EEG are considered gold-standard sleep assessments, they often involve laboratory assessments which are invasive, expensive and require familiarisation nights and thus are not without limitations. An alternative method for objectively assessing sleep in a non-invasive manner involves the use of wearable devices, such as actigraphy. Actigraphs are wrist-worn devices that measure sleep/wake activity via accelerometers, providing an indirect assessment of sleep measures using specialised algorithms (Fekedulegn et al., 2020). These devices typically determine sleep/wake activity based on a combination of factors, including the duration and/or frequency of movements, the amplitude or strength of movements, and the acceleration or speed of movement. Movement data collected across 24 hours is then analysed using algorithms that automatically assess sleep/wake cycles and estimate sleep architecture and various sleep parameters (Fekedulegn et al., 2020).

The concordance between actigraphy and PSG varies depending on the specific device and algorithm used, as well as the population being studied. Generally, actigraphy shows good agreement with PSG for sleep/wake scoring (e.g. estimates of sleep/wake scoring accuracy varies from 79%-85.9% (Dick et al., 2010; Lüdtke et al., 2021)), including older adults (Regalia et al., 2021), but may be less accurate in populations with sleep disorders or low sleep efficiencies (Alakuijala et al., 2021). While actigraphy may be less accurate than PSG in determining certain objective sleep quantifications, it offers several advantages. Actigraphy is less expensive, less invasive, and can be worn continuously over extended periods, making it suitable for most demographics and particularly useful for longitudinal sleep assessment (Fekedulegn et al., 2020; Regalia et al., 2021). This allows researchers and clinicians to gather data on sleep patterns in the participant's natural environment over multiple nights, providing a more representative picture of typical sleep behaviour (Fekedulegn et al., 2020).

However, actigraphy is not without limitations. As it relies on motion to assess activity, estimates of sleep onset latency (SOL) are often inaccurate (Tonetti et al., 2008; J. L. Martin & Hakim, 2011). For instance, an individual could be lying still but awake, which the actigraph might incorrectly interpret as sleep. Additionally, actigraphy may overestimate sleep time in individuals with insomnia who lie still while awake and underestimate sleep in those with high nocturnal motor activity, such as individuals with certain sleep disorders (Garcia et al., 2020). Thus, subjective measures of sleep are helpful in complementing and

augmenting actigraphy data when the researcher has additional information on sleep behaviour from the sleep diary, such as the time of sleep onset.

Subjective sleep measures include sleep diaries and sleep-related questionnaires. A sleep diary requires an individual to self-report daily estimates of sleep parameters and perceived sleep quality, including SOL, TST, WASO, SE, time in bed (TIB) and overall satisfaction with sleep. As sleep diaries rely on retrospective recall of prior sleep behaviour, these reports are vulnerable to misestimations. For example, older adults tend to underreport sleep disturbances on self-report when compared to objective measures such as PSG (Vitiello et al., 2004; Åkerstedt et al., 2016; Abraham et al., 2017). However, subjective measures of sleep still have utility in sleep research as they not only are cheaper to use than other objective measures, but they also capture the experiential aspects of sleep that objective measures cannot capture. For example, subjective reports of daytime sleepiness, an indicator of insufficient sleep, cannot be captured in objective measures. Whilst there are advantages and limitations to each approach, it is recommended that sleep studies incorporate both subjective and objective measures to reflect capturing independent but related aspects of sleep health (Buysse et al., 1991; Landry et al., 2015; Åkerstedt et al., 2016).

1.2.5 Defining Sleep Health: The SATED Model

Identifying measurable parameters of sleep that contribute to sleep health is essential, especially when considering how sleep affects cognitive health in ageing. While much research on sleep focuses on poor sleep health and associated outcomes, few papers have explicitly defined what constitutes sleep health. Buysse (2014) proposed five interrelated dimensions that form the foundation of good sleep health: sleep duration (the total amount of sleep obtained in 24 hours), sleep continuity (the consolidation of sleep), efficiency (the ease of falling asleep and staying asleep), sleep timing (the placement of sleep within a 24-hour day), and alertness/sleepiness during waking hours. These dimensions can be assessed using self-reports, behavioural assessments, and physiological measures. Buysse (2014) selected these five elements using the acronym SATED (Satisfaction, Alertness, Timing, Efficiency, Duration) because they can be expressed in positive terms and are measurable using self-report and behavioural measures.

Table 1: SATED Dimensions with Recommendations for Achieving Good Sleep Health (Buysse, 2014)

SATED Dimension	Description	Recommendation
Satisfaction/Quality	The subjective assessment of 'good or poor sleep	Subjectively satisfied with sleep quality
Alertness/Sleepiness/Napping	The ability to maintain attentive wakefulness	Low subjective sleepiness during the day
Timing (e.g. shift work, chronotype)	The placement of sleep within the 24-hour day	Regular Timing, low SD in the sleep window
Efficiency	The ease of falling asleep and returning to sleep	>70%
Duration	The total amount of sleep obtained within a 24-hour period	6-9 hours

These aspects that makeup sleep health have been chosen due to their association with adverse health outcomes when each aspect is not achieved. For example poor sleep quality is associated with poor mental health with a ‘U’-shaped association observed (Gadie et al., 2017; Clement-Carbonell et al., 2021), an increased risk of diabetes mellitus (Gao et al., 2022), poorer perceived health (Hale et al., 2013), poorer cognitive performance (Scullin & Bliwise, 2015), reduced quality of life (Medic et al., 2017; Chasens et al., 2014), and mood disorders (Medic et al., 2017). Thus, satisfaction with one’s sleep is a key component of sleep health and is associated with health-related factors. Similarly, reduced daytime alertness, such as daytime sleepiness, is associated with lower activity levels, greater daily functional impairment, productivity and vigilance (Gooneratne et al., 2003).

Additionally, the placement of sleep within 24 hours has also been shown to be associated with negative health outcomes when irregular sleep timing occurs. For example, for individuals undertaking shiftwork such as night shifts and early morning shifts, research has shown an association between weight gain and an elevated risk of coronary heart disease, stroke and cancer (Kecklund & Axelsson, 2016). Moreover, low sleep efficiency (<70%), that is spending large amounts of time in bed and not sleeping, was a predictor of cardiovascular mortality in the Sleep Heart Health Study examining 3810 participants during an approximately 11-year follow-up period.

Finally, many studies have found that extremely long sleep duration (>9 hours) and short sleep duration (≤ 6 hours) are associated with an increased risk of mortality (Kecklund & Axelsson, 2016) and increased risk of cognitive impairment (Leng & Yaffe, 2020) supporting a J-shaped association between sleep duration and mortality (Gu et al., 2022). A sleep duration between 6-8 hours appears to be optimal for health outcomes (Tsou, 2011; Liu et al., 2017; Leng & Yaffe, 2020; Gu et al., 2022; Gao et al., 2022).

As such, the SATED model provides a framework for the definition of sleep health and recommended parameters to support it. It is important to note that other aspects of sleep, such as the proportions or spectral power of specific sleep architecture (e.g., SWS, REM, etc.) have also been associated with functional and health outcomes and therefore are considered important aspects of sleep health. This is because sleep architecture cannot be self-reported, and psychometric studies indicate that it falls along the same dimension as overall satisfaction with sleep (Buysse, 2014). Thus, this model is not entirely comprehensive of all aspects contributing to sleep health, though it provides a coherent model of how specific aspects support health.

It is important to recognise that sleep is not static across the lifespan (Ohayon et al., 2004). As individuals age, their sleep patterns and quality naturally evolve, influenced by various biological, environmental, and lifestyle factors (Ohayon et al., 2004). These age-related changes in sleep can impact multiple dimensions of sleep health, as well as aspects of sleep architecture not captured by self-report measures. To consider how sleep health and ageing interact before examining this in the context of dementia, it is important first to examine how sleep typically changes across the lifespan in health ageing. This will serve as a comparison and better contextualise sleep disturbances often observed in age-related cognitive decline.

The following section will explore both the macro and micro changes in sleep architecture that occur with advancing age, offering insights into why older adults often experience alterations in their sleep patterns and quality.

1.3 Sleep Changes in Aging

One of the most common associations with ageing is changes in sleep patterns and quality. Approximately 50% of older adults report difficulties with sleep (Neikrug & Ancoli-Israel, 2010), which can be attributed to both macro and micro changes in sleep architecture. Macro changes refer to general alterations in sleep parameters, while micro changes pertain to changes within waveforms within each sleep stage (Malinowska et al., 2006; Mander et al., 2013a). It is important to note that while changes in sleep with advancing age are well-documented, the definition of ‘older adults’ varies across studies, which may impact the interpretation and comparison of findings. The National Institute of Health (National Institute of Health, 2024) defines older adults as individuals aged 65 and above, however, this classification varies across studies. Where possible, the following review will provide specific age ranges to clarify how ‘older adults’ are defined in each context.

1.3.1 Macro Changes in Sleep Architecture with Aging

Total Sleep Time (TST) reduces with advancing age, with an inverse linear association showing a decrease of approximately 10-12 minutes per decade in the adult population (Floyd et al., 2000; Ohayon et al., 2004; Floyd et al., 2007). The association is stronger when comparing young adults to middle-aged or older adults, but not significant among those aged 60 and over, suggesting a plateauing effect after age 60 (Ohayon et al., 2004). The effect size is larger for women than men, indicating a greater association between declining sleep duration and women (Ohayon et al., 2004).

Sleep Onset Latency (SOL) steadily increases with age, except between 30 and 50 years (Floyd et al., 2000; Ohayon et al., 2004). After age 60, the effect size of this increase is small and moderated by factors such as gender and health (Ohayon et al., 2004). Studies with male participants show larger effect sizes in SOL increases with age, while those with female

participants show only small effect sizes (Ohayon et al., 2004). This suggests that the impact of age on SOL is influenced by individual factors and is not substantial after age 60.

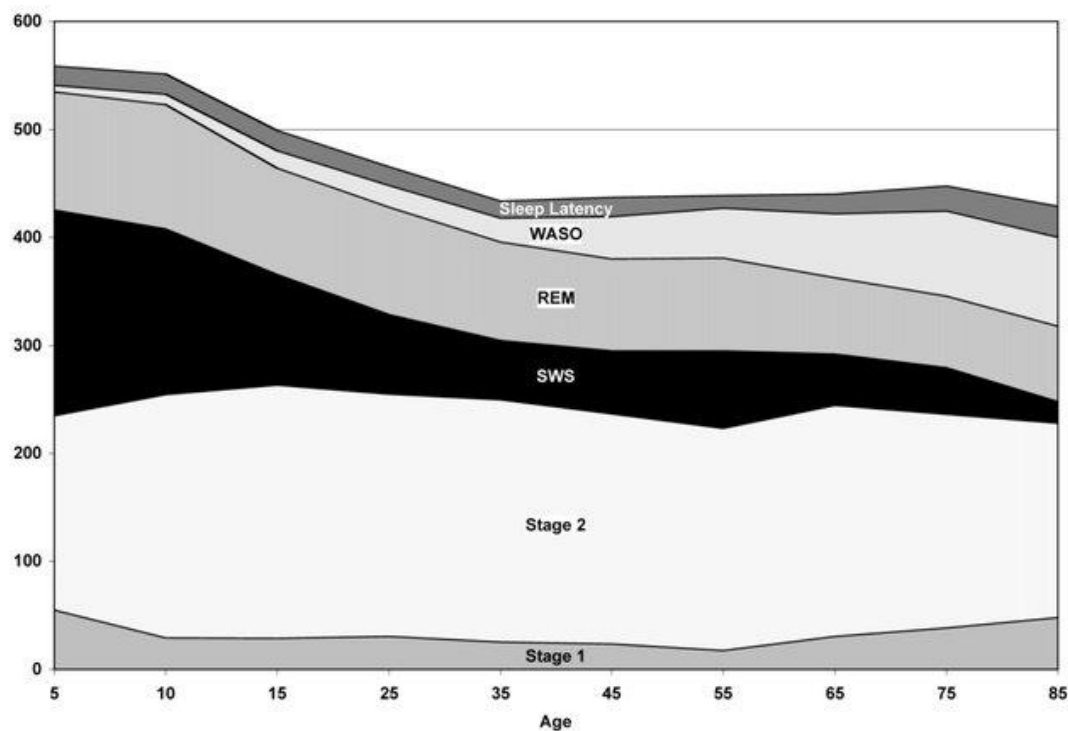
Sleep Efficiency (SE) steadily decreases after 60 years of age (Ohayon et al., 2004), with a longitudinal study finding an 18.6% decrease between 40 and 100 years (Didikoglu et al., 2020). Factors associated with ageing, such as pain, nocturia, sleep medication use, anxiety, and being single (for men), are strongly associated with SE below 80% (Desjardins et al., 2019), suggesting that these factors may contribute to the reduction in SE rather than ageing per se.

Sleep maintenance, measured by Wake After Sleep Onset (WASO), diminishes with age, with a higher number of arousals and longer duration of WASO (Ohayon et al., 2004). This decline plateaus at age 60, with an average increase of 10 minutes per decade between ages 30 and 60 (Ohayon et al., 2004). Changes in WASO show the largest effect size among all sleep variable changes across the ageing process, highlighting the significant impact of ageing on sleep maintenance.

Older adults experience alterations to their circadian phases, such as advanced circadian phase (early to bed and early to rise; (Duffy & Czeisler, 2002). Research suggests that older adults preserve their capacity for daytime alertness, with no association found between age and excessive daytime sleepiness (Hara et al., 2004). However, the frequency of napping increases with age (Foley et al., 2007; Furihata et al., 2016), potentially due to increased opportunity rather than a heightened propensity for daytime sleep (Mander et al., 2015).

Across adulthood, there are notable changes in the distribution of sleep stages. SWS reduces in total duration by around 2% per decade, with the percentage of reduction increasing to 3% per decade after age 40 (Ohayon et al., 2004). Older adults, compared to middle-aged adults, show an increase in time spent in stages 1 and 2, with the increase in stage 2 plateauing at age 60. Older adults also have shorter and fewer NREM-REM sleep cycles (Mander et al., 2015). Changes to REM sleep are more subtle, with a 4% difference in REM proportions between younger adults and those aged 60 and over (Ohayon et al., 2004). Despite objective deteriorations in sleep with age, older adults are less likely to complain of sleep problems than younger adults (Grandner et al., 2012). This may be due to older adults adapting their expectations of what constitutes acceptable sleep (Buysse et al., 1991; Grandner et al., 2012).

Figure 1: Sleep Architecture Changes Over the Lifespan (Ohayon et al., 2004)



1.3.2 Micro Changes in Sleep Architecture with Aging

In addition to macro changes in sleep stages across ageing, the expression of EEG-derived electrical oscillations within stages also changes. The most prominent changes are alterations in NREM oscillations, including slow-wave activity (SWA) and sleep spindles (Mander et al., 2015).

1.3.2.1 *Slow-Wave Activity (SWA)*

The most significant changes in SWA relate to absolute power reduction, which is not evenly expressed across head topography (Mander et al., 2013b) and is most prominent in the first NREM-REM cycles (Ferrillo et al., 2000). As individuals age, the amount and intensity of SWA can show an average reduction of up to 80% in the prefrontal cortex derivations and in the first NREM sleep cycles compared to younger adults (Mander et al., 2013). Another

change in SWA is characterised by decreased amplitude and a slowing of slow waves by 0.1 Hz, which is observed across most EEG derivations (Mander et al., 2015).

Mander et al., (2017) highlight the close relationship between SWA and the homeostatic sleep drive, or sleep pressure. In healthy young adults, the longer a person stays awake, the more sleep pressure accumulates, leading to an increase in SWA during subsequent sleep. This sleep pressure is then relieved in proportion to the SWA experienced, resulting in a typical hypnogram showing a high amount of SWA in the first half of the night, which gradually decreases as sleep pressure diminishes. However, in older adults, this homeostatic sleep regulation mechanism appears to be altered. Older individuals tend to exhibit less pronounced dissipations in SWA and do not experience as significant an increase in SWA in response to sleep deprivation as younger adults do (Mander et al., 2013a, 2015, 2017).

1.3.2.2 Sleep Spindles

In older adulthood, sleep spindles show alterations characterised by reductions in spectral power, density, duration, and amplitude, which also appear to be topographically and temporally specific (Mander et al., 2017). Compared to younger adults, middle-aged and older adults show reductions in the spectral power of spindles, with the greatest reductions occurring in the final sleep cycles of the night (Mander et al., 2017). Up to 50% reductions in sleep spindle power have been observed in men (Landolt et al., 1996). Moreover, the density of sleep spindles (how many occur per unit time) reduces with age over the brain's frontal areas, while age-related reductions in spindle duration are most prominent over posterior regions (Mander et al., 2017).

Mander et al. (2017) note that these age-related changes to spindles appear to be mutually exclusive from macro changes to stage 2 sleep, where spindles predominate, suggesting a distinction between macro-level sleep architecture changes and micro-level physiological changes with ageing (Ohayon et al., 2004). This distinction is important, especially when considering the link between changes in sleep and cognition. Focusing solely on either broad architectural changes or detailed physiological oscillations in relation to cognitive outcomes may obscure vital insights into how sleep impacts cognitive health in older adults.

1.3.3 Potential Mechanisms Underlying Sleep Changes with Aging

1.3.3.1 Galanin

Galanin is an inhibitory neuropeptide that promotes sleep by inhibiting wakefulness (Saper & Fuller, 2017). Clusters of galanin-expressing neurons within the ventrolateral preoptic nucleus (VLPO) are reduced in number at post-mortem examination in older individuals (Gabriel et al., 1994; Mufson et al., 2000). Interestingly, the severity of the reduction in galanin-expressing neurons in the VLPO has been found to predict the degree of sleep fragmentation experienced by individuals in the years prior to their death (Lim et al., 2014). This finding suggests that the loss of galanin-expressing neurons in the VLPO may contribute to the increased sleep fragmentation and disruption observed in older adults.

1.3.3.2 Orexin

Orexin, also known as hypocretin, is another neuropeptide that plays a role in maintaining wakefulness (Saper & Fuller, 2017). Orexin producing neurons are found in the lateral hypothalamic area (LHA) and project to various brain regions, including the ascending reticular activating system in the brainstem, which is involved in promoting arousal (Kessler et al., 2011; Saper & Fuller, 2017). In animal studies, older mice have been shown to have a 40% reduction in orexin levels compared to younger mice (Kessler et al., 2011). In humans, a smaller 10% reduction in orexin levels has been observed in older adults compared to younger individuals (Hunt et al., 2015). The age-related decline in orexin levels may contribute to the changes in sleep-wake regulation and the increased difficulty in maintaining consolidated wakefulness that is often reported by older adults (Sakurai, 2007).

1.3.3.3 Gray and White Matter Changes

Age-related structural changes in the brain, particularly in grey and white matter, may play a role in sleep changes observed in older adults. Mander et al. (2017) highlight how these changes in brain structure and connectivity contribute to sleep disturbances. Specifically, decreased grey matter volume and compromised white matter integrity in sleep-wake

regulatory regions, such as the prefrontal cortex and thalamus, correlate with disrupted sleep patterns in older adults. These structural alterations potentially impair communication and coordination between neural networks regulating sleep and wakefulness, resulting in fragmented and less consolidated sleep.

Taken together, these findings highlight potential mechanisms that may account for sleep-related changes in older adults. However, the prevailing view of sleep changes across healthy ageing, largely informed by the seminal meta-analysis conducted by Ohayon and colleagues (2004), is challenged by recent research. Whilst reductions in neuropeptides and changes to grey matter are evident in older adults, more recent research highlights the importance of considering individual variability in sleep changes with ageing, suggesting that changes to sleep in older adulthood may not be as generalised as previously thought.

1.3.4 Individual Variability in Sleep Changes with Aging

Scullin and Gao (2018) conducted a longitudinal study exploring how sleep changes with age using PSG assessments from the Sleep Heart Health Study (Quan et al., 1997), which collected data over two time periods (Timepoint 1: 1995-1998; Timepoint 2: 2001-2003) from adults aged 40 or over without any history of sleep-disordered breathing (SDB). A total of 3,295 participants completed both PSG assessments. Interestingly, when Scullin and Gao analysed the data cross-sectionally by averaging sleep parameters for each age group at each time point, the results were similar to those of Ohayon et al. (2004). However, when the data was reanalysed longitudinally, comparing Timepoint 2 to Timepoint 1, the researchers found substantial intra-individual variability (differences for the same person at different time points) and inter-individual variability (differences in sleep patterns between people in the same age group at time points).

Contrary to the cross-sectional data showing a reduction in sleep duration with age, participants gained an average of 4.6 minutes of sleep in the five years between assessments. The researchers also found that sleep fragmentation, as measured by wake after sleep onset (WASO), increased significantly with age. After five years, 31.4% of adults had doubled the amount of WASO, with the largest increase observed in those aged 60 and over (Scullin & Gao, 2018). In those aged 80+, half of the participants had WASO of >100 minutes. These

findings suggest that the longitudinal analysis revealed more severe increases in sleep fragmentation compared to the cross-sectional study by Ohayon et al. (2004). The researchers sought to determine whether this impacted sleep architecture since WASO increased more than total sleep time (TST). While they found significant differences for decreases in slow-wave sleep (SWS; 6-minute reduction) and rapid eye movement (REM) sleep (3-minute increase), the effect sizes were very small, suggesting that the increase in WASO had little effect on sleep architecture. When exploring whether individuals who showed reductions in SWS were likely to show reductions in REM sleep, only a weak association was found.

The paradoxical finding that greater WASO had little effect on REM and SWS led the researchers to investigate differences between SWS and REM sleep. The authors found that for some individuals, reductions in SWS were associated with an increase in REM sleep, which they suggest reflects a potential compensatory mechanism for SWS loss (Scullin & Gao, 2018). The authors suggested that this may promote cognitive perseveration as an increase in REM sleep which may counteract the effects of SWS loss. Additionally, they proposed that for individuals showing both a reduction in REM and SWS, this may lead to negative health outcomes as outlined in prior literature associated with reductions in REM and SWS, such as cognitive decline.

The variability in sleep changes with ageing observed in the Scullin and Gao (2018) study suggests more intra and inter-individual variability than previously thought. Whilst some deterioration in in sleep-wake/centres of the brain is observed in older adults, poor sleep does not appear to be an inevitable consequence of ageing but rather highlights that some individuals may be more vulnerable to changes in sleep quality than others. This is particularly important when considering the role of poor sleep in dementia, as this potential vulnerability may be linked with cognitive consequences. Therefore, the next section of this review will examine how sleep-related changes are linked to cognition, starting with reviewing healthy young adults and comparing older adults to examine how sleep changes are related to cognition and cognitive decline in ageing.

1.3.5 The Relationship Between Sleep and Cognition in Healthy Ageing

Poor sleep quality and insufficient sleep duration have been consistently associated with negative impacts on cognitive function in young adults. Cross-sectional studies using self-report measures like the Pittsburgh Sleep Quality Index (PSQI) have demonstrated that poorer sleep quality is linked to deficits in executive function, attention, working memory, and decision-making performance, independent of confounding factors such as depression and anxiety (Benitez & Gunstad, 2012; Nebes et al., 2009; Telzer et al., 2013; Noort et al., 2016). Additionally, sleep deprivation has been shown to have detrimental effects on cognition. A comprehensive review of 19 randomised controlled trials involving 766 young adults found that sleep deprivation ranging from 24 to 72 hours significantly impaired reaction times, psychomotor vigilance, and increased errors in reaction tasks (Griggs et al., 2022). Total sleep deprivation studies have shown that young adults experience substantial declines in visuospatial and verbal working memory after 36 hours without sleep (Pasula et al., 2018).

Objective measures of sleep using actigraphy have provided further evidence of the sleep-cognition relationship in younger adults. Greater variability in sleep quality has been associated with poorer visuospatial learning and memory performance (Stiver et al., 2021). Additionally, as measured by actigraphy, non-restorative sleep has been linked to impaired executive function (Tinajero et al., 2018). The impact of poor sleep extends beyond acute cognitive deficits. Sleep restriction has been shown to impair executive inhibitory control and increase risk-taking behaviour (Rossa et al., 2014). Moreover, young adults reporting less than 7 hours of sleep per night demonstrate poorer executive function and working memory performance compared to those with better sleep quality (Parrilla et al., 2024). While some studies have not found significant associations between subjective sleep quality and cognitive performance (Zavecz et al., 2020), most evidence suggests a strong link between sleep and cognitive function in young adults.

1.3.6 Healthy Older Adults and Cognition

Before considering the role of sleep and its interaction with ageing and cognition, it is important to note that neurocognitive changes are observed in healthy ageing, irrespective of sleep issues. Generally, 'crystallised' intelligence, which refers to the accumulation of knowledge stemming from prior learning and past experiences such as vocabulary and

general knowledge (Sligh et al., 2005), remains stable across the lifespan (Wang & Kaufman, 1993), however 'fluid' intelligence, which refers to mental processes related to thinking, reasoning and problem-solving (Unsworth et al., 2014), decline with advancing age (Ghisletta et al., 2012).

Cognitive abilities such as executive functioning, processing speed, and psychomotor ability tend to peak at around 30 years of age and then decline steadily with each year of ageing (Salthouse, 2012). It is thought that many of these cognitive changes are related to age as a result of normal reductions in processing speed (Harada et al., 2013; Bosnes et al., 2022), which is a slowed rate at which people can perform cognitive tasks (Eckert, 2010).

Processing speed does not rely on one single neural system but is dependent on coordinated connectivity across multiple regions and networks within the brain. Thus, age-related cortical thinning and reduced grey and white matter associated with ageing are also associated with reduced processing speed. Whilst related to processing speed slowing, changes in memory are also seen with healthy ageing. However, non-declarative memory such as episodic memory tends to remain stable across the lifespan and changes to episodic memory before age 60 indicate unhealthy ageing, or pathological ageing (Irwin et al., 2018).

With regards to the connection between cognition and sleep, a comprehensive review by Scullin and Bliwise, (2015) integrated 50 years of research on sleep, cognition, and ageing finding complex relationships between these factors. The study examined seven research domains, including self-reported sleep correlation studies, actigraphy and neuropsychology correlational studies, PSG, EEG and neuropsychology correlational studies, sleep deprivation experiments, napping experiments, sleep-dependent memory consolidation experiments, and nocturnal sleep intervention experiments. The review found that self-report studies generally show an association between poor sleep in middle age and cognitive decline, but sleep-cognition associations are less consistent in older adults. For example, Jelicic et al., (2002) found no association between subjective sleep complaints and cognitive decline in older adults, while Yaffe (2007) reported that older women with greater nighttime wakefulness had an increased risk of developing cognitive impairment.

However, the review found that for actigraphy studies, which measure motor activity as a proxy for sleep, there were more consistent correlations between poor sleep and poor cognition in older adults (Scullin & Bliwise, 2015). However, the authors note that this

discrepancy between subjective and objective sleep measure findings may be confounded by mixing healthy older adults with patient groups, raising an important methodological concern. Distinguishing cognitively healthy individuals from those with undiagnosed cognitive decline can be challenging, even when using neuropsychological batteries, neuroimaging, and biomarkers. Another explanation for the discrepancy between self-report and objective measures of sleep in ageing may relate to how older individuals perceive their sleep. Grandner et al., (2012) suggest that older adults may complain less about sleep quality because they have lower expectations of sleep quality, suggesting that for self-report studies, individuals may be underreporting poor sleep, potentially obscuring the relationship between poor sleep and cognition. However, PSG studies also show inconsistent correlations with cognitive performance, indicating that perception alone does not fully explain this phenomenon (Scullin & Bliwise, 2015).

Moreover, the review found that for experimental sleep deprivation, studies show that sleep deprivation tends to impair cognition in young adults but has less of an impact on older adults, suggesting that age may modify sleep-cognition relationships (Scullin & Bliwise, 2015). Additionally, napping studies indicate that naps benefit cognition in young and middle-aged adults but show fewer benefits for older adults. Similarly, studies of sleep-dependent memory consolidation consistently show impairments in older compared to younger adults, with younger adults demonstrating greater sleep-dependent memory consolidation (Scullin & Bliwise, 2015). Sleep intervention studies aiming to improve sleep in older adults generally fail to produce cognitive benefits, unlike findings in younger age groups (Scullin & Bliwise, 2015). Interestingly, Walsh et al., (2014) found that weaker circadian rhythms in women were associated with worse cognitive function five years later, especially with regards to executive function. This suggests that factors moderating the sleep-cognition link may vary by gender, although more research is needed to investigate this relationship in men.

Taken together, while sleep and cognition are often correlated in young and middle adulthood, healthy older adults show an apparent weakening or differentiation of these associations (Scullin & Bliwise, 2015; Mander et al., 2017). Scullin and Bliwise (2015) propose that this may reflect a reduced sleep need (although Mander et al., (2017) argue against this) or perhaps a potential compensatory mechanism such as neural plasticity (S. N. Burke & Barnes, 2006) or alterations to microsleep architecture (e.g. increased REM to SWS

ratio; Scullin & Gao, 2018), or reduced benefits of sleep processes in cognition due to age-related deterioration (Mander et al., 2017). Longitudinal evidence that poor sleep in middle age predicts later cognitive decline suggests that sleep disturbances across the lifespan, particularly in middle age, may have cumulative effects on cognition (Scullin & Bliwise, 2015; Mander et al., 2017).

1.3.7 Summary of Sleep and Cognition in Healthy Ageing

Recent research has challenged the prevailing view that alterations to sleep quality in ageing are a universal feature of ageing (Scullin & Gao, 2018). Longitudinal research presents a different pattern of sleep changes with ageing compared to cross-sectional studies, revealing a complex and heterogeneous relationship between sleep, cognition, and ageing, characterised by significant individual variability (Ohayon et al., 2004; Scullin & Gao, 2018). While some older adults experience substantial changes in their sleep patterns and quality, others maintain relatively stable sleep throughout their lifespan (Scullin & Gao, 2018).

The findings of significant variability found within sleep and ageing data may account for the paradoxical findings that older adults show an apparent weakening of association between sleep and cognition compared to middle-aged and younger adults (Scullin & Bliwise, 2015). For example, experimental studies on sleep deprivation, napping, and sleep-dependent memory consolidation generally show less impact or benefit for older adults than younger individuals. Factors contributing to this variability may include compensatory mechanisms, comorbidities, and gender differences (Burke & Barnes, 2006; Scullin & Gao, 2018). Importantly, poor sleep quality in middle age has been identified as a predictor of later cognitive decline and appears to have a more consistent association between poor sleep and cognition, than for older adults, suggesting cumulative effects of sleep disturbances across the lifespan. In the context of healthy ageing, poor sleep should not be viewed as an inevitable consequence of growing older. Rather, it signifies an increased risk for specific changes under certain conditions, potentially leading to reductions in cognitive function.

In contrast to the literature on sleep and cognition for healthy older adults, the relationship between sleep disturbances and cognitive decline is more consistently observed in people living with dementia (Bubu et al., 2017). Individuals with dementia show greater disruptions

in sleep quality compared to their age-matched counterparts without dementia (Cipriani et al., 2015; Cagnin et al., 2016; Bubu et al., 2017), and these disturbances may contribute to the progression of and development of cognitive decline (Bubu et al., 2017; D’Rozario et al., 2020).

While much research has focused on sleep and cognition in AD, comparatively less is known about this relationship in Vascular Cognitive Impairment (VCI; Fernandez-Mendoza et al., 2020). The prevalence of VCI may be underestimated due to evolving nosology, highlighting the need for more focused research in this area (Rockwood, Wentzel, et al., 2000). Given the scope of this review and the importance of improving our understanding of VCI, the following sections will examine the relationship between sleep, cognition, and VaD while also considering AD due to the overlapping pathology in mixed dementia, which falls under the VCI framework (Bowler, 2002, 2005).

1.4 Sleep and Dementia

The relationship between poor sleep and dementia appears to be bidirectional (Ju et al., 2014; P. Li et al., 2023). Sleep disturbances not only contribute to an increased risk of developing dementia (Liu et al., 2017; Fernandez-Mendoza et al., 2020; Sabia et al., 2021) but are also more prevalent among those living with dementia compared to age-matched peers (Zhou et al., 2019; Casagrande et al., 2022). This suggests that sleep issues could be both a symptom and a contributing factor to the disease. Numerous studies have also shown that sleep problems can exacerbate dementia pathology while the progression of dementia can worsen sleep disturbances, potentially creating a cycle that impacts both sleep quality and cognitive function bidirectionally (Ju et al., 2014; Li et al., 2023).

Several longitudinal studies and meta-analyses have investigated the relationship between sleep disturbances and the risk of developing dementia, highlighting how disruptions in sleep patterns, quality and duration may contribute to the onset of dementia. For example, a 25-year follow-up study from the Whitehall II cohort found that both short (<6 hours/night) and long (>9 hours/night) sleep durations were associated with a higher risk of developing dementia in middle-aged and older adults (Sabia et al., 2021). This finding is supported by a meta-analysis by Shi et al., (2018), which synthesised data from 18 longitudinal studies

involving nearly 250,000 participants with an average 9.49-year follow-up. The meta-analysis revealed a significant association between sleep disturbances and an increased risk of all types of dementia, including AD and VaD, where those with sleep disturbances had a 1.47-fold higher risk of developing VaD compared to those without sleep issues. Interestingly, the study found that sleep-disordered breathing was associated with a 1.23 relative risk, as were general sleep issues (RR=2.23). However, insomnia did not confer a significantly higher risk of developing VaD, suggesting the existence of potentially distinct sleep-related risk pathways for different types of dementia.

These findings are further supported by an extensive review by Xu et al., (2020), which included 51 cohort studies. The review identified several sleep-related factors associated with an increased risk of all-cause dementia, including insomnia, sleep fragmentation, excessive sleepiness, high sleep onset latency, REM-sleep disorder, and excessive time in bed. Notably, the study found a U-shaped association between sleep duration and risk of cognitive decline, finding that both short (<4 hours) and excessive (>10 hours) sleep were associated with an increased risk of cognitive impairment. Specifically, for VaD, the review found significant associations with REM-sleep disorder (RR=1.90), sleep-disordered breathing (RR=1.29), long time in bed (RR=1.15) and habitual napping (RR=1.46). Interestingly, subgroup analysis comparing AD and VaD did not significantly alter these results, indicating that these sleep disturbances may be general risk factors for various types of dementia, including VaD.

However, the review revealed some distinctions in the risk profile for VaD compared to other types of dementia (Xu et al., 2020). Unlike AD, where extreme sleep durations (<4 hours or >10 hours) were significantly associated with increased risk, this 'U' shaped relationship was not statistically significant for VaD. Additionally, insomnia did not show a significant association with VaD risk, contrasting with its relationship to all-cause dementia. These findings suggest that while there are shared sleep-related risk factors between VaD and other types of dementia, there may be distinct pathways through which sleep disturbances influence VaD risk uniquely. The stronger associations observed for REM-sleep disorder, SDB, and excessive daytime sleepiness could point to specific mechanisms related to vascular health or nocturnal cerebral blood flow regulation (Culebras & Anwar, 2018). However, it is important to note that the authors acknowledged limitations in the number of VaD-specific studies included in their analysis, potentially affecting the power to detect certain associations (Xu et al., 2020). However, in a nationwide population-based study involving over 2.7 million

participants aged 40 and over, the study found a 2.10-fold significant increased risk of mortality in those with VaD and insomnia compared to those without insomnia, which was higher than the AD and insomnia group (RR=1.73; Baek et al., 2021).

Not only do sleep disturbances predict increased dementia risk, but they are also more prevalent in those living with dementia compared to age-matched peers. For example, Zhou et al., (2019) found that in 84 AD patients and 92 healthy older adults (HOAs), sleep disorders were more common in those with AD (55.9%) compared to HOAs (15.2%). Moreover, a systematic review of HOA and AD participants found that 34 out of 45 studies (75.%) show a higher prevalence of sleep disturbances in pathological ageing than in healthy older adults (Casagrande et al., 2022). However, exact prevalence estimates of sleep disturbances vary depending on measures used (i.e. objective, subjective) and outcome measures assessed (i.e. sleep disorders, sleep quality, general sleep parameters such as SE, SOL, WASO).

Sleep disturbances appear to contribute to the pathogenesis of dementia through several mechanisms. One proposed mechanism involves the glymphatic system, a brain-wide network of channels that facilitates the clearance of toxic waste products, including amyloid-beta ($A\beta$) and tau proteins, which are known to accumulate in the brains of individuals with AD and contribute to pathogenesis (Spira et al., 2013; Boyle et al., 2015; Soria Lopez et al., 2019). The glymphatic system is thought to be most active during sleep, particularly during SWS (Hablitz et al., 2019), where clearance is 60% faster in sleep than in wake (Xie et al., 2013). When sleep is disrupted, the function of the glymphatic system is impaired, leading to the accumulation of neurotoxic waste. Studies have shown that for healthy adults, one night of acute sleep deprivation was associated with significantly increased $A\beta$ deposition (Shokri-Kojori et al., 2018) and selective disruption of SWA was associated with acute increases in $A\beta$ but not tau. In contrast, tau increase was associated with poor quality over several days (Ju et al., 2017), suggesting that sleep architecture acts differentially on levels of neurotoxic proteins (Ibrahim et al., 2024). Moreover, studies have found significant associations in healthy adults with lower sleep efficiency, frequent napping, greater WASO, as well as self-reported shorter sleep duration and lower sleep quality with greater β -Amyloid burden (Spira et al., 2013; Ju et al., 2013).

Moreover, longitudinal studies indicate that circadian disruptions correlate with cognitive decline such that circadian disruption predicts worse cognitive performance, which in turn leads to greater circadian disruptions, suggesting a cycle where poor sleep contributes to cognitive decline and vice versa. Cognitive decline is typically assessed using standardised neuropsychological tests targeting various cognitive domains. Common measures include the Mini-Mental State Examination (MMSE; Folstein, 1975) and the Montreal Cognitive Assessment (MoCA; Nasreddine et al., 2005), both widely used to evaluate global cognitive function. These assessments cover key domains such as attention, memory, language, visuospatial skills, executive function, and orientation. More specific tasks, such as the Rey-Osterrieth Complex Figure Task for memory recall, the Trail Making Test (TMT) for cognitive flexibility and executive function, and verbal fluency tasks like the FAS word generation test, are also frequently used to assess domain-specific cognitive abilities.

In the Rush Memory and Ageing Project involving 1401 participants with a 14-year follow-up, Li et al., (2023) found that frequent daytime naps, an indicator of excessive daytime sleepiness, were associated with a higher risk of AD and that longer and more frequent naps was correlated with worse cognition a year later. Conversely, worse cognition was correlated with more excessive naps a year later. Additionally, Wilckens et al., (2018) examined the role of sleep in connection with amyloid- β presence, associated with AD pathology, and memory performance in 41 healthy older adults (mean age 83 years), focusing on actigraphy assessed sleep fragmentation (i.e. WASO). The study found that then when examining memory recall (Rey-Osterrieth Complex Figure task), cognitive flexibility (Trail Making Task) and verbal fluency (FAS word generation), WASO moderated the relationship between A β and memory such that those with poorer sleep and A β had poorer cognitive performance, particularly for memory.

1.4.1 Sleep and Vascular Cognitive Impairment (VCI)

The relationship between sleep and dementia appears to be bidirectional, although research specifically examining this relationship in VCI remains limited, highlighting a disparity in sleep and cognitive health research between AD and VCI. Nevertheless, some studies indicate a bidirectional link specifically for those with VCI, particularly concerning specific sleep disorders. Sleep-disordered breathing (SDB), insomnia, and hypersomnolence (excessive

daytime sleepiness) have emerged as unique predictors of VaD. Other factors of poor sleep quality, such as excessive time in bed, greater sleep fragmentation, and short sleep duration, have also been identified as risk factors for VaD.

Research examining the role of these factors in the pathogenesis of VCI has primarily focused on SDB. Pan & Kastin, (2014) reported a high prevalence of SDB in dementia patients, with 40-70% affected compared to only 5-19% of cognitively unimpaired, age-matched peers. Xu et al. (2020) found that SDB was associated with a 1.29 relative risk of developing VaD, while Chang et al., (2013) reported an even higher increased risk (HR = 1.93). Beyond increased risk, SDB has been linked to poorer cognitive function over time. A longitudinal study by Blackwell et al., (2015), involving 2,636 older adults followed for an average of 3.4 years, found that nocturnal hypoxemia was associated with poorer global cognition. Specifically, for every 5-point increase in the oxygen desaturation index (number of oxygen desaturations of $\geq 3\%$ per hour of sleep), there was a decline of 0.36 points in the Mini-Mental State Examination (MMSE) score.

The mechanisms underlying the relationship between SDB and cognition are suggested to be linked to vascular factors. SDB, characterised by intermittent hypoxia and sleep fragmentation, leads to several pathophysiological processes that may contribute to vascular damage and cognitive decline. These include oxidative stress, with intermittent hypoxia generating reactive oxygen species and promoting oxidative stress in brain tissues (A. S. P. Lim et al., 2014). SDB also triggers inflammatory responses, increasing the production of pro-inflammatory cytokines (Mehra & Redline, 2008; Kapsimalis et al., 2008). Chronic intermittent hypoxia can compromise the integrity of the blood-brain barrier, potentially allowing harmful substances to enter the brain (Lim & Pack, 2014). Furthermore, SDB significantly alters cerebral blood flow patterns, causing dramatic swings in blood flow to the brain during apnoeic episodes (Yoshihisa & Takeishi, 2019). Lastly, the repeated stress on blood vessels and changes in intrathoracic pressure have been suggested to impair the glymphatic system, which is responsible for clearing metabolic waste from the brain (Ju et al., 2013; Lim & Pack, 2014; Yoshihisa & Takeishi, 2019).

Indeed, these potential mechanisms are supported by a longitudinal study that involved examining 167 participants at autopsy who completed polysomnography with a mean of 6.4 years prior to their death (Gelber et al., 2015). The study examined brain lesions,

neurofibrillary tangles and neuritic plaques, microinfarcts, generalised brain atrophy, Lewy bodies, neuronal loss and gliosis in the locus coeruleus in conjunction with measures of SDB such as hypopneas, oxygen saturation, duration of SWS and arousals. The study found that greater SWS was associated with less generalised atrophy, and sleep duration with lower blood oxygen saturations (<95%) was associated with higher levels of microinfarcts (OR=3.88), higher minimum oxygen saturation during REM sleep was associated with less neuronal loss and cognitive scores decline less in those with greater SWS duration, supporting that lower nocturnal oxygen saturation and SWS are associated with greater brain atrophy and development of microinfarcts. Thus, taken together, research suggests that sleep disturbances not only increase the risk of developing VaD but that the progression of VCI may also worsen sleep quality, creating a potential cycle of cognitive deterioration.

While these mechanisms are primarily associated with SDB, other sleep disturbances common in VaD, such as insomnia and EDS, may contribute to cognitive decline through related pathways. Insomnia, for instance, is associated with increased sleep fragmentation and reduced SWS which serves an important role in the clearance of metabolic waste products from the brain via the glymphatic system, including amyloid- β (Gelber et al., 2015). Reduced SWS could therefore lead to the accumulation of neurotoxic substances, potentially exacerbating cognitive decline (Xie et al., 2013). EDS, on the other hand, has been associated with an increased risk of VaD (OR = 4.44) but not other types of dementia (Elwood et al., 2011), suggesting a unique relationship between EDS and vascular cognitive impairment. The mechanisms underlying this association are not fully understood but may involve disrupted circadian rhythms and altered cerebral blood flow patterns during wakefulness (Culebras & Anwar, 2018). The interplay of these various sleep disturbances and their associated mechanisms suggests that general sleep quality, beyond specific sleep disorders, may significantly impact cognitive function in VCI. Chronic sleep fragmentation, reduced SWS, and altered sleep architecture associated with insomnia, SDB and EDS all contribute to poor sleep quality (Lavie, 2007), regardless of specific aetiology suggesting a connection between poor sleep quality and cognition in VCI.

The impact of general sleep quality on cognition in individuals diagnosed with VaD or milder stages of VCI remains understudied. This knowledge gap is particularly concerning for several reasons. Firstly, the actual prevalence of VCI may be underestimated due to evolving diagnostic criteria and nosology. As the VCI framework now encompasses earlier cases of

cognitive impairment related to cerebrovascular disease and mixed dementia (with concomitant AD and VaD pathology), some researchers suggest that VCI may be the leading cause of neurodegeneration worldwide (Rockwood, Wentzel, et al., 2000). Secondly, accurate cognitive profiling through neuropsychological assessments is crucial for discriminating between dementia subtypes, especially given the heterogeneous nature of the VCI population.

VaD is typically characterised by prominent deficits in executive function, attention, and processing speed, while memory impairment may be less severe in early stages compared to AD (O'Brien & Thomas, 2015). These cognitive profiles inform the classification of VCI subtypes, such as amnesic (memory impairment) and non-amnesic mild cognitive impairment (Petersen, 2016). These subtypes help inform the risk of progression, as non-amnesic MCI is associated with an increased risk of AD, whilst non-amnesic is associated with non-AD dementia, such as VaD (Petersen et al., 2001; Petersen, 2004; Stephan et al., 2009; Ferman et al., 2013; Petersen, 2016; Rundek et al., 2022). Moreover, research has shown that there are distinct patterns of cognitive trajectories in people with non-amnesic MCI (naMCI) such that those with naMCI tend to show faster cognitive decline than amnesic MCI (Lee et al., 2018). Thus, these subtype divisions help to identify individuals at greatest risk of conversion to dementia.

However, the potential impact of sleep on specific cognitive domains in VCI raises important questions about the accuracy of cognitive subtype discrimination and severity estimation. Sleep plays a crucial role in various cognitive processes, including memory consolidation (Stickgold, 2005; Stickgold & Walker, 2005) and executive function (Wilckens et al., 2014) in both healthy individuals and those with AD (Mander et al., 2017). Conversely, disturbed sleep negatively affects this process and is associated with poorer memory performance (Stickgold, 2005). Similarly, impaired sleep has been linked to diminished executive function in both healthy adults and those with dementia (Mander et al., 2017). If sleep disturbances in VCI significantly affect these cognitive domains, as seen in AD and given the overlapping pathology between AD and VCI, it could potentially obscure accurate assessment of cognitive profiles. For instance, poor sleep quality might lead to an overestimation of memory impairment in individuals with VCI, potentially resulting in misclassification of cognitive subtypes or severity estimation. Moreover, sleep disturbances might disproportionately affect executive function in VCI, given the vulnerability of frontal-subcortical circuits to vascular damage (Muzur et al., 2002; Moretti et al., 2005), potentially

exaggerating the executive dysfunction typically associated with VCI. This potential confounding effect of sleep on cognitive assessment in VCI has not been thoroughly investigated and represents a significant gap in our understanding. Clarifying these relationships is crucial for accurate diagnosis, prognosis, and development of targeted interventions.

In addition, regardless of the specific cognitive impacts, the high prevalence of sleep disturbances in VCI and their known effect on quality of life highlights the need for effective sleep interventions in this population. Sleep issues can exacerbate daytime fatigue, mood disturbances, and caregiver burden, significantly impacting the overall wellbeing of individuals living with dementia (Porter et al., 2015; Scullin & Bliwise, 2015; Mander et al., 2017). Sleep also plays an important role in emotional processing and emotional regulation, both of which are important for maintaining psychological wellbeing. For example, a meta-analysis by Pilcher & Huffcutt (1996) found that mood is more affected by sleep deprivation or sleep loss than cognitive or motor performance. Moreover, studies have shown that sleep disruptions are associated with heightened emotional reactivity, reduced emotional resilience and impaired regulation of negative emotions (Mauss et al., 2013; Palagini et al., 2018; Wassing et al., 2019). These impairments may be particularly detrimental for individuals with VCI, who may already face emotional challenges related to cognitive decline such as loss of independence, neuropsychiatric symptom expression and social isolation. Thus, emotional dysregulation related to sleep disruption could contribute both negatively impact cognitive health and emotional wellbeing.

Whilst there is very little research regarding sleep, cognitive function and wellbeing for people with VCI, research shows that sleep disturbances are a modifiable risk factor as many interventions have shown efficacy in improving sleep quality. For example, some include CBT-I, multi-component therapy, exercise interventions and sleep education, all showing improvements in sleep in those with and without dementia (Montgomery, 2004; Thondala et al., 2023; Dyer et al., 2018). However, many of these interventions require input from facilitators or external guidance from clinicians and research teams, limiting their accessibility. Given the potentially high prevalence of VCI, the need remains for more widely accessible, non-pharmacological treatments for those with VCI targeted at improving sleep and wellbeing in this population.

In light of these knowledge gaps and their significance, this thesis aims to:

- Firstly, better characterise the impact of sleep disturbances on cognitive function in individuals with VaD. By providing a more comprehensive understanding of how sleep is associated with various cognitive domains in this population, this research will contribute to developing targeted interventions and management strategies.
- Second, this thesis aims to develop and validate a novel emotional memory narrative task specifically designed to explore memory processing and sleep-dependent memory consolidation in people with VaD. This tool will assess the effects of sleep on task performance in this population and will facilitate future research on the interactions between sleep, memory, and vascular cognitive impairment.
- Finally, this thesis will investigate the potential of a non-pharmacological fiction-reading intervention to improve sleep quality in both healthy older adults and individuals with VaD. By focusing on accessible, low-input interventions, this research will provide valuable insights into the feasibility and effectiveness of non-pharmacological approaches to sleep improvement in these populations.

By addressing these aims, this research seeks to advance our understanding of the relationship between sleep, cognition, and VCI while providing practical solutions for improving sleep and potentially cognitive outcomes in affected individuals. The findings from this research could have significant implications for the diagnosis, management, and treatment of VCI, ultimately contributing to improved care and quality of life for individuals living with this condition.

Chapter 2. The Effect of Sleep Disturbances on Cognitive Performance in Vascular Cognitive Impairment: Findings from the National Alzheimer's Coordinating Center Uniform Dataset

2.1 Abstract

This study investigated the impact of sleep disturbances on cognitive performance in individuals with Vascular Cognitive Impairment (VCI), focusing on Vascular Dementia (VaD). Using data from the National Alzheimer's Coordinating Center (NACC) database, cognitive performance across multiple domains was compared between those with and without sleep disorders and sleep issues (total $n = 111207$), as measured by the presence and severity of captured by Neuropsychiatric Inventory Questionnaire (NPI-Q), specifically in groups including Healthy Older Adults (HOA, $n = 59407$), self-reported Subjective Cognitive Decline (SCD; $n = 20839$), Mild Cognitive Impairment (MCI; $n = 26599$), and clinically assessed VaD ($n = 4362$). Results showed that individuals with VaD and sleep issues performed worse across several cognitive domains compared to those without sleep issues, including global cognitive function ($d = .68$), orientation ($d = .69$), executive function ($d = .31$), memory ($d = .22$), and language ($d = .19$). Interestingly, visuospatial function did not differ between sleep conditions for any group. The study provides novel evidence that sleep disturbances are negatively associated with cognition in VaD. Limitations, including the cross-sectional design and lack of robust sleep measures, highlight the need for further longitudinal and experimental research to explore the relationship between sleep and cognition in VCI empirically. However, the strength of this research lies in the large sample size of each cohort, which has implications for refining clinical criteria to account for sleep-related impairment and developing targeted interventions.

2.2 Introduction

The classification and understanding of Vascular Dementia (VaD) have evolved significantly over the years (Bowler, 2002; Román et al., 2004; Rundek et al., 2022). Historically, VaD was primarily recognised as multi-infarct dementia (MID), resulting from multiple large cortical infarcts (Hachinski et al., 1975). An infarct refers to tissue death due to a lack of blood supply, often caused by large vessel disease or strokes that block major brain arteries (Saver, 2008). MID was marked by a stepwise deterioration of cognitive function, with each infarct causing a noticeable and temporally dependent decline in cognitive abilities (Román et al., 2004). However, it became apparent that several other types of cerebral vascular injuries contributed to cognitive decline. These included cerebral small vessel disease (CVD), which refers to a chronic and progressive disorder of the arterioles, capillaries and other small veins supplying white matter and deep structures of the brain (Pinter et al., 2015; Chojdak-Lukasiewicz et al., 2021); strategic infarcts, which are single infarcts in crucial brain areas that govern behaviour and cognition (Tatemichi et al., 1995; Sanker et al., 2022); chronic cerebral hypoperfusion, a reduced blood flow to the brain (Yata & Tomimoto, 2014); and cerebral haemorrhage, bleeding within the brain (Pasquier & Leys, 2000). Additionally, it was discovered that the pathology of Alzheimer's Disease (AD) and cerebrovascular disease can co-occur, giving rise to the identification of mixed pathologies or mixed dementia (Rockwood, Macknight, et al., 2000; Jellinger & Attems, 2007; Custodio et al., 2017).

To accommodate this expanded understanding, the term Vascular Cognitive Impairment (VCI) was introduced as an umbrella term encompassing all forms of cognitive impairment associated with CVD (Bowler, 2002; Calabrese et al., 2021; Rundek et al., 2022). This term thus acknowledges that various vascular pathologies can lead to cognitive deficits. For a dementia diagnosis, cognitive impairment must be objectively recognised using standardised neuropsychological tests and must significantly interfere with the ability to live and function independently (Kasper et al., 2020). However, the conceptualisation of VCI also includes milder forms of cognitive impairment, such as Mild Cognitive Impairment (MCI), where impairment does not interfere with independent functioning but still can be objectively detected. This shift in terminology reflects the recognition that vascular pathology can cause a spectrum of cognitive deficits, from MCI to dementia (e.g. VaD), so long as there is evidence of vascular aetiology (Román et al., 2004; see table 2 for VCI subtypes).

Table 2: VCI Terminology (Bir et al., 2021)

Terminology	Description/cause
Small vessel disease (SVD) /Binswanger's disease	Sub-cortical infarcts
Multi-infarct dementia	Cortical infarct, large artery occlusion (atherothrombotic or cardioembolic)
Strategic	Thalamus, caudate, hippocampus and genu of internal capsule
Hypoperfusion dementia	Watershed infarct/ orthostatic hypotension and variation in blood pressure
Mixed dementia	Cerebrovascular Disease along with Alzheimer's disease pathology or other dementia pathology
Haemorrhagic	Micro-bleed, Cerebral Amyloid Angiopathy
Hereditary vascular dementia	CADASIL (NOTCH 3 gene mutation) and CARASIL (mutation in HtrA serine protease gene)
Vascular dementia/Vascular cognitive impairment/post-stroke dementia	All of the above causes

2.2.1 Conceptual Advantages and Disadvantages of VCI

The VCI concept has several advantages over the traditional VaD criteria. Firstly, whereas previous diagnostic criteria meant that only individuals with impairment severe enough to impair daily function were recognised, the VCI framework enables the early identification of at-risk individuals. For example, whilst not everyone with MCI will convert to dementia, research suggests that individuals with MCI have an elevated risk of conversion. For example, Thaipisuttikul et al., (2022) found that of 250 adults with MCI aged 50 and over, 18.4% converted to dementia within an average of 1 year. Thus, by recognising earlier stages of cognitive impairment, the VCI framework enables the early identification of at-risk

individuals who have not converted to dementia. This enables timely intervention and allows for close monitoring of disease progression. Secondly, VCI acknowledges the heterogeneity of CVD and its diverse impact on cognition. By moving beyond the narrow focus of MID, the VCI framework enhances research opportunities into the varied pathophysiological contributions to cognitive impairment, ensuring that less subtle forms of VCI are not overlooked, leading to a more accurate understanding of the condition's subtypes. Finally, the VCI framework supports improved diagnostic precision. This assists clinicians and researchers in developing tailored treatment and management plans, potentially leading to more effective patient outcomes (Van Der Flier et al., 2018).

However, this evolving conceptualisation has also revealed greater heterogeneity in the cognitive manifestations of VCI compared to the typical amnesic profile of AD, not only in terms of severity but also in terms of constellations of cognitive symptoms (Bowler, 2002; Román et al., 2004; Rundek et al., 2022). While AD follows a relatively stereotypical pattern of memory impairment that progresses to multiple domains over time (Brooks & Loewenstein, 2010), the cognitive deficits seen in VCI vary significantly depending on the location, extent and underlying pathology of cerebrovascular damage leading to 'patchy' and inconsistent deficits (Erkinjuntti & Rockwood, 2001; Bowler, 2002; Frances et al., 2016; Sudo et al., 2017).

2.2.2 Cognitive Symptoms in VCI

Whilst generally speaking, VCI is associated with executive dysfunction (i.e. issues with planning, organising and implementing sequencing), the cognitive deficits seen in VCI vary significantly depending on the location, extent and underlying pathology of cerebrovascular damage (Desmond, 2004; Bowler, 2005). For example, MID dementia, a type of VCI caused by multiple small strokes, typically presents with a stepwise deterioration in cognitive function temporally linked with an event of vascular injury. Memory impairment is often an early symptom, followed by executive dysfunction with other domains, such as language and visuospatial abilities, affected later (Sari et al., 2013).

In contrast, Subcortical Ischemic Vascular Dementia (SIVD), associated with small vessel disease in deeper structures of the brain, often presents with a more insidious, slower onset. A

profile of psychomotor slowness characterises SIVD due to loss of control in executive function (Román et al., 2002). Additionally, working memory retrieval deficits are common in SIVD, with a relative sparing of language and recognition memory (Tierney et al., 2001; Tian et al., 2023). Attention deficits are more prevalent in those with small vessel disease than large vessel disease (Sengupta et al., 2019). In contrast, individuals with intracranial haemorrhage are mainly associated with episodic memory, psychomotor and executive function impairments (P. Y. Garcia et al., 2013).

Cerebral Amyloid Angiopathy (CAA) is another important contributor to VCI. CAA is characterised by the accumulation of amyloid-beta protein in the walls of blood vessels in the brain (Yamada, 2015). This condition can lead to cognitive impairment through haemorrhagic (bleeding) and ischemic (reduced blood flow) mechanisms, as well as its association with AD pathology, such as through neurofibrillary tangles and amyloid-beta deposition (Arvanitakis et al., 2011; Boyle et al., 2015; Yamada, 2015). CAA is primarily associated with AD pathology, which includes the formation of neurofibrillary tangles (abnormal accumulation of tau proteins inside neurons) and amyloid-beta plaques in brain tissue (Yamada, 2015). This association between vascular and amyloid angiopathy pathology can result in a mixed cognitive profile, with cognitive features of both subcortical VaD and AD (Rockwood, Macknight, et al., 2000; De Reuck et al., 2016; Custodio et al., 2017). Specifically, CAA is linked to impaired perceptual speed and episodic memory but does not typically affect semantic memory, working memory, visuospatial abilities, or global cognition to the same extent (Arvanitakis et al., 2011), though presentation varies depending on the severity of pathology (Boyle et al., 2015). Thus, characterising VCI in terms of cognitive presentation is challenging (Moorhouse & Rockwood, 2008).

2.2.3 Importance of cognitive characterisation in VCI

The cognitive characterisation of VCI is important for several reasons. One of the primary goals of the evolving nosology of VCI is to incorporate early cases of cognitive decline, such as MCI, to identify individuals at risk and improve prognostic outcomes. Accurate discrimination between VCI subtypes, including early cases, is essential for clinical purposes and research, particularly in prospective longitudinal studies aimed at determining specific risk factors and monitoring clinical progression over time. A better understanding of the

cognitive profiles of VCI subtypes can inform the development of more precise diagnostic criteria, which have continuously refined to balance diagnostic specificity and sensitivity. By enhancing the accuracy of diagnostic criteria, clinicians and researchers can more effectively identify and manage VCI cases, leading to improved patient outcomes and a clearer understanding of the diverse cognitive manifestations of cerebrovascular disease. Moreover, a well-defined cognitive characterisation of VCI subtypes can facilitate the development of targeted interventions and personalised treatment strategies, as well as aid in designing clinical trials and interpreting research findings.

However, given the variability of cognitive symptoms within VCI, accurately characterising cognitive impairment is challenging. The presence of sleep disturbances may further complicate this challenge. In dementia, research suggests that there is a bidirectional link between poor sleep and AD (Ju et al., 2014, 2017; Liu et al., 2017; Zhou et al., 2019; Fernandez-Mendoza et al., 2020). Firstly, there is evidence that sleep problems may be an early indicator of AD pathology since amyloid-beta ($A\beta$) pathology begins to accumulate during the preclinical stages of AD (Sperling et al., 2013; An et al., 2014). Changes in sleep patterns also occur at the same time (An et al., 2014). For example, one study found that decreased sleep efficiency was seen in cognitively normal individuals who showed amyloid pathology compared to those who did not (Ju et al., 2017). Moreover, changes in sleep quality, such as increased sleep fragmentation, early morning awakenings, and difficulty maintaining sleep, become more pronounced in individuals with AD, often before cognitive symptoms become noticeable (Ju et al., 2014).

Furthermore, poor sleep is proposed to exacerbate underlying neuropathology through several mechanisms. Slow-wave sleep (SWS) is crucial for clearing metabolic waste products, including $A\beta$, from the brain (Ju et al., 2017; Scullin & Gao, 2018). The glymphatic system, which is more active during SWS, facilitates this clearance. Studies have shown that sleep deprivation reduces the efficiency of the glymphatic system, leading to increased accumulation of $A\beta$ and tau proteins in the brain (Xie et al., 2013). Acute sleep deprivation in humans has been shown to increase soluble $A\beta$ levels in cerebrospinal fluid (CSF) by 25-30%, and chronic sleep deprivation in animal models accelerates $A\beta$ deposition and tau pathology (Xie et al., 2013; Ju et al., 2014). This accumulation of $A\beta$ and tau disrupts sleep patterns further.

Additionally, studies have shown that sleep disturbances are a risk factor for progression to AD. One study indicated that individuals with sleep disorders had a 1.94-fold increased risk of developing AD (Shi et al., 2018). Sleep issues are also more common in those with AD compared to age-matched controls, with approximately 25-66% of AD patients experiencing significant sleep disturbances (Kim et al., 2011; Guarnieri & Sorbi, 2015). As AD progresses, these sleep disturbances become more severe, further impacting cognitive function and quality of life (Ju et al., 2014). This progression suggests that not only can sleep disturbances serve as an early warning sign of AD, but they also exacerbate the underlying neuropathology, thereby accelerating cognitive decline, pointing to a bidirectional relationship between poor sleep and dementia-related pathology. Moreover, research has consistently demonstrated that poor sleep, particularly sleep disorders, negatively impacts cognitive function in AD. For example, a meta-analysis by Bubu et al., (2017) found that individuals with AD who experienced sleep disturbances had significantly worse cognitive outcomes compared to those without sleep issues. This proposed bidirectional link between poor sleep and cognitive function in AD may also be present in VCI due to overlapping pathology.

Evidence suggests that sleep issues not only increase the risk of developing VCI but are also more prevalent in individuals with VCI compared to age-matched controls. For instance, a meta-analysis by Shi et al. (2018) found that individuals with sleep disturbances had a 1.47-fold higher relative risk of developing VaD. In this study, SDB was associated with a 1.23-fold higher relative risk, and general sleep issues were associated with a 2.23-fold higher relative risk. Furthermore, in individuals with Subcortical Ischemic Vascular Dementia (SIVD), the severity of white matter hyperintensities (WMHs), which are small microbleeds and lesions in white matter (d'Arbeloff et al., 2019) was found to be significantly associated with self-reported sleep disturbances, particularly excessive sleepiness (Cheng et al., 2013). Despite the limited research on the specific effects of poor sleep on cognitive function in VCI, it is reasonable to hypothesise that the sleep-related mechanisms observed in AD may also be present in individuals with VCI, especially considering that mixed dementia, a subtype of VCI, shares pathology with AD. Moreover, the risk factors for VCI and its subtypes, such as hypoxia, age-related dysfunction of cerebral blood flow, increased permeability of the blood-brain barrier, endothelial disruption, systemic inflammation, oxidative stress, cardiovascular issues, amyloid-beta burden, and tau phosphorylation, may be

exacerbated by sleep disturbances through various pathways, potentially resulting in poorer cognitive outcomes.

2.2.4 Potential Sleep-Related Mechanisms in VCI

Sleep-disordered breathing (SDB), such as obstructive sleep apnoea (OSA), can lead to intermittent hypoxia, which has been shown to increase oxidative stress and systemic inflammation (Lavie, 2007). Hypoxia can also contribute to endothelial dysfunction and increased blood-brain barrier permeability, potentially facilitating the entry of neurotoxic substances into the brain (Lim & Pack, 2014). Furthermore, OSA is associated with a higher risk of cardiovascular diseases, such as hypertension and atrial fibrillation, which are known risk factors for VCI (Moorhouse & Rockwood, 2008; Frances et al., 2016; Fernandez-Mendoza et al., 2020). Disruptions in the sleep-wake cycle, such as irregular sleep patterns and reduced SWS, may also contribute to cognitive decline in VCI. SWS is crucial for the clearance of amyloid-beta from the brain, and sleep deprivation has been shown to increase amyloid-beta levels (Xie et al., 2013). Moreover, the circadian rhythm regulates the sleep-wake cycle, which is important for maintaining optimal cardiovascular function. Disruptions in the circadian rhythm, such as those caused by irregular sleep patterns, can lead to nocturnal non-dipping of blood pressure, which is associated with an increased risk of cardiovascular events and cognitive decline (Cuspidi et al., 2019). In addition to the clearance of amyloid-beta, SWS is also important for the consolidation of memories and synaptic plasticity (Xie et al., 2013; Tononi & Cirelli, 2014; Mander et al., 2017). Reduced SWS has been associated with impairments in memory consolidation and executive function, common cognitive deficits in VCI (Bowler, 2005; Yaffe, 2007).

2.2.5 The Importance of Understanding the Effects of Sleep on Cognitive Symptoms in VCI

The literature on sleep and dementia suggests a scenario in which poor sleep may contribute to cognitive decline in VCI. However, given the limited research on the impact of sleep disruptions on cognitive function, specifically in VCI, the interaction between sleep and various cognitive domains in this condition remains unclear. Moreover, there is considerable

variability in the cognitive presentation of VCI, which highlights the need for a comprehensive understanding of how sleep disturbances influence cognitive function across the spectrum of VCI severity. This is important for several reasons.

Firstly, sleep issues may affect the accuracy of cognitive assessment in relation to diagnosing VCI. Due to the inclusion of mild cognitive impairment within the VCI classification, detecting subtle changes in cognition is crucial for diagnosing MCI and distinguishing between MCI and VaD. If sleep issues have a deleterious effect on cognitive function, it could lead to overestimating disease severity. This is particularly important when distinguishing between MCI and VaD, as the presence of sleep-related cognitive deficits may make an individual appear to meet the criteria for dementia (i.e., cognitive impairment interfering with the ability to function independently) rather than MCI (i.e., showing objective impairment but still able to function independently), thus potentially confounding neuropsychological assessment outcomes. This misclassification could have significant implications for treatment, prognosis, and support services provided to the individual. However, it is important to note that radiological evidence of cerebrovascular disease (CVD) is required to receive a diagnosis of VCI. Thus, potential sleep-related effects may not result in the misdiagnosis of dementia subtypes.

Secondly, accurately distinguishing between amnesic and non-amnesic cases of MCI is crucial, as amnesic MCI predicts conversion to AD. In contrast, non-amnesic MCI predicts conversion to other dementias, such as VaD. Research has shown that memory is particularly affected by poor sleep, and tools used to diagnose MCI, such as the MoCA and MMSE, may lack the sensitivity to differentiate between sleep-related deficits and genuine cognitive impairment. Consequently, sleep-related deficits could result in lost points on these assessments, potentially leading to a misdiagnosis of MCI in cases of sleep deprivation or disturbance. Thus, given the difficulty in cognitively characterising VCI and research efforts focusing on improving the sensitivity and specificity of classification criteria to enhance diagnosis, understanding whether sleep disruption plays a role in the cognitive profile of individuals with VaD is crucial. Research in this area could lead to more accurate diagnostic tools and better-targeted treatments, ultimately improving patient outcomes.

Finally, sleep is a modifiable risk factor. For example, numerous studies have demonstrated that improving sleep quality and treating sleep disorders can benefit cognitive function in

various populations, including older adults and individuals with dementia (Billington et al., 2013; Javed et al., 2023). If sleep does indeed have a deleterious effect on cognitive function in VCI, addressing sleep disturbances in individuals with VCI may serve to mitigate some of the deleterious effects of poor sleep on cognitive decline and thereby improve overall functioning, enabling people to live as well as possible for as long as possible.

2.3 Aims of The Study

The primary aim of this study is to determine whether individuals with VCI and sleep disturbances exhibit poorer performance across a range of cognitive domains compared to those without sleep issues. To achieve this aim, data from the National Alzheimer's Coordinating Center (NACC) database will be used to examine cognitive performance across domains such as global cognition, orientation, visuospatial abilities, executive function, attention, memory, and language in individuals with and without sleep disorders and disturbances. Sleep disorders will be assessed using clinician reports, while sleep disturbances will be measured using the Neuropsychiatric Inventory Questionnaire (NPI-Q). The NPI-Q assesses nighttime behaviours, including measures of waking too early (circadian disturbance), waking during the night (sleep fragmentation), and taking excessive naps (excessive daytime sleepiness). Given that sleep disturbances have been shown to accelerate cognitive impairment across multiple domains in Alzheimer's disease (AD), and considering the shared pathology between AD and VCI, it is hypothesised that individuals with VCI and sleep issues will perform worse across all cognitive domains compared to those without sleep disturbances.

Secondly, this study aims to investigate the effect of sleep disturbances on cognitive function along the dementia spectrum in VCI. While the effect of sleep issues on cognitive function in VCI remains unclear, it is important to consider that cognitive tests may be susceptible to ceiling effects and that compensatory mechanisms for sleep loss have been observed in healthy older adults experiencing age-related sleep changes. Therefore, this study will focus on vascular dementia (VaD), as individuals with VaD exhibit greater levels of cognitive impairment and are more likely to demonstrate sleep-related deficits if they exist. However, given that VCI encompasses milder forms of impairment and that sleep disturbances have been shown to negatively impact cognitive function in mild cognitive impairment (MCI) and

even in prodromal stages of dementia, such as subjective cognitive decline (SCD), where individuals perceive their performance to be worse than before despite no objective impairment, this study will include healthy older adults (HOA), SCD, MCI, and VaD groups to determine the impact of sleep issues on cognitive function along the dementia spectrum. It is hypothesised that greater sleep-related deficits will be observed in those with more severe cognitive impairment, as more severe forms of impairment are associated with more extensive underlying pathological changes that may interact with the degradation of sleep/wake centres in the brain, as observed in AD. This approach aligns with the evolving nosology of VCI, which seeks to improve our knowledge of VCI subtypes from mild to severe impairment by integrating a spectrum of impairment underpinned by cerebrovascular disease.

Although the NACC database does not phenotype MCI participants into vascular mild cognitive impairment, all-cause MCI will be used as a comparison group in this novel study. The MCI group will serve as a general comparison to the VaD primary interest group, and the limitations of this approach will be discussed in the study. By addressing the knowledge gap regarding the relationship between sleep disturbances and cognitive function in VCI and identifying at-risk cognitive domains and groups across the cognitive impairment spectrum with a specific focus on VaD, this study aims to contribute to the growing body of knowledge on the role of sleep in cognitive health, specifically in VCI, with potential implications for clinical and research classification and sleep-related interventions.

2.3.1 Aims:

- 1) Determine whether those with VaD and sleep issues (combining sleep disorders and disturbances in nighttime behaviours as measured by the NPI-Q) have poorer performance than those without
- 2) To determine which, if any, cognitive domains are affected by sleep issues according to global cognition, orientation, visuospatial abilities, executive function, attention, memory, and language, compared to those without sleep issues, with a focus on VaD
- 3) To compare VaD with MCI, SCD and HOA to determine the impact of sleep issues along the dementia spectrum.

2.3.2 Hypotheses

- 1) Performance across all cognitive domains will be worse in those with VaD and sleep issues compared to those without
- 2) Sleep-related deficits will be worse in those with more severe impairment such that VaD will show greater sleep-related deficits due to greater cognitive impairment and disruption to sleep/wake regulatory systems in the brain

2.4 Method

2.4.1 The National Alzheimer's Coordinating Center Uniform Data Set

The National Alzheimer's Coordinating Center (NACC) database is a large database that combines data from 33 primary centres and 4 exploratory centres in the United States, all under the umbrella of the National Institute on Aging's (NIA) Alzheimer's Disease Research Center (ADRC) program (Xie et al., 2013; Tononi & Cirelli, 2014; Mander et al., 2017). This database has collected prospective, standardised clinical evaluations from 2005 until now. The UDS with a December 2022 data freeze was used for this study.

The Uniform Data Set (UDS) within NACC includes assessments of participants, covering a wide range of data like demographics, neurological exam results, neuropsychological test batteries, and clinical diagnoses of cognitive decline and impairment related to dementia. Participants or their legal representatives must give informed consent to be part of the UDS, ensuring ethical compliance for their data to be used for secondary analysis. All data collected is deidentified to protect individual privacy. The UDS has undergone three iterations over time, each reflecting improvements in the neuropsychological batteries to keep up with advancing research. Version 1 was used from 2005 to 2012, version 2 from 2012 to 2015, and version 3 has been used since 2015. Due to these different versions of the UDS, some neuropsychological batteries have changed over time, resulting in varying sample sizes for particular batteries reported in this analysis. For secondary data analysis in this study, approval was obtained from the NACC to use the database after submitting a research proposal. Ethical approval was also obtained from Swansea University Psychology Department Ethics Committee (5382).

2.4.2 Participants

Four distinct groups were selected from the National Alzheimer's Coordinating Center (NACC) UDS version 1-3 dataset for this study: Healthy Older Adults (HOAs), individuals with Subjective Cognitive Decline (SCD), those with Mild Cognitive Impairment (MCI), and those with Vascular Dementia (VaD).

HOA participants were identified using the 'NACCUDSD' variable, which indicates normal cognitive status confirmed by clinician judgement (NACCUDSD=1). SCD participants were selected based on the method employed in previous studies using the UDS (Kielb et al., 2017; Liew, 2019; Ismail et al., 2021; Ahn et al., 2021). Specifically, individuals were classified as SCD if they reported subjective memory decline, as determined by the 'DECSUB' variable, while clinician judgement confirmed the absence of objective cognitive impairment (NACCUDSD) using the Clinical Dementia Rating Scale (CDR ® Dementia Staging Instrument; Hughes et al., 1982) with a score of 0. This approach ensures consistency with established stratification procedures in the literature.

MCI participants were classified based on clinician judgement using the CDR ®, with either amnesic or non-amnesic types indicated as NACCUDSD=3. Thus, those with MCI in this study contain both amnesic and non-amnesic MCI. VaD participants were identified based on NINDS-AIREN criteria (Román et al., 1993) as confirmed by clinicians to be presumptive or possible VaD, which was assessed using neuroimaging evidence and clinical and neuropsychological assessments. This criterion included neurological signs consistent with subcortical ischemic vascular dementia (SIVDFIND), a presumptive etiologic diagnosis of VaD (VASC), probable VaD (VASCIF) and possible VaD (VASCPS/VASCPSIF). Those with non-vascular, neurodegenerative, or psychiatric disorders that could account for cognitive deficits were excluded.

The groups were further subdivided into 8 groups based on the presence or absence of poor sleep. Poor sleep was determined by the presence of at least one of the following: a sleep disorder (including apnoea (APNEA, SLEEPAP), REM sleep behaviour disorder (RBD, REMDIS), insomnia (INSOMN), unspecified sleep issue (OTHSLEEP, SLEEPOTH), or hypsomnia (HYPOSOM)), or the presence of nighttime behaviours, a neuropsychiatric symptom captured by the Neuropsychiatric Inventory-Questionnaire (NPI-Q; Cummings, 1997). Nighttime behaviours included waking during the night, waking too early in the morning, and taking excessive naps. These indicators of poor sleep represent measures of sleep fragmentation, circadian misalignment, and excessive sleepiness and have been used as outcome measures in numerous dementia research studies examining sleep disturbances (Atayde et al., 2022; Pillai et al., 2022; Mudalige et al., 2023; Koren et al., 2023). The NPI-Q assesses sleep disturbances first by indicating their presence (yes or no), and if present,

provides a severity rating of 1-3, with 3 indicating the most severe disturbance. The absence of the above criteria was classified as no sleep issues. Only participants with complete data for variables of interest were included. Consequently, the 8 cohort categories included;

- HOA with No Sleep Issues (HOA+ NSI),
- HOA with Poor Sleep (HOA + Poor Sleep),
- SCD and No Sleep Issues (SCD + NSI),
- SCD with Poor Sleep (SCD + Poor Sleep),
- MCI with No Sleep Issues (MCI + NSI),
- MCI with Poor Sleep (MCI + Poor Sleep),
- VaD with No Sleep Issues (VaD + NSI) and
- VaD with Sleep Issues (VaD + Sleep Issues).

Table 3: Demographic Characteristics According to Group

Group	HOA (<i>n</i> = 59407)		SCD (<i>n</i> = 20839)		MCI (<i>n</i> = 26599)		VaD (<i>n</i> = 4362)	
Sleep Condition	No Sleep Issue	Sleep Issue	No Sleep Issue	Sleep Issue	No Sleep Issue	Sleep Issue	No Sleep Issue	Sleep Issue
N (Total=111207)	48991	10416	14811	6028	18429	8170	3079	1283
Age, M (SD)	73.83 (10.37)	73.11 (9.79)	74.67 (9.95)	73.01 (9.64)	76.22 (9.68)	74.15 (9.68)	79.77 (8.44)	79.26 (8.70)
Sex, M/F	M=16576 F=32415	M=3978 F=6438	M=5280 F=9531	M=2289 F=3739	M=8442 F=9987	M=4567 F=3603	M=1497 F=1582	M=683 F=600
Education (years), M (SD)	16.29 (6.12)	16.4 (6.54)	16.02 (5.71)	15.97 (5.33)	15.69 (6.35)	15.95 (6.79)	15.57 (9.21)	15.17 (8.7)

2.4.3 Materials

Seven cognitive domains were assessed across all groups, and neuropsychological tests were used to assess each domain as outcome measures to examine cognitive function across all groups. The cognitive domains assessed were global cognition, orientation, visuospatial, attention, executive function, language, and memory.

2.4.3.1 Global Cognitive Function

The Mini-Mental State Exam (MMSE; Folstein et al., 1975) and the Montreal Cognitive Assessment (MoCA) total scores were used to assess global cognitive function. The MMSE is a 30-item standardised questionnaire used to screen for cognitive impairment. It evaluates several aspects of cognitive function, including orientation to time and place, attention, verbal memory, language, and visuospatial ability, out of a maximum score of 30. A score of 23 or less indicates the presence of cognitive impairment (Schultz-Larsen et al., 2007). The Montreal Cognitive Assessment is also a rapid screening tool for cognitive impairment. Similarly, out of a maximum score of 30, it assesses memory, executive functioning, attention, language, visuospatial abilities, and orientation. For both the MMSE and MoCA, higher scores indicate better cognitive function.

In the UDS Version 3, the MoCA replaced the MMSE due to its superior sensitivity in identifying MCI, AD and VCI (Nasreddine et al., 2005; Dong et al., 2010; Siqueira et al., 2019). A study comparing the two assessments found that the MoCA had excellent sensitivity (90% for MCI, 100% for AD) and very good to excellent specificity (87%), while the MMSE had poor sensitivity (18% for MCI, 78% for AD) but excellent specificity (100%; Nasreddine et al., 2005). Notably, 73% of MCI participants scored in the abnormal range on the MoCA but in the normal range on the MMSE, demonstrating the MoCA's superiority in detecting MCI.

2.4.3.2 Orientation

Temporal and geographical orientation were assessed using specific subscales from the MoCA and MMSE. The MMSE assesses participants on temporal orientation with questions about the current year, month, date, and time, and on geographical orientation by asking about their current location, including country, city, and institutional setting, contributing to a combined maximum score of 10 points (5 for each type of orientation). Conversely, the MoCA evaluates these orientations with items on the date, month, year, day, place, and city for 6 possible points. Higher scores indicate better functioning. Studies indicate that orientation, especially temporal, is a reliable indicator of daily functioning in individuals with dementia and predictive of overall cognitive deterioration over time (Guerrero-Berroa et al., 2009; Razani et al., 2009). However, these measures are less effective for detecting milder cognitive impairments (Nasreddine et al., 2005).

2.4.3.3 Visuospatial

Visuospatial abilities were assessed by combining subscale scores from the MoCA into a composite visuospatial variable with a maximum score of 5, as well as the Benson Complex Figure Test (BCFT; maximum score of 17). The MoCA-derived composite included the modified Trail Making Test (TMT-B; maximum score of 1), the Copy of the Cube Task (score of 1), and The Clock Drawing Test (maximum score of 3). The TMT-B measures visuomotor tracking and executive functioning by requiring participants to alternately connect sequences of numbers and letters in ascending order, challenging mental flexibility and frontal lobe function (Kortte et al., 2002; Oosterman et al., 2010). Additionally, the Copy of the Cube task tests spatial planning and perception as participants are instructed to reproduce a three-dimensional cube. The Clock Drawing Test evaluates visuoconstructional skills by asking individuals to draw a clock at a set time and assesses the contour, number placement, and hand accuracy.

The BCFT relies primarily on visuospatial abilities but also on visual memory and executive functions such as organisation and working memory (Jiskoot et al., 2023). Participants are tasked with copying complex geometric shapes and subsequently reproducing them from memory. The BCFT used within the National Alzheimer's Coordinating Center Uniform Data Set (NACC-UDS) represents a simplified version of the Rey-Osterrieth Complex Figure Test, modelled on the same scoring system. Eight major figural elements must be drawn, with 1

point for accuracy of elements and 1 point for placement of elements. A bonus point is awarded if each element is accurately drawn, properly placed, in proper proportions, with no extra lines, and all connections between elements are clean. This gives rise to a maximum of 17 points, where higher scores indicate better performance.

2.4.3.4 Attention

Attention was assessed using MoCA attention subscale tasks such as the Digit Span Forward (DSF) task, which required participants to repeat a sequence of 5 numbers in the order presented to participants. The DSF measures the retention of auditory stimuli and articulatory rehearsal and is scored out of a maximum point of 1. The Digit Span Backwards (DSB) requires participants to repeat a sequence of 3 numbers in backwards order and is scored out of a maximum point of 1. The Letter A tapping test was also used to assess attention and involves the examiner reading a sequence of letters. Each time the letter A appears in the sequence, the participant must tap a surface with their hand. It assesses sustained and focused attention and inhibition of non-A letters with a maximum score of 1. Finally, the Serial 7 subtractions assessed attention, with a maximum score of 3. Participants must subtract seven from a starting number and then keep subtracting seven until the examiner tells them to stop after five subtractions. These tasks were combined to create a composite measure of attention, giving rise to a maximum score of 6.

2.4.3.5 Executive Function

Executive function is measured using the Trail Making Test-A and Trail Making Test-B (TMT-A, TMT-B). In part A, participants must draw a line connecting numbers in ascending order, which assesses visual scanning, numeric sequencing, and psychomotor speed. However, part B is considered a more robust measure of executive function. In this part, participants must alternate between connecting numbers and letters in ascending order (e.g., 1-A, 2-B, 3-C, etc.). This task requires cognitive flexibility, a key component of executive function, as participants need to switch between two different mental sets (numbers and letters) while maintaining the overall goal of the task. The ability to efficiently shift between these mental sets relies on frontal regions of the brain, which are known to be involved in

executive function. Part B also involves greater spatial distance between the stimuli than Part A, increasing the difficulty of the task's visual search and executive function load.

Participants are instructed to complete the test as quickly as possible, with a cut-off time of 300 seconds to limit the assessment duration (Bowie & Harvey, 2006).

Additionally, commission errors, such as connecting targets in the wrong order, are often recorded alongside the completion time. The TMT allows participants to reattempt the correct response after a mistake is made without affecting their overall score. Therefore, measuring both the correct number of lines and the number of commission errors is crucial for a comprehensive performance assessment. A participant with many commission errors could achieve the same number of correct lines as someone without any errors, but the presence of commission errors may indicate underlying executive dysfunction. Commission errors can reflect issues with inhibitory control (difficulty suppressing the prepotent response of connecting targets in numerical or alphabetical order), working memory (trouble holding the task's rules and current position in mind), attention (lapses in focus), and monitoring (failure to effectively monitor performance; Pearce et al., 2016; Pantiou et al., 2018). Thus, to capture these important aspects of executive function, the measures for this study include the number of correct lines and commission errors for both part A and part B of the TMT.

2.4.3.6 Memory

Several measures will be used to assess memory, including Weschler Memory Scales-Revised (WMS-R) digit span forward and backwards, the WMS-R logical memory IIA- immediate and delayed, the immediate and delayed Craft Story 21 task (Craft et al., 1996) and the MoCA MIS.

The Wechsler Memory Scale-Revised (WMS-R) digit span forwards and backwards are subtests of the WMS-R intelligence tests for adults and children. These subtests assess different aspects of memory and cognitive function. In the digit span task, participants hear a sequence of digits and are asked to verbally recall the sequence either in the same order as presented (forwards) or reverse order (backwards). The task begins with a sequence of two digits, and if the participant correctly recalls the sequence, an additional digit is added to the next sequence. This process follows the same protocol, with a maximum of 12 trials and a

sequence length of up to 8 digits. The task ends if the participant completes all trials, reaches the maximum sequence length, or fails to recall a particular trial on three attempts.

The forward digit span task primarily assesses verbal short-term memory, requiring participants to store and immediately recall a sequence of digits. In contrast, the backward digit span task is believed to measure working memory, as it involves storing the informational strings and manipulating them using attentional control and processing resources. Successful performance on the backward digit span task requires participants to maintain the digit sequence in memory while reversing the order, placing a greater demand on cognitive resources than the forward digit span task (Yoshimura et al., 2023).

The Logical Memory (LM) task from the Weschler Memory Scale (WMS) assesses immediate and delayed episodic memory. The test consists of participants listening to 2 short stories which contain 25 units of recall (groups of words within the story). Immediately after each story presentation, participants complete an immediate recall. Participants completed a delayed recall 30 minutes later.

The Craft-21 story task (Craft et al., 1996), introduced in the Uniform Data Set (UDS) version 3 (Nester et al., 2023), is similar to the LM task in assessing immediate and delayed episodic memory. Participants are presented with a story to recall, and their performance is scored out of 25 units. The Craft-21 task replaced the LM task in the UDS battery as part of an effort to update neuropsychological batteries with non-proprietary tests (Weintraub et al., 2018). Licensing costs and restrictions on sharing instruments internationally posed challenges for collaboration, making the transition to non-proprietary tests advantageous. Moreover, the LM task was the only task in the UDS battery to show practice effects improved performance with repeated testing (Weintraub et al., 2018; Nester et al., 2023).

Craft and colleagues designed 22 stories piloted on healthy young people and tested for equivalency. These stories were then provided to the Neuropsychology Work Group of the National Institute on Aging (NIA) Clinical Task Force for consideration (Weintraub et al., 2018, p. 3). The work group determined that three stories were most closely related to the LM task, and a final story was chosen for its content relevance to diverse clinical populations, resulting in the development of the Craft-21 task. The scoring of the Craft-21 task is similar to the LM task, offering two options: verbatim scoring, where exact recall of units is scored,

and paraphrase scoring, which allows gist units to be scored. This analysis chose verbatim scoring due to its higher sensitivity (Weintraub et al., 2018, p. 3).

Finally, the MoCA Memory Index Score (MIS) is derived from the delayed recall task of the MoCA, where participants are asked to learn and remember a list of five words. After approximately five minutes, during which other cognitive tasks are administered, participants are asked to recall as many words as possible from the list. The MoCA-MIS ranges from 0 to 15 points, with each word correctly recalled without cues awarded 3 points, correctly recalled after a category cue awarded 2 points, and correctly recalled after a multiple-choice cue awarded 1 point.

2.4.3.7 *Language*

To assess language skills, specifically verbal fluency and semantic memory, an adapted version of the category fluency task from the Consortium to Establish a Registry for Alzheimer's Disease (CERAD; Momi et al., 1989) neuropsychological battery was used. In this test, participants are given a category prompt and are asked to generate as many semantically related items as possible within 60 seconds. The task is scored based on the number of unique, correct responses provided, with a maximum score of 77 for each category.

In the UDS dataset, participants completed two trials of the category fluency task: one with a vegetable category cue and another with an animal category cue. To create a more sensitive outcome measure, the scores from both trials were combined to form a composite score, resulting in a maximum possible score of 144. The category fluency task relies on several cognitive processes, including semantic memory retrieval, executive function, and language production. Semantic memory, a subcomponent of long-term memory, refers to storing and retrieving general knowledge and facts, including understanding word meanings and categorical relationships (Friedrich et al., 2020). Executive function is involved in the strategic search and retrieval of information from semantic memory, as well as in monitoring performance and avoiding repetition. Language production skills are necessary for the rapid and fluent generation of words in response to the category cue.

2.4.3.8 Summary of Measures

Table 4: Summary of Measures According to Cognitive Domain, Measure and Corresponding Maximum Score

Cognitive Domain	Measure	Maximum Score
Global Cognition	MMSE	30
	MoCA	30
Orientation	MMSE Orientation (geographical and temporal)	10
	MoCA Orientation	6
Visuospatial	MoCA visuospatial composite (TMT-B(1), Copy of Cube Task (3), Clock Drawing Task (1))	5
	Benson Complex Figure Test (BCFT)	17
Executive Functioning	TMT-B – number of correct lines	24
	TMT-B- Commission Errors	40
Attention	MoCA Attention Composite (forward and backward digit span (2), Letter A task (1), Serial 7 subtraction (3))	6
Memory	WMS-R forward	12
	WMS-R backwards	12
	LM immediate	25
	LM delayed	25
	Craft 21 Immediate	25
	Craft 21 Delayed	25
	MoCA Memory Index Score	15
Language	Category Fluency Composite (Animals and Vegetables)	144

2.5 Analysis

A series of 4x2 factorial Analyses of Covariances (ANCOVAs) were performed to examine the differences in cognitive performance between those with and without sleep issues across four groups: healthy older adults (HOA), subjective cognitive decline (SCD), mild cognitive impairment (MCI), and vascular dementia (VaD). The two factors were the group (HOA, SCD, MCI, and VaD) and sleep condition (presence or absence of sleep issues).

Analyses controlled for covariates such as age (NACCAGE), sex (SEX), education level (EDUC), and specific medication use, including beta blockers (NACCBETA), antipsychotics (NACCAPSY), and sedatives, anxiolytics, or hypnotic agents (NACCAANX). Additionally, a history of depression within the last two years (DEP2YRS), years of alcohol consumption (ALCOHOL), and years of smoking (SMOKYRS) were included as control variables.

Following the factorial ANCOVAs, post-hoc tests using Bonferroni corrections were performed to further explore the effects of group and sleep conditions on the cognitive measures. All tests maintained a significance threshold of $p < .05$, with adjustments made for multiple comparisons. Effect sizes are reported as partial eta squared (η^2p).

All statistical analyses were conducted using JASP (JASP, 2023) and assumptions for ANCOVA, including normality, homogeneity of variances, and linearity, were checked. Violations of ANCOVA assumptions are reported, and corrections such as Greenhouse-Geisser are applied to these instances.

2.6 Results

The results section will first examine the effect of sleep issues on global cognition, as assessed by the MoCA and MMSE. Subsequently, individual cognitive domains will be assessed, including:

1. Orientation: Evaluated using the MoCA and MMSE
2. Visuospatial functioning: Measured by the MoCA and Benson Complex Figure test
3. Executive functioning: Assessed using the Trail Making Test Part B (Trails-B), considering the number of correct lines and commission errors
4. Attention: Using a MoCA-derived composite score
5. Memory
 - a. Logical Memory test (immediate and delayed recall)
 - b. Craft Story 21 (immediate and delayed recall)
 - c. MoCA Memory Index Score
6. Language: Using category fluency tasks such as animal and vegetable naming

2.6.1 Global Cognition

2.6.1.1 Global MoCA Scores

Table 5: Global MoCA Scores Adjusted for Years of Education

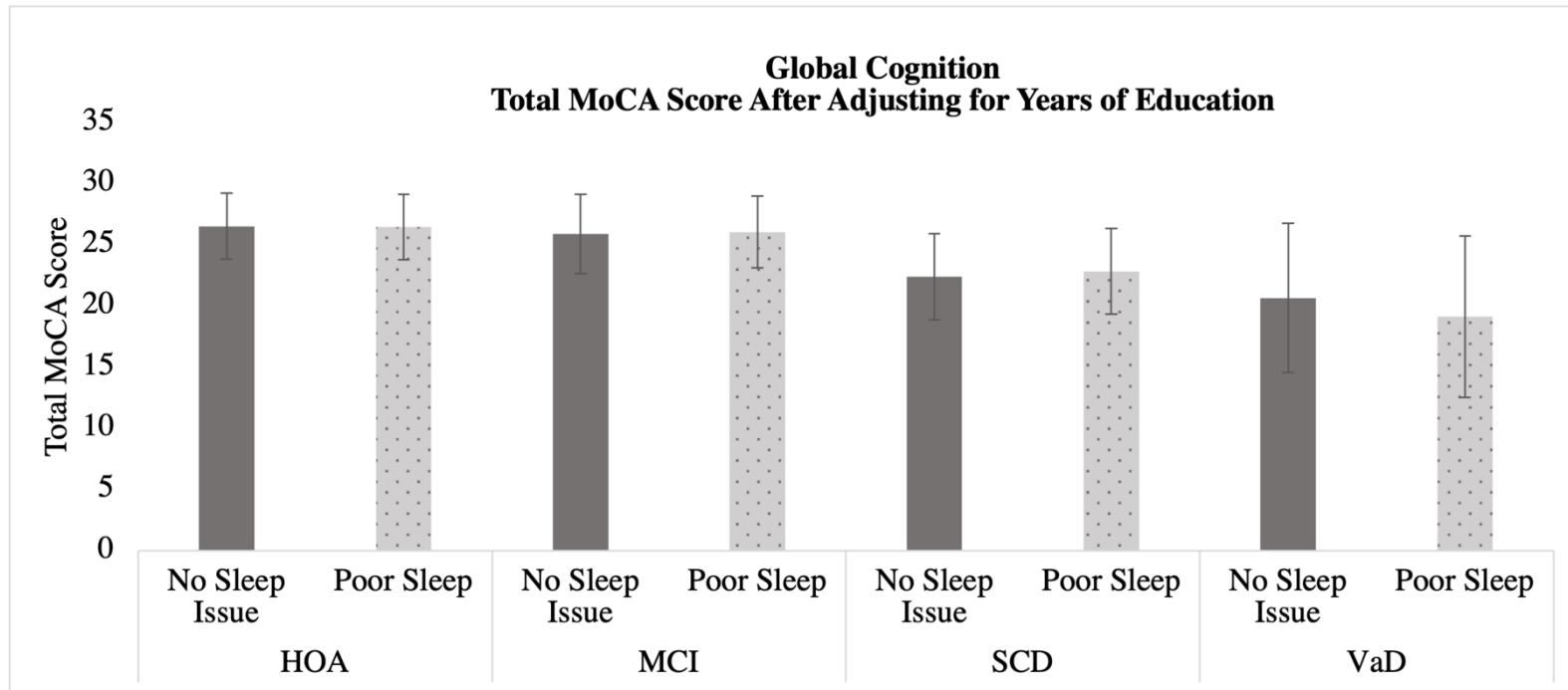
Group	N	Mean	SD
Healthy + No Sleep Issue	11573	26.51	2.70
Healthy + Poor Sleep	5342	26.47	2.67
SCD + No Sleep Issue	3479	25.89	3.23
SCD + Poor Sleep	3077	26.04	2.94
MCI + No Sleep Issue	4010	22.37	3.52
MCI + Poor Sleep	3623	22.83	3.50
VaD + No Sleep Issue	170	20.66	6.10
VaD + Poor Sleep	185	19.14	6.60
Total	31459		

In the 2x4 ANCOVA model, there was a significant main effect of group on global cognition as assessed by the MoCA, $F(3, 7524) = 785.06$, $p < .001$, $\eta^2p = 0.24$. Conversely, no significant main effect was observed for sleep condition, $F(1, 7524) = 0.02$, $p = 0.89$, $\eta^2p < .001$, suggesting that the presence or absence of sleep issues did not significantly impact global cognition after accounting for covariates. Furthermore, there was a significant interaction between group and sleep issue, $F(3, 7524) = 4.41$, $p < .001$, although the effect size was small ($\eta^2p < .001$). This suggests that cognitive performance significantly differed for global cognition, although this varied across groups.

Among the covariates, sex and age showed significant effects, all $p < .001$, indicating they significantly affected global cognition. Other covariates like beta-blocker use, use of psychotics, use of hypnotics/anxiolytics, and smoking years were also significant ($p's < .001$) but had smaller effect sizes ($\eta^2p's < .001$). Alcohol use ($p = .78$) and depression in the last 2 years ($p = .36$) were not significant contributors to overall cognitive function. As the MoCA scores were already adjusted for years of education, years of education were not used as a covariate in this analysis.

Post-hoc analysis revealed that all groups significantly differed from one another, giving rise to a hierarchy in scores as follows: HOAs>SCD>MCI>VaD (p 's<.001), as expected. Within the VaD group, there was not a statistically significant difference between those who had sleep issues compared to those who did not in terms of global MoCA scores ($p = 1.00$, $d = 0.05$). Interestingly, individuals with MCI and sleep issues scored significantly higher than those without sleep issues ($p < .001$, $d = 0.15$). For the SCD ($p=1.00$, $d=-.04$) and HOA ($p=1.00$, $d=.02$) groups, scores were not significantly different between sleep conditions. In summary, according to the MoCA, performance in global cognition only differed significantly for those with MCI; those who had sleep issues performed better than those without, though the difference in performance was small.

Figure 2: Global MoCA Score After Adjusting for Years of Education According to Group with and without Sleep Issues



Note. Global MoCA scores are automatically adjusted for years of education, meaning one additional point is given to those with ≤ 12 years of education. The MoCA is scored out of 30 points, with higher scores indicating better global cognitive performance.

2.6.1.2 Total MMSE Scores

Table 6: Total MMSE Score (Using D-L-R-O-W Subdomains)

Group	N	Mean	SD
Healthy + No Sleep Issue	32165	28.98	1.38
Healthy + Poor Sleep	3540	28.94	1.42
SCD + No Sleep Issue	10131	28.5	1.88
SCD + Poor Sleep	2261	28.41	1.92
MCI + No Sleep Issue	12662	27.03	2.57
MCI + Poor Sleep	3734	27.08	2.51
VaD + No Sleep Issue	2532	24.12	5.91
VaD + Poor Sleep	907	22.6	6.66
Total	67932		

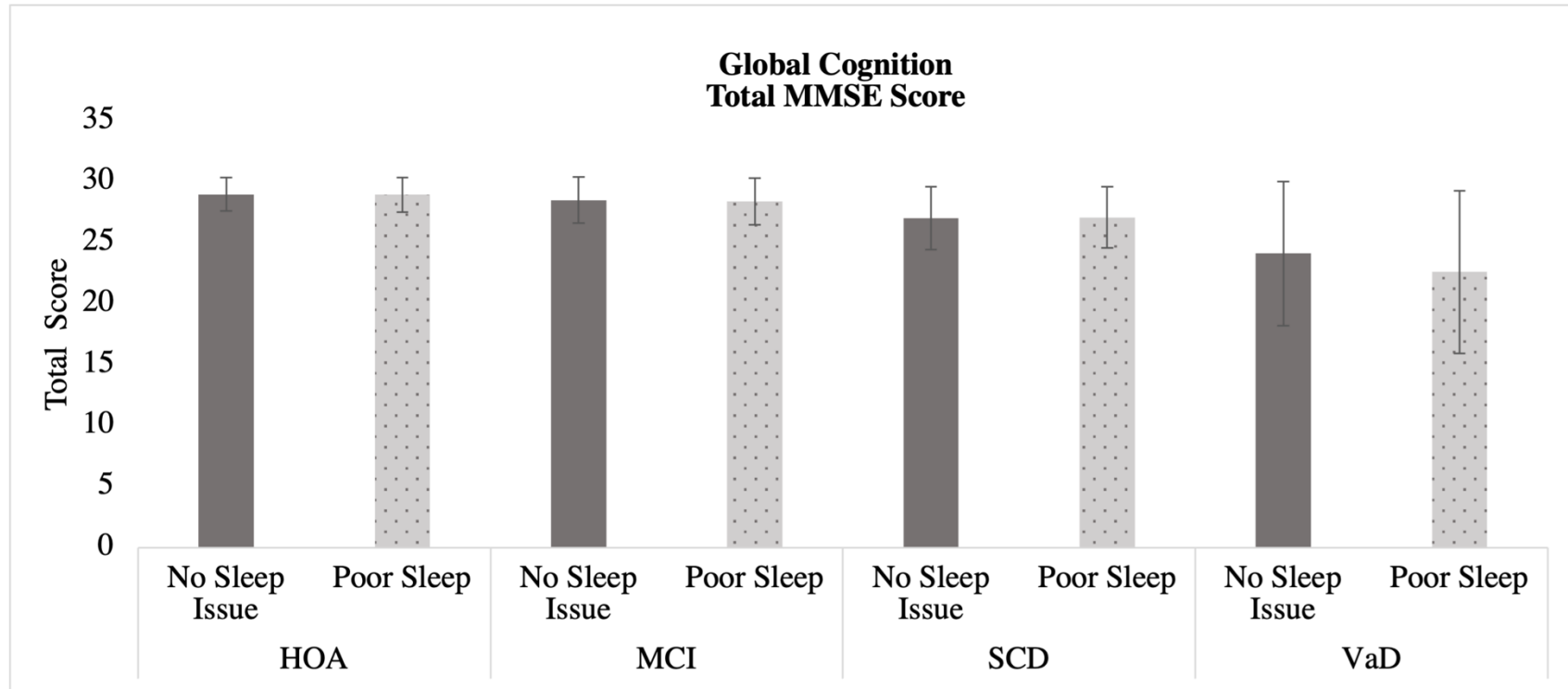
Results of the 2x4 ANCOVA revealed a significant main effect of group on total MMSE scores $F(3,61602)=4018.08$, $p<.001$, $\eta^2p=.16$. There was also a significant main effect of sleep condition on MMSE scores $F(1, 61602)=174.80$, $p<.001$, $\eta^2p<.001$. Moreover, there was a significant interaction between group and sleep condition $F(3,61602)=86.31$, $p<.001$, $\eta^2p<.001$.

Among the covariates, sex, education, age, use of psychotics, use of anxiolytics/hypnotics, and depression in the last 2 years all had a significant effect on overall MMSE cognition ($p's<.001$), whereas the use of beta-blockers ($p=.64$) and smoking years ($p=.11$) did not.

Post-hoc analysis showed that all groups differed significantly in global cognitive function scores, with the hierarchy being HOAs > SCD > MCI > VaD (all $p's < .001$). Cognitive function, as indicated by total MMSE scores, was significantly worse for individuals with VaD and sleep issues ($M=27.61$, $SD=3.26$) compared to those without sleep issues ($M=28.25$, $SD=2.47$, $p<.001$, $d=.68$). In contrast, cognitive function in individuals with MCI did not differ significantly between sleep conditions ($p=1.00$, $d=.02$), SCD ($p=.47$, $d=.06$), or HOAs ($p=1.00$, $d<.001$). These results suggest that for global cognitive function, assessed by the

MMSE, performance was poorer for those with sleep issues than those without, however, this was only for the VaD group.

Figure 3: Total MMSE Score Assessing D-L-O-W Subdomains



Note. The MMSE assesses D-L-O-W domains: Delayed Memory, Language, Orientation, and Working Memory. The maximum score for the MMSE is 30. Higher scores indicate better global cognitive function.

Cognitive impairment is assessed using global measures of cognitive functioning, primarily through assessments such as the MoCA and MMSE. These assessments employ cutoff scores to indicate varying levels of cognitive impairment. For instance, on the MoCA, a score of 25 or below suggests MCI, scores between 10-17 indicate moderate impairment, and scores ranging from 0-9 represent severe impairment. Similarly, the MMSE uses thresholds where scores below 24 indicate MCI, 10-18 suggest moderate impairment, and 9 or less signify severe impairment.

As anticipated, the results demonstrated that cognitive performance declined across the spectrum of impairment from HOA to VaD. The analysis of sleep issues' effect on global cognition revealed interesting patterns. For the MMSE, sleep issues affected performance only in those with VaD, while other groups showed no significant impact. Conversely, the MoCA results indicated that individuals with sleep issues and MCI actually performed better than those without sleep issues, while no difference was observed between VaD patients with and without sleep issues.

The unexpected finding in MCI patients could be spurious; however, it is also plausible that the impact of poor sleep varies across cognitive domains. Alternatively, the tests may not be equally sensitive in all domains, and the overall MoCA and MMSE scores might mask differences in specific cognitive functions related to sleep issues. Given these considerations, subsequent analyses focused on examining the effect of sleep issues on cognitive performance across various individual domains to provide a more granular examination of the relationship between sleep and cognitive function across different groups.

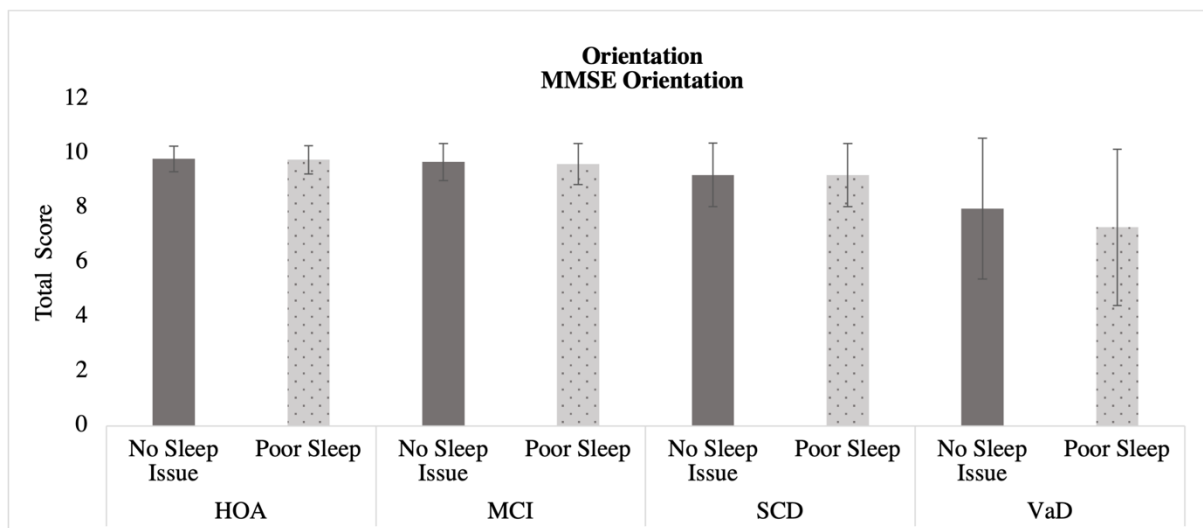
2.6.2 Orientation

2.6.2.1 MMSE Orientation Subscore

Table 7: Mean Orientation scores according to MMSE (out of 10)

Group	N	Mean	SD
Healthy + No Sleep Issue	32283	9.81	0.47
Healthy + Poor Sleep	3553	9.78	0.52
SCD + No Sleep Issue	10168	9.71	0.68
SCD + Poor Sleep	2265	9.62	0.75
MCI + No Sleep Issue	12755	9.22	1.17
MCI + Poor Sleep	3752	9.21	1.16
VaD + No Sleep Issue	2566	7.98	2.59
VaD + Poor Sleep	913	7.31	2.87
Total	68255		

Figure 4: Mean Orientation scores according to MMSE (out of 10)



After combining the data from two MMSE orientation questions relating to time (MMSEORDA) and place (MMSEORLO), a new composite variable assessing orientation

was created, giving rise to a maximum score of 10, where higher scores indicate better performance.

Results show a significant main effect of group on MMSE orientation scores $F(3, 61837)=3196.07$, $p<.001$, $\eta^2p=.13$. Moreover, there was a significant main effect on the presence/absence of sleep issues on orientation scores $F(1,61837)=214.85$, $p<.001$, $\eta^2p<.001$. There was also a significant interaction between group and sleep status $F(3,61837)=72.35$, $p<.001$, $\eta^2p<.001$.

In terms of covariates, alcohol, years of education, age, use of psychotics, use of anxiolytics/hypnotics, and depression in the last 2 years had a significant effect on orientation scores (all p 's $<.001$). The use of beta blockers also had a significant effect ($p=.01$), whereas sex ($p=.96$) and smoking years ($p=.51$) did not.

In the post hoc comparisons assessing sleep condition and their impact on MMSE orientation scores, individuals with sleep issues ($M=9.33$, $SD=1.36$) performed 0.19 units worse than those without sleep issues ($M=9.58$, $SD=.99$), $t(14.66) = 0.2$, $p < .001$, $d=.20$.

Post-hoc analyses indicated significant differences in orientation scores among all groups, following the pattern $HOA > SCD > MCI > VaD$ (all p 's $<.001$). Specifically, individuals with VaD and sleep issues had worse orientation scores ($M=7.31$) than those without sleep issues ($M=4.92$, $p<.001$, $d=-.69$). Conversely, orientation scores did not differ significantly for those with MCI with or without sleep issues ($p=1.00$, $d<.001$). Among the SCD group, those with sleep issues ($M=9.62$) scored significantly lower than those without sleep issues ($M=9.71$, $p=.03$, $d=.08$). Sleep issues had no significant impact on orientation scores for HOAs ($p=1.00$, $d=.03$). In summary, orientation scores were worse for individuals with VaD and sleep issues than those without, with a medium effect size, and to a lesser extent, those with SCD, with a small effect size. However, orientation scores were not significantly different between those with sleep issues and those without in the MCI and HOA groups.

2.6.3 MoCA Orientation

Table 8: MoCA Total Orientation Scores

Group	N	Mean	SD
Healthy + No Sleep Issue	12750	5.91	0.3
Healthy + Poor Sleep	5987	5.91	0.32
SCD + No Sleep Issue	3811	5.89	0.36
SCD + Poor Sleep	3435	5.89	0.35
MCI + No Sleep Issue	4334	5.55	0.81
MCI + Poor Sleep	3902	5.66	0.68
VaD + No Sleep Issue	179	4.94	1.72
VaD + Poor Sleep	193	4.62	1.88
Total	34591		

For orientation scores as measured by the MoCA, six orientation questions were combined to create a composite overall orientation score, including date (MOCAORDT), month (MOCAORMO), year (MOCAORYR), day (MOCAORDY), place (MOCAORPL), and city (MOCAORCT), giving rise to a maximum score of 6 points where higher scores indicate better performance.

A significant main effect was observed for both group and sleep condition on MoCA orientation scores (Group: $F(3, 7700) = 286.13, p < .001, \eta^2p = .10$; Sleep Condition: $F(1, 7700) = 20.75, p < .001, \eta^2p < .001$). Additionally, there was a significant interaction between group and sleep condition ($F(3, 7700) = 9.16, p < .001, \eta^2p < .001$).

Regarding covariates, sex, years of education, and age significantly influenced MoCA orientation scores (all p 's $< .001$). Medication use of anxiolytics/hypnotics ($p = .02$), depression within the last two years ($p = .05$), and years of smoking ($p = .03$) also had a significant impact, though with small effect sizes. Conversely, alcohol use ($p = .84$), use of beta-blockers ($p = .76$), and use of psychotics ($p = .41$) did not.

In the post hoc comparisons assessing sleep issues and their effect on MoCA orientation

scores, individuals with poor sleep ($M=5.81$, $SD=.54$) scored 0.13 units lower than those without sleep issues ($M=5.83$, $SD=.52$), $t(-4.55) = -0.26$, $p < .001$. Post-hoc analyses indicated significant differences in MoCA orientation scores across all groups (p 's $< .001$), except between HOAs and SCDs ($p = .10$). Specifically, HOAs had higher scores than all other groups except for SCDs, and SCDs outperformed all groups except HOAs. MCI had higher scores than the VaD group. Examining the interaction between group and sleep issues, no significant impact of poor sleep was found on orientation scores for either HOAs ($p = 1.00$, $d < .001$) or SCDs ($p = 1.00$, $d = .05$). In contrast, those with MCI and poor sleep performed better than those without ($p = .01$, $d = .14$). Those with VaD and poor sleep had lower orientation scores than those without, showing a significant difference ($p < .001$, $d = .94$) with a large effect size (Wennberg et al., 2017). In summary, sleep issues adversely affected orientation scores only in the VaD group but not in HOAs or SCDs. Surprisingly, those with MCI and poor sleep outperformed those without sleep issues.

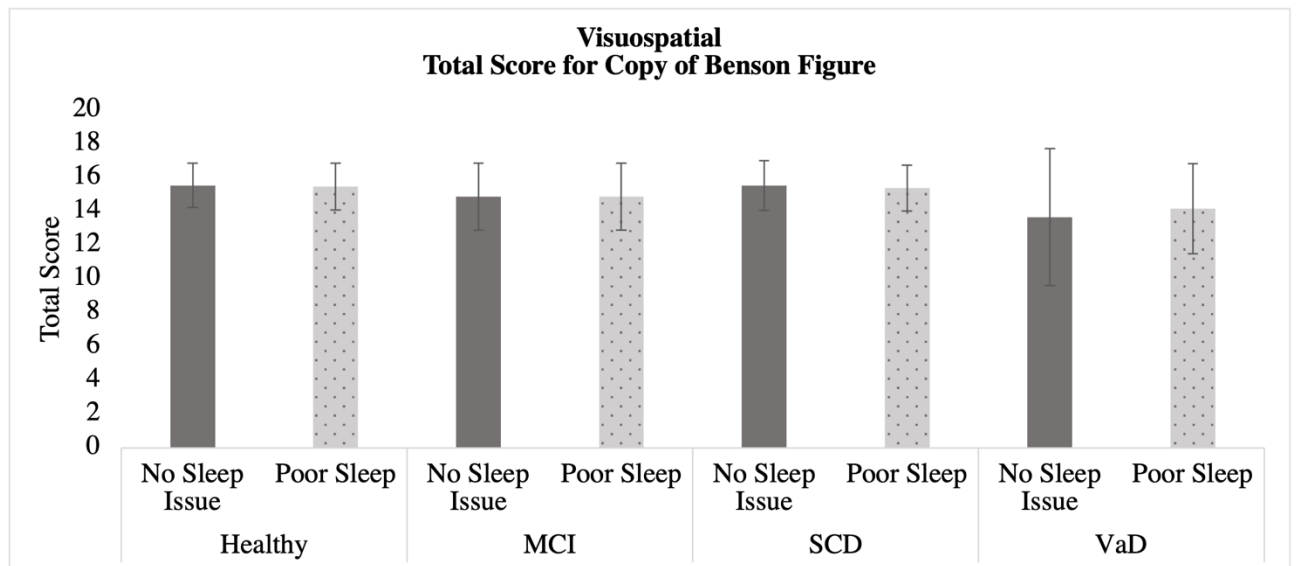
2.6.4 Visuospatial

2.6.4.1 Benson Figure (immediate recall)

Table 9: Mean Scores for Copy of Benson Figure

Group	Sleep Issue	N	Mean	SD
HOA	No Sleep Issue	2293	15.54	1.3
	Poor Sleep	1163	15.47	1.38
MCI	No Sleep Issue	1232	14.88	1.98
	Poor Sleep	1269	14.88	1.98
SCD	No Sleep Issue	808	15.53	1.47
	Poor Sleep	776	15.37	1.35
VaD	No Sleep Issue	38	13.66	4.05
	Poor Sleep	48	14.15	2.67

Figure 5: Mean Total Scores for Copy of the Benson Figure (Visuospatial)



Note. Maximum Score = 17

Results indicate a significant main effect of group on Benson Figure scores, $F(3,7610)=80.67$, $p<.001$, $\eta^2p=.03$. However, there was no main effect of sleep condition on the Benson Figure performance, $F(1,7610)=1.06$, $p=.30$, $\eta^2p<.001$. Similarly, no interaction effect was found between group and sleep condition, $F(1,7610)=1.72$, $p=.16$, $\eta^2p<.001$.

Among the covariates, only smoking years, age, alcohol use, and years of education significantly impacted Benson Figure performance (all p 's $<.001$). Factors such as sex ($p=.43$), use of beta-blockers ($p=.40$), use of psychotic medications ($p=.15$), use of anxiolytics/hypnotic medications ($p=.70$), and depression within the last two years ($p=.12$) showed no significant influence.

Post-hoc analyses revealed significant differences in performance across all groups (all p 's $<.001$), except between the HOA and SCD groups ($p=1.00$). Specifically, both HOA and SCD outperformed all other groups, followed by MCI, with VaD showing the lowest scores. In summary, while group differences were apparent in Benson Figure performance, the Benson Figure scores were not significantly different across sleep conditions for all groups.

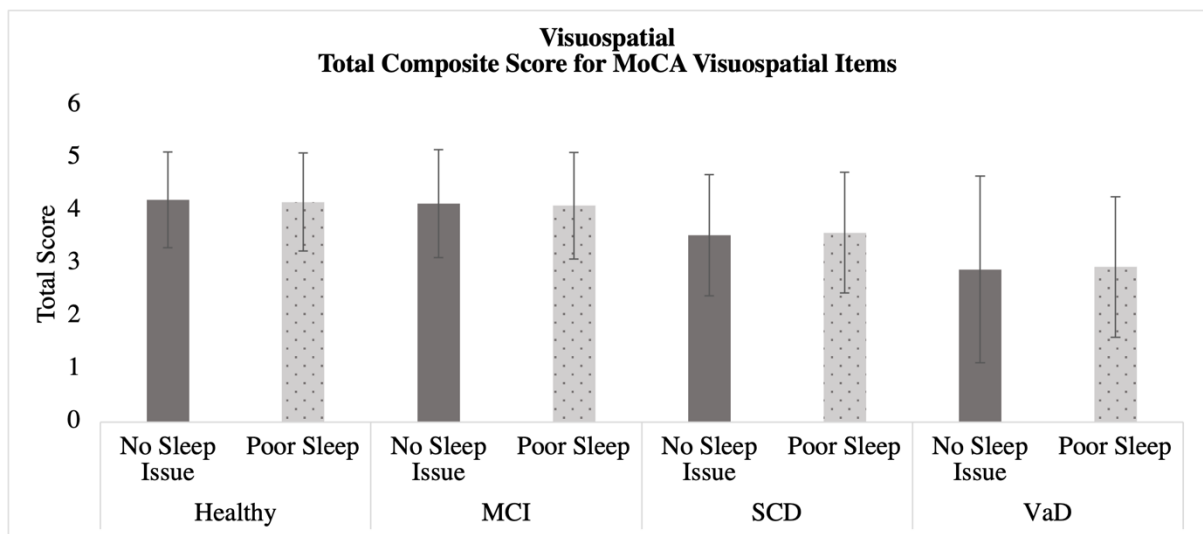
2.6.4.2 *MoCA Visuospatial*

A composite variable for visuospatial skills derived from the MoCA included a trails drawing (MOCATRAI), a copy of a cube drawing (MOCACUBE), clock contour (MOCACLOC), clock numbers (MOCACLON) and clock hands (MOCACLOH). All of these carry a maximum score of 1, giving rise to a maximum score of 5, where higher scores indicate better visuospatial performance.

Table 10: Mean Total Score for Composite MoCA Visuospatial Items

Group	Sleep Issue	N	Mean	SD
HOA	No Sleep Issue	2297	4.21	0.91
	Poor Sleep	1162	4.17	0.93
MCI	No Sleep Issue	811	4.14	1.02
	Poor Sleep	774	4.1	1.01
SCD	No Sleep Issue	1230	3.54	1.15
	Poor Sleep	1263	3.59	1.14
VaD	No Sleep Issue	38	2.89	1.77
	Poor Sleep	49	2.94	1.33

Figure 6: Total Composite Score for MoCA Visuospatial Items



Results showed a significant main effect of group on MoCA visuospatial performance, $F(3,7607)=183.33$, $p<.001$, $\eta^2p=.07$. In contrast, the presence or absence of sleep issues did not significantly affect visuospatial performance, $F(1,7607)=.02$, $p=.89$, $\eta^2p<.001$. Similarly, no interaction was found between group and sleep condition, $F(3,7607)=.50$, $p=.68$, $\eta^2p<.001$.

Regarding covariates, factors such as sex, years of education, age, use of psychotic medication, and smoking years had a significant influence on visuospatial performance (all

$p's < .001$). Additionally, the use of anxiolytics/hypnotics also affected performance ($p = .04$), albeit with small sample sizes ($\eta^2 p$ ranges from .02 to $< .001$). On the other hand, variables like alcohol use ($p = .11$), use of beta-blockers ($p = .18$), and depression within the last two years ($p = .12$) showed no significant impact.

Post-hoc analyses indicated significant differences in MoCA visuospatial performance across all groups (all $p's < .001$) except for the HOA and SCD groups ($p = 1.00$). Specifically, HOAs and SCDs performed better than MCIs, outperforming the VaD group. In summary, while group membership influenced MoCA visuospatial scores, the presence or absence of sleep issues did not significantly impact MoCA-derived visuospatial scores.

2.6.5 Executive Function

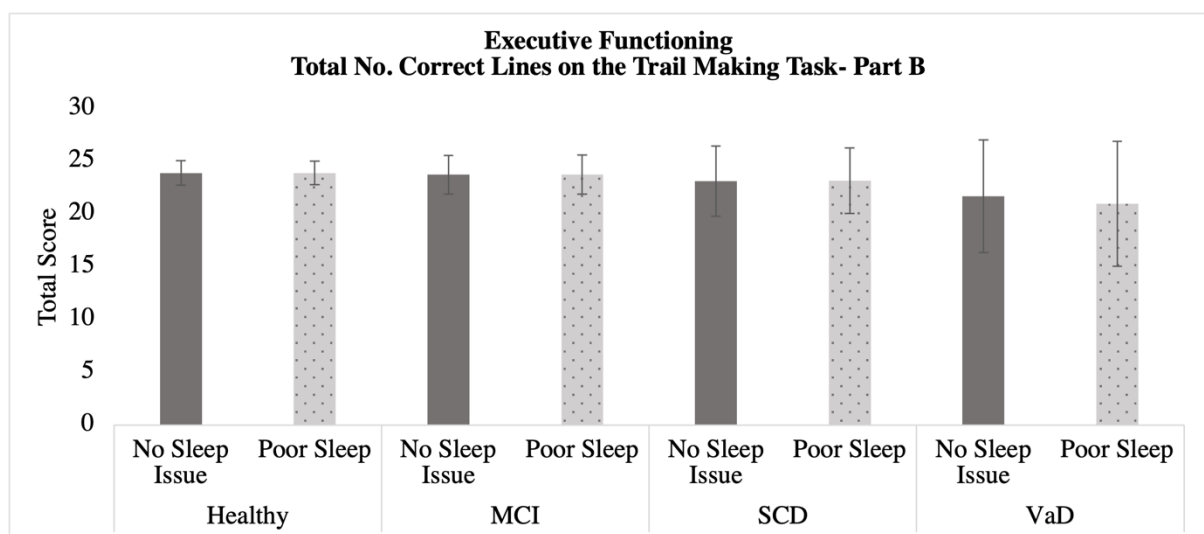
2.6.5.1 Trail Making Task- Trail B

2.6.5.1.1 Number of Correct Lines

Table 11: Total Number of Correct Lines for Part B of the Trail-Making Task

Group	Sleep Issue	N	Mean	SD
HOA	No Sleep Issue	24804	23.88	1.17
	Poor Sleep	3343	23.89	1.13
MCI	No Sleep Issue	8156	23.73	1.83
	Poor Sleep	2268	23.74	1.86
SCD	No Sleep Issue	8927	23.11	3.31
	Poor Sleep	3405	23.15	3.1
VaD	No Sleep Issue	1684	21.69	5.34
	Poor Sleep	546	20.97	5.93

Figure 7: Total number of correct lines on the trail-making task, Part B.



When examining performance, in terms of number of correct lines for the Trail Making t=Task- Part B scored out of a maximum of 24, results reveal a significant main effect of group $F(3, 53116)=660.98, p<.001, \eta^2p=.04$, and sleep condition $F(1,53116)=29.74, p<.001, \eta^2p<.001$. Moreover, there was a significant interaction between group and sleep condition, $F(3,53116)=12.16, p<.001, \eta^2p<.001$.

Among the covariates, education, age, sex, use of psychotic medication, and a history of depression within the last two years significantly affected Trail B performance (all p 's $< .001$). Whereas alcohol use, use of beta-blockers, use of anxiolytics/hypnotics, and smoking years did not (all p 's $> .05$).

In the post hoc comparisons evaluating sleep issues on the Trail Making Task - Part B, individuals with poor sleep completed 0.19 fewer correct lines than those without sleep issues, $t(5.45) = 0.08, p < .001, d=.08$.

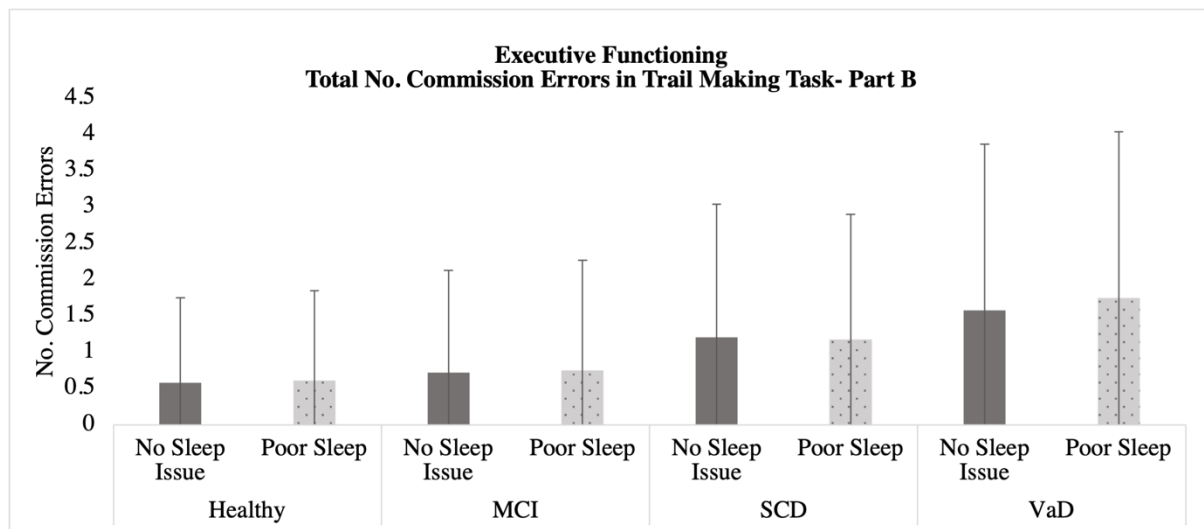
Post-hoc analysis revealed that all groups performed significantly differently, such that $HOA>SCD>MCI>VaD$ (all p 's $<.001$). Moreover, those with VaD and sleep issues performed worse on Trail B than those without ($p<.001, d=-.31$). Whereas, within all other groups, performance did not significantly differ depending on sleep condition (all p 's $=1.00$), with small effect sizes (all d 's $<.001$). Overall, this suggests that sleep issues may disproportionately affect executive function in individuals with VaD compared to HOAs, SCD and those with MCI.

2.6.5.1.2 Trail Making B- Number of Commission Errors (out of 40)

Table 12: Total Number of Commission Errors of the Trail-Making Task -Part B

Group	Sleep Issue	N	Mean	SD
HOA	No Sleep Issue	24458	0.58	1.17
	Poor Sleep	3317	0.61	1.24
MCI	No Sleep Issue	8130	0.72	1.41
	Poor Sleep	2268	0.75	1.52
SCD	No Sleep Issue	8924	1.21	1.83
	Poor Sleep	3408	1.18	1.72
VaD	No Sleep Issue	1683	1.58	2.29
	Poor Sleep	550	1.75	2.29

Figure 8: Total Number of Commission Errors of the Trail-Making Task -Part B



Results indicated a significant main effect of group on the number of commission errors in the Trail Making Task-Part B, $F(3,52721)=417.81$, $p<.001$, $\eta^2p=0.02$. Additionally, sleep issues were found to have a significant main effect on performance, $F(1,52721)=9.11$, $p<.001$, $\eta^2p<.001$. However, the interaction between group and sleep condition was not significant, $F(3,52721)=1.51$, $p=0.21$, $\eta^2p<.001$.

Among the covariates, sex, education, age, use of psychotic medication, and a history of depression within the last two years (all p 's<.001) and use of anxiolytics/hypnotics (p =.03) had a significant impact on commission errors, though with small effect sizes (all η^2p 's<.001). Alcohol use and beta-blocker use did not significantly affect performance (p >.05).

Post-hoc comparisons revealed that all groups differed significantly regarding commission errors (all p 's<.001). Overall, the performance sequence regarding the fewest commission errors, was HOA > SCD > MCI > VaD, and the effect sizes were generally in the small to medium range. For the Trail Making Task - Part B, focusing on the number of commission errors, individuals with poor sleep made 0.07 more commission errors than those without sleep issues, $t(3.02) = -0.05$, p <.001. Post-hoc comparisons for sleep issues indicate that those with no sleep issues had, on average, fewer commission errors than those with poor sleep (p <.001, d =-.05), with a mean difference of -0.07. Therefore, the number of commission errors on the Trail Making Task-Part B was worse for those with poor sleep than without for all groups.

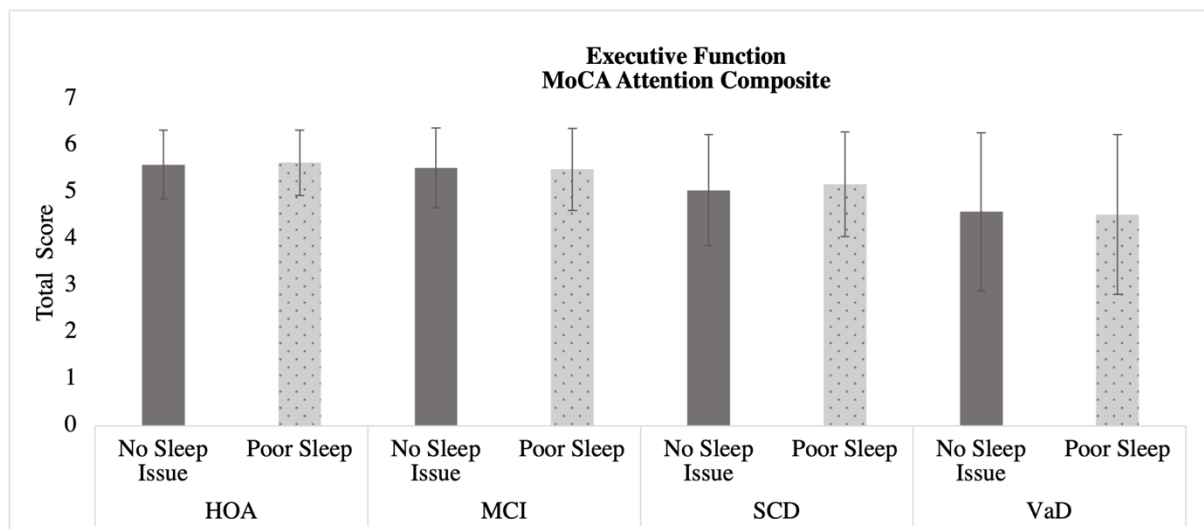
2.6.6 Attention

MoCA attention tasks were combined to create a composite attention variable with a larger range of scores. These include forward and backward digit span tasks, Letter A task (each carrying a maximum score of 1), and Serial 7 subtraction (carrying a maximum score of 3). This gave rise to a maximum total score of 6, where higher scores indicate better performance.

Table 13: Mean and SD Scores for Composite MoCA Attention Subscale Tasks

Group	Sleep Issue	N	Mean	SD
Healthy	No Sleep Issue	2324	5.6	0.74
	Poor Sleep	1177	5.64	0.7
MCI	No Sleep Issue	823	5.53	0.86
	Poor Sleep	783	5.5	0.88
SCD	No Sleep Issue	1236	5.05	1.19
	Poor Sleep	1265	5.18	1.12
VaD	No Sleep Issue	37	4.59	1.69
	Poor Sleep	49	4.53	1.71

Figure 9: MoCA Attention Composite



The results revealed a significant main effect of group, $F(3) = 173.68$, $p < .001$, $\eta^2p = 0.06$. However, there was no significant main effect of sleep condition on MoCA composite attention scores, $F(1) < .001$, $p = 0.92$, $\eta^2p < .001$. The interaction between group and sleep condition was not significant, $F(3) = 1.84$, $p = 0.14$, $\eta^2p < .001$.

Post-hoc analyses examining the main effect of group revealed that, as expected, HOAs performed better than those with SCD ($d=.11$) who outperformed those with MCI ($d=.47$)

who did better than VaD ($d=.57$, all $p's < .001$). Overall, this suggests that the presence of sleep issues does not affect MoCA-derived attention scores, however group membership does.

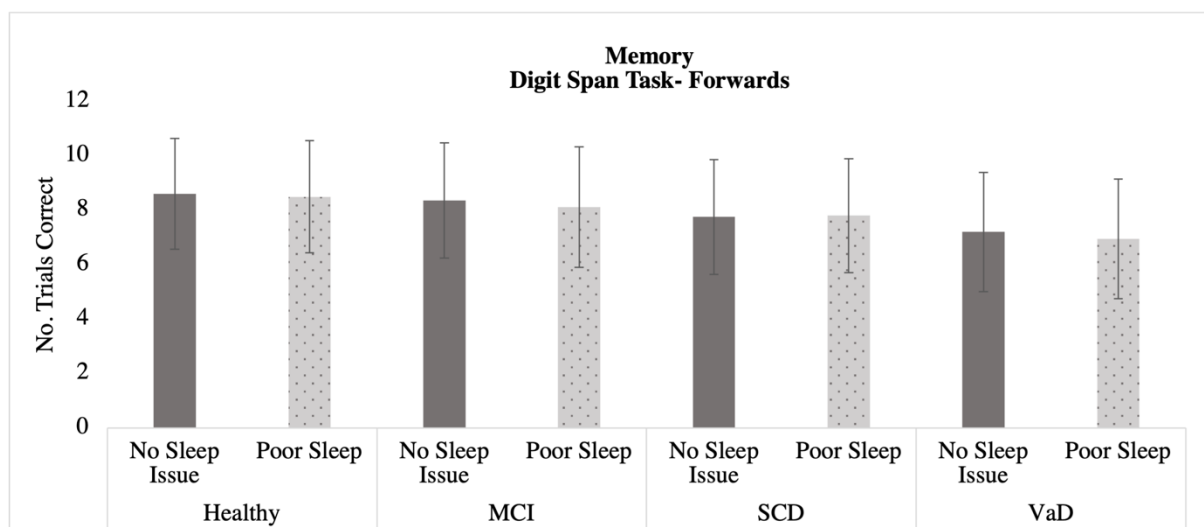
2.6.7 Memory

2.6.7.1 Immediate Memory : Digit forward – number of correct trials

Table 14: Total Number of Correct Trials in Digit Span-Forward

Group	Sleep Issue	N	Mean	SD
Healthy	No Sleep Issue	29313	8.6	2.04
	Poor Sleep	2815	8.49	2.06
MCI	No Sleep Issue	9096	8.36	2.12
	Poor Sleep	1887	8.11	2.21
SCD	No Sleep Issue	11636	7.75	2.11
	Poor Sleep	3265	7.8	2.09
VaD	No Sleep Issue	2300	7.2	2.19
	Poor Sleep	778	6.95	2.2

Figure 10: Total Number of Correct Trials in Digit Span-Forward



Results indicated a significant main effect of group on performance in the Digit Span Forward (DIGIF) task, $F(3, 61073) = 360, p < .001, \eta^2p = 0.02$. There was also a significant main effect of sleep condition, $F(1, 61073) = 21.85, p < .001, \eta^2p < .001$. There was also a significant interaction between group and sleep issue, $F(3, 61073) = 6.04, p < .001, \eta^2p < .001$.

Among the covariates, sex, education, and age, along with beta-amyloid levels, use of psychotic medication and beta-blockers, alcohol use, history of depression within the last two years, and smoking history, all had significant impacts on DIGIF performance (all p 's $< .001$), though with small effect sizes (all η^2p 's $< .01$). Use of anxiolytics/hypnotics was the only covariate that did not significantly affect performance ($p = 0.76$).

In a post hoc analysis examining the effect of sleep issues on the DIGIF, all groups differed significantly, such that $\text{HOA} > \text{SCD} > \text{HOA} > \text{VaD}$ (all p 's $< .001$). Additionally, there was a significant mean difference of 0.14 units on the DIGIF, $t(4.67) = p < .001$, Cohen's $d = 0.07$, with those sleep issues scoring lower than those without. These results suggest that sleep quality has a modest but statistically significant impact on task performance on the DIGIF across different groups.

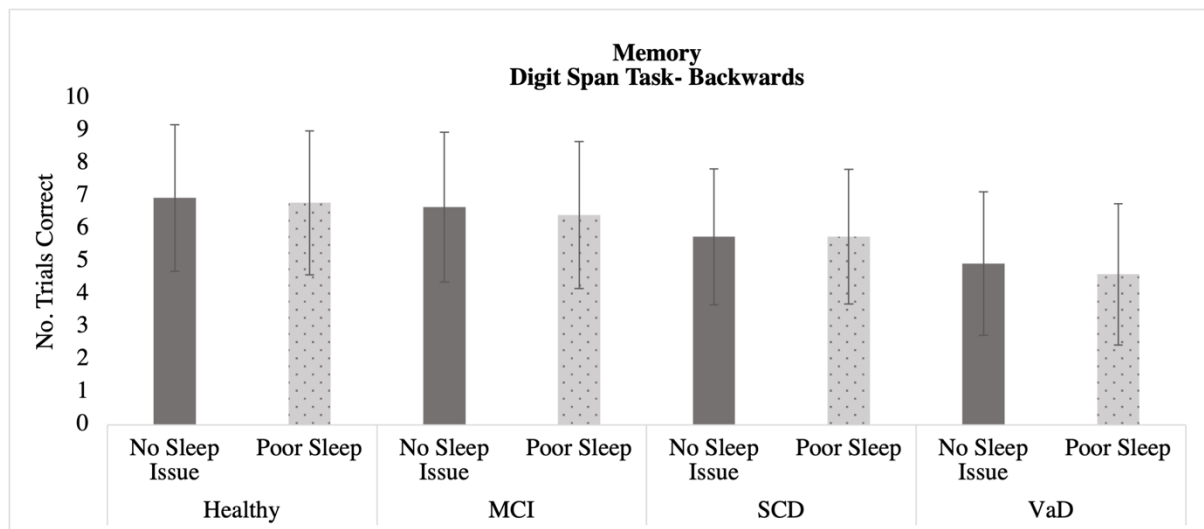
Finally, in terms of interactions, there was no significant difference between those with poor sleep and those without for VaD ($p = .30, d = -.11$), MCI ($p = 1.00, d < .001$), and HOAs ($p = .40, d = -.05$). However, performance on the DIGIF was worse for those with sleep issues compared to those without for SCDs ($p < .001, d = -.12$). Overall, individuals with sleep issues performed worse on the DIGIF than those without, with those having SCD being particularly susceptible to sleep-related performance deficits.

2.6.7.2 Digit Backwards – number of correct trials

Table 15: Total Number of Correct Trials in Digit Span-Backwards

Group	Sleep Issue	N	Mean	SD
Healthy	No Sleep Issue	29307	6.95	2.24
	Poor Sleep	2815	6.8	2.2
MCI	No Sleep Issue	9088	6.67	2.29
	Poor Sleep	1887	6.43	2.25
SCD	No Sleep Issue	11623	5.76	2.08
	Poor Sleep	3263	5.76	2.06
VaD	No Sleep Issue	2290	4.94	2.19
	Poor Sleep	773	4.61	2.16

Figure 11: Total Number of Correct Trials in Digit Span-Backwards



Performance on the Digit Span Backward (DIGIB) task showed a significant main effect of group, $F(3, 61029) = 695.86$, $p < .001$, $\eta^2p = 0.03$. There was also a significant main effect of sleep condition, $F(1, 61029) = 36.13$, $p < .001$, $\eta^2p < .001$, and a significant interaction between group and sleep condition, $F(3, 61029) = 4.32$, $p < .001$, $\eta^2p < .001$.

Among the covariates, factors like sex, education, age, use of beta-blockers, use of psychotic medication, and smoking history significantly affected performance (all p 's < .001), albeit with small effect sizes (all η^2p 's < .01). No impact was observed from a history of depression within the last two years ($p = 0.68$).

Post hoc analyses revealed that all groups differed significantly on the task, with the following hierarchy: HOA > MCI > SCD > VaD (all p 's < .001). The effect sizes for these comparisons ranged from moderate to large (Cohen's $d = 0.14 - 0.88$). An additional post hoc analysis on sleep issues indicated a mean difference of 0.18, $t(6.01) = p < .001$, Cohen's $d = 0.08$, showing that those with sleep issues performed worse than those without.

Finally, those with sleep issues had poorer performance than those without for VaD ($p=.03$, $d=-0.14$), SCD ($p<.001$, $d=-.12$), and HOA ($p<.001$, $d=.07$) but not for MCI ($p=1.00$, $d=-.02$). Overall this shows that performance in terms of the DIGIB performance was worse when people had sleep issues compared to those without, except for those with SCD.

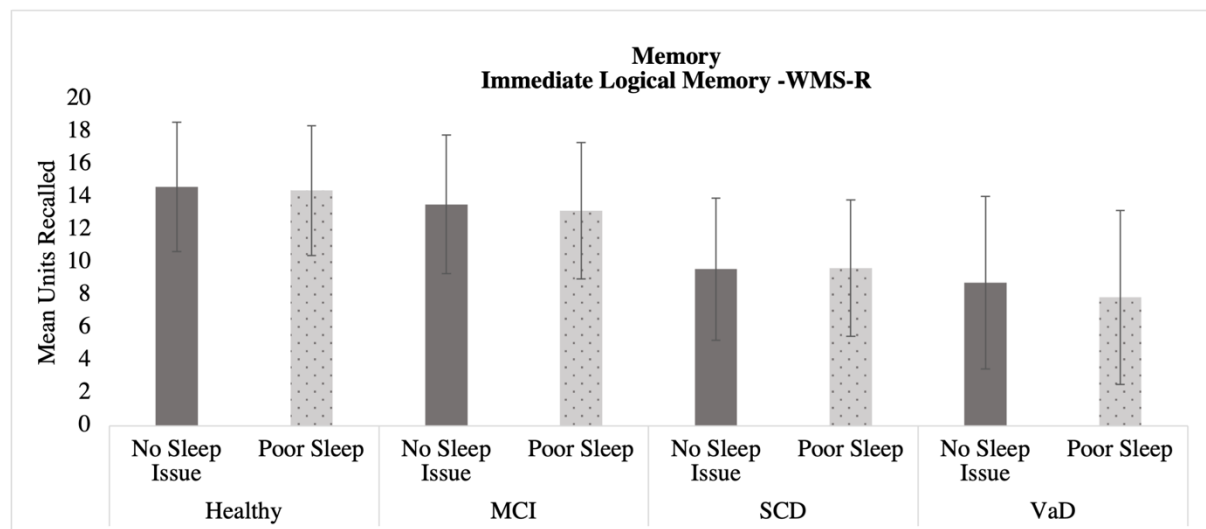
Immediate Logical Memory from the Weschler Memory Scale-Revised

The Logical Memory (LM) subtest of the Weschler Memory Scale-Revised (WMS-R) is a standardised verbal narrative episodic memory assessment. A short story is read to participants (Story A), and participants are asked to recall the story 20 or 30 minutes later, providing both an immediate and delayed free recall metric. Scores reflect the correct number of units recalled out of a possible 25.

Table 16: Total Number of units recalled on the Immediate LM subtest of the WMS-R

Group	Sleep Issue	N	Mean	SD
HOA	No Sleep Issue	29289	14.63	3.96
	Poor Sleep	2814	14.41	3.97
MCI	No Sleep Issue	9089	13.56	4.24
	Poor Sleep	1884	13.17	4.17
SCD	No Sleep Issue	11582	9.61	4.35
	Poor Sleep	3259	9.66	4.18
VaD	No Sleep Issue	2276	8.77	5.28
	Poor Sleep	770	7.87	5.33

Figure 12: Mean Number of units recalled on the Immediate LM subtest of the WMS-R



A significant main effect was observed for group, $F(3, 60946) = 2788.12$, $p < .001$, $\eta^2p = 0.12$. There was also a significant main effect of sleep condition on immediate LM performance, $F(1, 60946) = 35.22$, $p < .001$, $\eta^2p < .001$. Additionally, there was a significant interaction between group and sleep condition, $F(3, 60946) = 8.93$, $p < .001$, $\eta^2p < .001$.

Post-hoc tests revealed that there were significant differences in terms of mean units recalled across all groups (all p 's $< .001$) such that $HOA > SCD > MCI > VaD$. Moreover, in the analysis

focused on the impact of sleep issues on immediate recall performance in the LM test from the WMS-R, a post-hoc comparison revealed a significant difference between participants with no sleep issues and those with poor sleep. Specifically, participants with poor sleep scored on average 0.34 points lower than those without sleep issues ($p<.001$, $d=.08$).

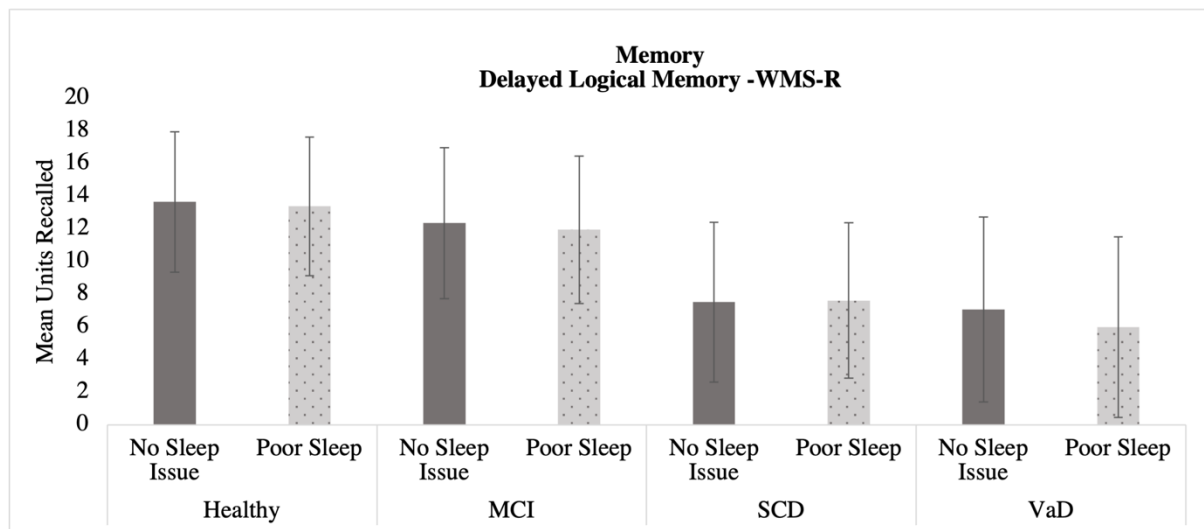
Finally, those with sleep issues performed worse than those with no sleep issues for VaD ($p<.001$, $d=-.20$), and SCD ($p<.001$, $d=-.10$), whereas there were no significant differences for MCI ($p=1.00$, $d=.01$) and HOA ($p=.35$, $d=-.05$) on immediate LM test performance.

2.6.7.3 Delayed Logical Memory from the Weschler Memory Scale-Revised (WMS-R) Top of Form

Table 17: Total Number of units recalled on the Delayed LM subtest of the WMS-R

Group	Sleep Issue	N	Mean	SD
HOA	No Sleep Issue	29285	13.66	4.3
	Poor Sleep	2813	13.39	4.24
MCI	No Sleep Issue	9085	12.36	4.62
	Poor Sleep	1885	11.95	4.51
SCD	No Sleep Issue	11569	7.52	4.9
	Poor Sleep	3256	7.62	4.75
VaD	No Sleep Issue	2263	7.07	5.66
	Poor Sleep	764	5.99	5.52

Figure 13: Mean Number of units recalled on the Delayed LM subtest of the WLM-R



Bottom of Form

An analysis of covariance (ANCOVA) was performed to evaluate the main effects of group on delayed recall, as measured by the Delayed Logical Memory (LM) test of the Wechsler Memory Scale-Revised (WMS-R). Several covariates were controlled for in the analysis. A significant main effect was found for group, $F(3, 60903) = 3340.38, p < .001, \eta^2p = 0.14$. A significant main effect was also noted for the presence or absence of sleep issues, $F(1, 60903) = 39.31, p < .001, \eta^2p < .001$. Additionally, there was a significant interaction between group and sleep condition, $F(3, 60903) = 11.33, p < .001, \eta^2p < .001$.

Post-hoc analysis revealed that all groups significantly differed in performance such that $HOA > SCD > MCI > VaD$ (all p 's $< .001$). Moreover, in the presence or absence of sleep issues, participants with sleep issues exhibited a mean difference of 0.4 units lower on the Delayed LM test of the WMS-R compared to those with no sleep issues ($t(60903) = 6.27, p < .001, d = .09$). Those with sleep issues performed worse than those without sleep issues for VaD ($p < .001, d = -.22$), SCD ($p < .001, d = -.10$) and there was no significant difference for HOA ($p = .15, d = -0.06$) and MCI ($p = 1.00, d = 0.02$).

2.6.7.4 MoCA Memory Index Score

The MoCA Memory Index Score (MIS) is calculated based on a participant's ability to recall five target words. Points are allocated as follows:

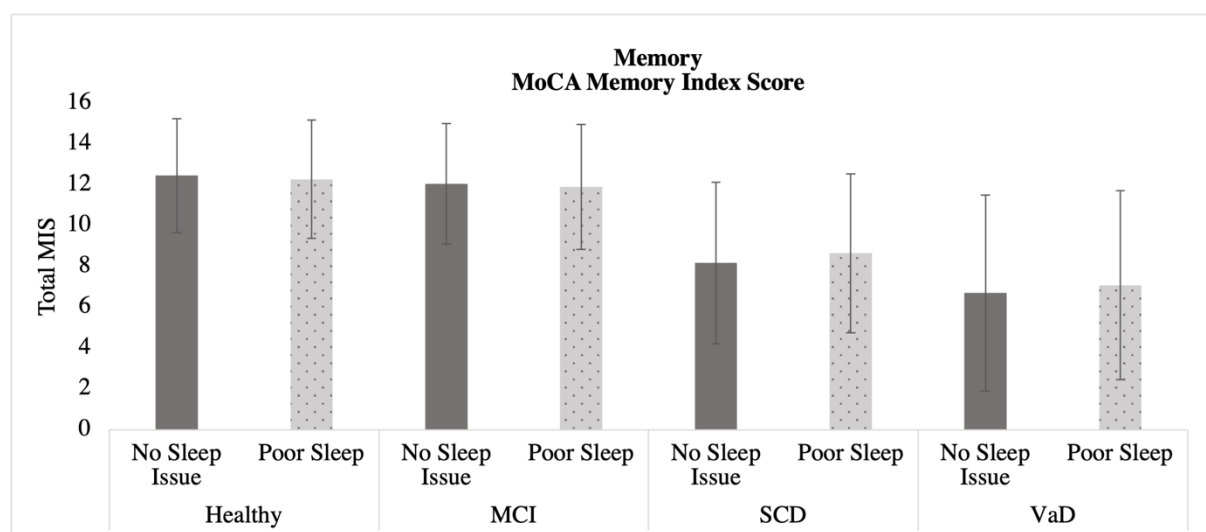
1. Immediate recall of target words without cues earns one point per word, and these points are multiplied by 3.
2. If a word is not immediately recalled, a category cue is provided. Successfully recalling the word after the cue earns one point, which is then multiplied by 2.
3. If the participant still cannot recall the word after the category cue, they are given a multiple-choice option that includes the target word. Correctly identifying the word earns one point, which is not multiplied.

According to MoCA scoring guidelines, scores from delayed recall without cues (MOCARECN) were multiplied by 3, scores from delayed recall with category cues (MOCARECC) were multiplied by 2, and scores from delayed recall with multiple choices (MOCARECR) were not multiplied. These scores are then combined to form a composite MIS with a maximum score of 15, where higher scores indicate a better recall performance.

Table 18: Total Mean and SD Memory Index Score out of 15 per group

Group	Sleep Issue	N	Mean	SD
HOA	No Sleep Issue	2342	12.46	2.79
	Poor Sleep	1187	12.28	2.89
MCI	No Sleep Issue	830	12.06	2.95
	Poor Sleep	793	11.9	3.06
SCD	No Sleep Issue	1263	8.18	3.95
	Poor Sleep	1297	8.66	3.89
VaD	No Sleep Issue	42	6.71	4.8
	Poor Sleep	53	7.09	4.63

Figure 14: Total MoCA Memory Index Score out of 15



An analysis of covariance (ANCOVA) was conducted to examine the effects of group on MoCA derived Memory Index Score (MIS), controlling for various covariates. There was a significant main effect of group, $F(3, 7790) = 678.46$, $p < .001$, $\eta^2p = 0.21$. The main effect of sleep issue was not significant, $F(1, 7790) = 0.6$, $p = .44$, $\eta^2p < .001$. Additionally, there was a significant interaction between group and sleep issue, $F(3, 7790) = 6.46$, $p < .001$, $\eta^2p < .001$.

In the ANCOVA model, several covariates were included to control for their effects on the MIS. Age ($\eta^2p=.02$) , sex ($\eta^2p=.02$), use of anxiolytics/hypnotics ($\eta^2p<.001$) were significant (all $p<.001$) as was use of psychotic medication ($p=.04$, $\eta^2p<.001$) and use of beta-blockers ($p=.04$, $\eta^2p<.001$). Whereas years of education ($\eta^2p<.001$), depression history ($p=.25$, $\eta^2p<.001$), alcohol use history ($p=.97$, $\eta^2p<.001$) and smoking years ($p=.22$, $\eta^2p<.001$) were not.

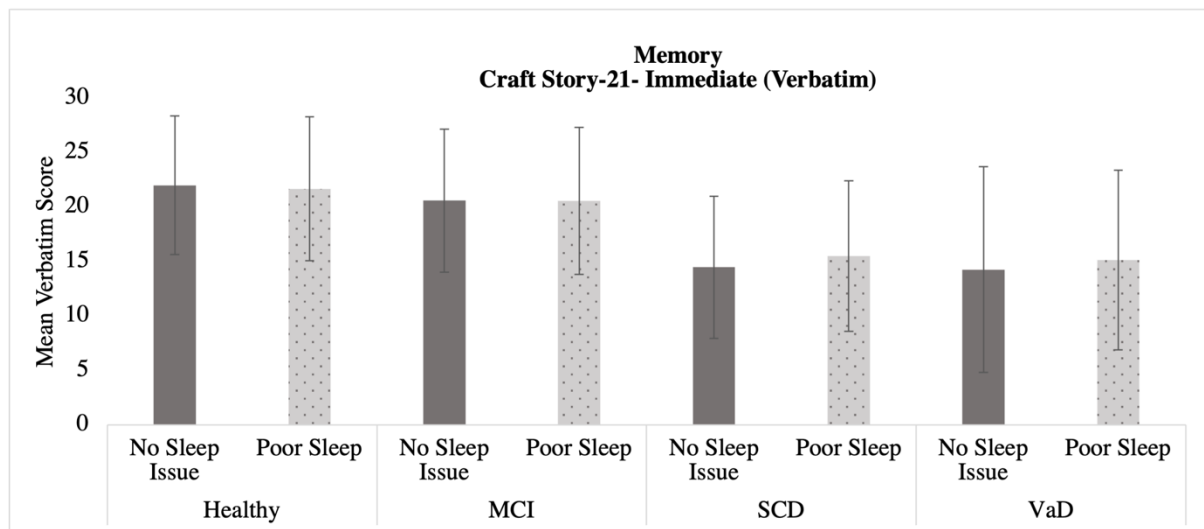
Post-hoc comparisons of group revealed that all groups performed significantly differently (all $p's<.001$) such that HOAs>SCD>MCI>VaD. Moreover, there was no significant difference between those with sleep issues and those without for VaD ($p=1.00$, $d=.16$), SCD ($p=1.00$, $d=-.07$) and HOAs ($p=1.00$, $d=-1.10$), whereas those with MCI and poor sleep performed worse than those without sleep issues ($p<.001$, $d=.15$).

2.6.7.5 Craft 21- Immediate

Table 19: Mean Verbatim Score on the Immediate Craft-21 Assessment

Group	Sleep Issue	N	Mean	SD
Healthy	No Sleep Issue	2311	22.01	6.36
	Poor Sleep	1173	21.69	6.59
MCI	No Sleep Issue	818	20.6	6.55
	Poor Sleep	782	20.57	6.75
SCD	No Sleep Issue	1225	14.48	6.53
	Poor Sleep	1259	15.51	6.91
VaD	No Sleep Issue	35	14.26	9.44
	Poor Sleep	48	15.15	8.24

Figure 15: Mean Verbatim Score on the Immediate Craft-21 Assessment



An ANCOVA was conducted to assess the effects of group and sleep issues on the immediate verbatim recall score of Craft-21 task. A significant main effect was observed for group, $F(3, 7634) = 464.25$, $p < .001$, $\eta^2p = 0.15$. There was no significant main effect of sleep issues, $F(1, 7634) = 1.75$, $p = 0.19$, $\eta^2p < .001$. However, there was a significant interaction between group and sleep issues, $F(3, 7634) = 5.53$, $p < .001$, $\eta^2p < .001$.

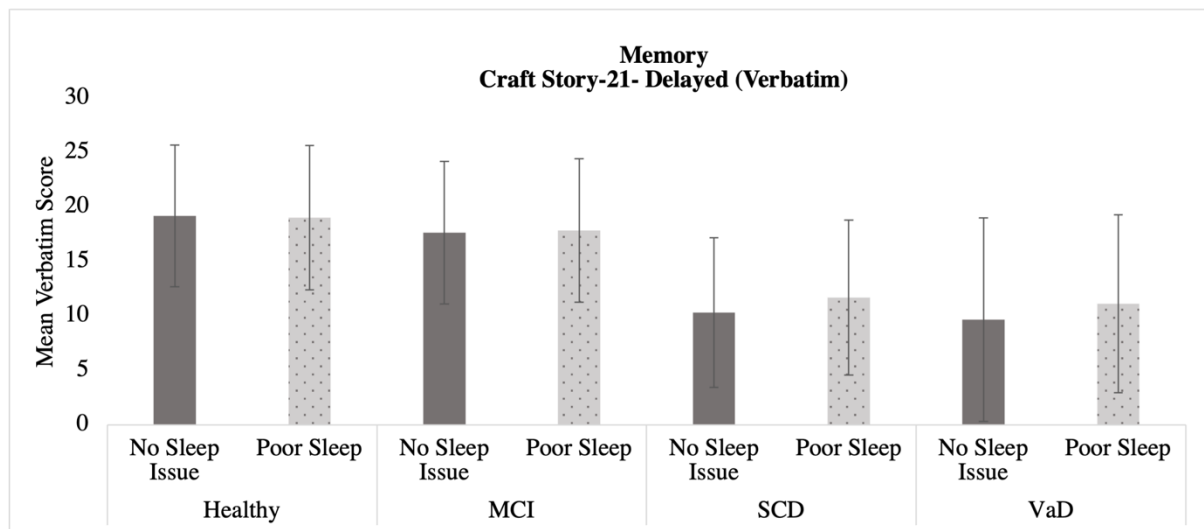
Post-hoc analysis revealed that all groups differed significantly (all p 's<.001) with the exception of MCI and VaD, where there was no significant difference ($p=1.00$). Overall, HOAs outperformed the SCD group who in turn outperformed the MCI and VaD group. Moreover, there was no significant difference between those with sleep issues and those without for VaD ($p=1.00$, $d=.19$), SCD ($p=1.00$, $d<.001$) and HOA ($p=1.00$, $d=-.05$), however, for MCIs those with poor sleep performed worse than those without sleep issues ($p<.001$, $d=.17$).

2.6.7.6 Delayed Recall Craft-21

Table 20: Mean Verbatim Score on the Delayed Craft-21 Assessment

Group	Sleep Issue	N	Mean	SD
HOA	No Sleep Issue	2311	19.2	6.5
	Poor Sleep	1171	19.03	6.63
MCI	No Sleep Issue	818	17.67	6.54
	Poor Sleep	781	17.85	6.58
SCD	No Sleep Issue	1222	10.33	6.87
	Poor Sleep	1252	11.71	7.11
VaD	No Sleep Issue	35	9.69	9.34
	Poor Sleep	48	11.13	8.16

Figure 16: Mean Verbatim Score on the Delayed Craft-21 Assessment



In terms of delayed verbatim Craft-21 score, there was a significant main effect for group, $F(3, 7631) = 694.79$, $p = .00$, $\eta^2 p = 0.21$, but not for sleep condition, $F(1, 7632) = 3.37$, $p = 0.07$, $\eta^2 p < .001$. However, the interaction between group and sleep issues was significant, $F(3, 7632) = 6.37$, $p < .001$, $\eta^2 p < .001$.

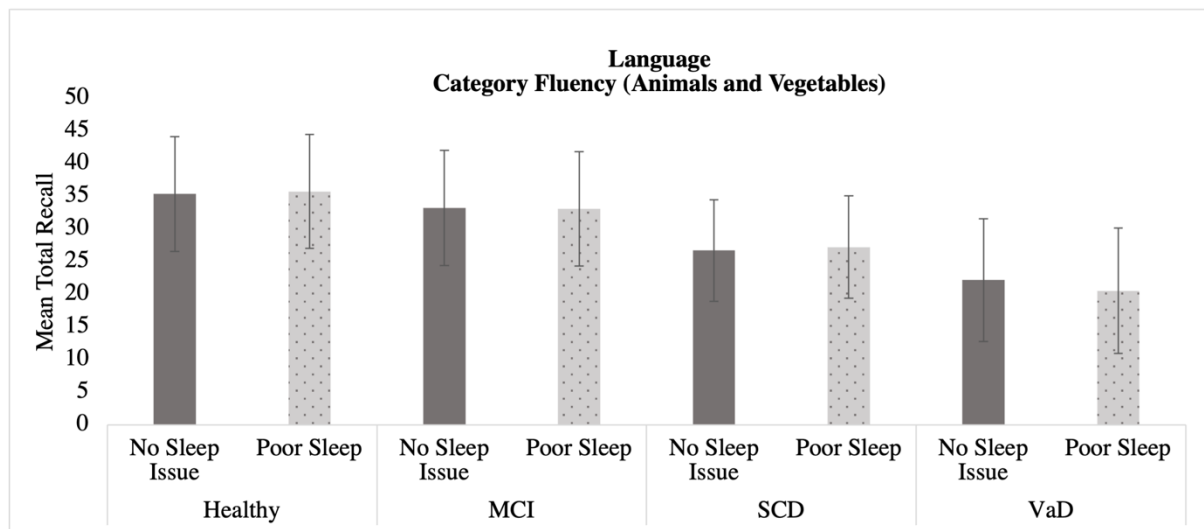
All groups differed significantly (all p 's $< .001$) with the exception of MCI and VaD ($p = 1.00$) such that $HOA > SCD > MCI = VaD$. The interaction post hoc analyses revealed that those with poor sleep had a better delayed story recall than those without sleep issues for MCI ($p < .001$, $d = .21$), but there was no significant difference for all other groups (all p 's $= 1.00$).

2.6.8 Language

Table 21: Total Mean Category Fluency for Animals and Vegetables Out of 144

Group	Sleep Issue	N	Mean	SD
Healthy	No Sleep Issue	31620	35.37	8.78
	Poor Sleep	3985	35.74	8.69
MCI	No Sleep Issue	9895	33.22	8.79
	Poor Sleep	2672	33.09	8.74
SCD	No Sleep Issue	12828	26.72	7.77
	Poor Sleep	4527	27.22	7.83
VaD	No Sleep Issue	2319	22.18	9.38
	Poor Sleep	818	20.54	9.58

Figure 17: Mean Category Fluency for Animals and Vegetables Out of 144



When analysing Category Fluency (combining Animals and Vegetables) with a maximum possible score of 144, a significant main effect was found for group, $F(3) = 2834.23$, $p < .001$, $\eta^2 p = 0.11$, and for sleep condition, $F(1) = 19.51$, $p < .001$, $\eta^2 < .001$. The interaction between group and sleep issue was also significant, $F(3) = 10.23$, $p < .001$, $\eta^2 p < .001$.

Post-hoc analyses revealed that all groups performed significantly differently (all p 's < .001) such that HOA > SCD > MCI > VaD. When assessing the presence or absence of sleep issues, participants with sleep issues had a mean difference of -0.47 in Category Fluency scores when compared to those without. This difference was statistically significant, $t(68647) = 4.42$, $p < .001$, with a small effect size as indicated by a Cohen's d of 0.06.

Finally, those with poor sleep performed worse than those without for VaD ($p < .001$, $d = -.19$), but there was no significant difference between MCI ($p = 1.00$, $d = .02$), SCD ($p = .06$, $d = -.07$), and HOA ($p = 1.00$, $d = .01$) suggesting that those with VaD and poor sleep disproportionately affected compared to all other groups.

2.6.9 Summary of Findings

Table 22: Summary of Findings

Cognitive Domain	Subdomain	Test	Group	Sleep Condition	Interaction	Post-hoc Summary
Global		MoCA	HOA>SCD>MCI>VaD*	NO	MCI + SI better	MCI + SI better (d=.015)
	D-R-O-L-W	MMSE	HOA>SCD>MCI>VaD*	YES	VaD + SI worse	No differences for all groups in terms of sleep, but for VaD, SI performed worse (d=.68) with a moderate effect size
Orientation		MMSE	HOA>SCD>MCI>VaD*	YES	(VaD + SCD) + SI worse	Sleep negatively affects groups, but particularly VaD (d=.69) and SCD (d=.08)
		MoCA	(HOA=SCD*ns)>MCI>VaD*	YES	VaD + SI= worse MCI + SE= better	All groups were negatively affected by sleep issues, except MCI, which performed better (d=.14). VaD was particularly worse (d=.94)
Visuospatial		Benson	(HOA=SCD*ns)>MCI>VaD*	NO	NO	N/A
		MoCA- visuospatial	(HOA=SCD*ns)>MCI>VaD*	NO	NO	N/A
Executive Function	Processing speed	Trail A-Correct	HOA=SCD *ns SCD=MCI*ns HOA>MCI* MCI>VaD*	YES	VaD + SI = worse	Only VaD significant difference, sleep issues performed worse (d=.21)

	Processing Speed	Trail B- Correct	HOA>SCD>MCI>VaD*	YES	VaD + SI = worse	Sleep negatively affected all groups, but particularly VaD (d=.31).
		Trail A- Errors	(HOA=SCD*ns)>MCI>VaD*	NO	NO	N/A
		Trail B- Errors	HOA>SCD>MCI>VaD*	YES	NO	Sleep issues had a small impact on more errors for all groups (d=.05)
	Attention	Attention- MoCA	HOA>SCD>MCI>VAD*	NO	NO	N/A
Memory		Digit Forwards	HOA>SCD>MCI>VAD*	YES	SCD + SI = worse	Sleep issues showed poorer performance, particularly SCD (d=.12)
		Digit Backwards	HOA>SCD>MCI>VAD*	YES	VaD, MCI, HOA + SI = worse	Sleep issues negatively impacted all groups except SCD. (small effect sizes)
	Working memory	Logical memory – Immediate	HOA>SCD>MCI>VAD*	YES	VaD + SI = worse SCD + SI= worse	VaD (d=.20), SCD (.10) + SI= worse
	Delayed recall	Logical memory	HOA>SCD>MCI>VAD*	YES	VaD, SCD + SI = worse	VaD (d=.22), SCD (d=.10) + SI = worse
	Delayed Recall	MoCA MIS	HOAs>SCD>MCI>VaD*	NO	MCI + SI= worse	MCI + SI= worse (d=.15) – no other sig differences
	Working memory	Craft story 21- Immediate	HOA>SCD>(MCI=VaD*ns)*	NO	MCI + SI= worse	MCI + SI = worse (d=.17)

	Delayed recall	Craft Story 21-Delayed	HOA>SCD>(MCI=VaD*ns)*	NO	MCI + SI = better	MCI + SI= better (d=.21)
Language	Category fluency	Animals and Vegetables Naming	HOA>SCD>MCI>VaD*	YES	VaD + SI = worse	VaD + SI = worse (d=.19)

Note 1: (* indicates a significant main effect of group, *ns indicates a non-significant main effect of group)

2.7 Discussion

This study aimed to investigate the impact of sleep disturbances on cognitive performance in individuals with Vascular Cognitive Impairment (VCI), specifically focusing on Vascular Dementia (VaD), the most severe form of VCI (Bowler, 2005). Despite being the second most common form of dementia, VCI has received less attention than Alzheimer's Disease (AD) in terms of understanding the effects of sleep on cognitive functioning. The main objectives of this study were twofold. First, the study sought to determine whether sleep disturbances have an effect on cognitive performance in individuals with VaD and, if so, to identify cognitive domains affected. Second, by examining a spectrum of impairment ranging from Healthy Older Adults (HOA), Subjective Cognitive Decline (SCD), Mild Cognitive Impairment (MCI) to VaD, I aimed to ascertain whether any potential sleep effects are particularly pronounced at different levels of cognitive impairment. To achieve these objectives, I examined multiple cognitive domains, as the specific effects of sleep disturbances on the cognitive functions of individuals with VCI were previously unclear. This approach aimed to identify which if any, aspects of cognitive function are most vulnerable to sleep-related disturbances in this population.

I hypothesised that 1) sleep disturbances would negatively affect cognitive performance in those with VaD, 2) those with VaD and sleep issues would show poorer performance across all cognitive domains than those without and 3) sleep-related deficits would be worse in those with more severe cognitive impairment, as greater cognitive impairment would likely exhibit greater sleep-related differences in cognitive performance due to greater pathological disruption to sleep/wake regulatory systems in the brain compared to milder forms of dementia (Swaab & Bao, 2011), and where ceiling effects in neuropsychological battery tests may obscure the relationship between sleep and cognition (Franco-Marina et al., 2010) in milder forms of dementia.

Regarding hypothesis 1, which expected that individuals with VaD and sleep issues would show poorer performance than those without, the study found evidence of sleep-related impairments in the VaD group. For hypothesis 2, which suggested that sleep issues would negatively impact all cognitive domains, the results revealed that individuals with VaD sleep issues performed worse across all domains except visuospatial functioning. In relation to

hypothesis 3, which expected that greater severity of impairment would result in more pronounced sleep-related impairments, the study found mixed results. As anticipated, cognitive performance generally declined with worsening cognitive status (i.e., HOA > SCD > MCI > VaD), though there were exceptions where HOAs and the SCD group performed similarly, such as in MoCA orientation and visuospatial tasks.

The findings of this study provide a novel and important first step in demonstrating that sleep issues negatively impact cognition in VaD. This research establishes a foundation for detecting patterns of sleep-related cognitive impairments in VaD, which is crucial for identifying specific mechanisms by which sleep disturbances affect cognitive function. Determining the role of sleep in cognitive function in VCI may then assist in refining clinical and research criteria to account for sleep-related impairments and to develop targeted interventions to ameliorate the impact of sleep disturbances on cognitive health in VCI.

2.7.1 VaD Group Findings

The study revealed that individuals with VaD and sleep issues demonstrated poorer performance across several cognitive domains compared to those without sleep issues. These domains included global cognitive function, orientation, executive function, memory, and language. Notably, visuospatial function did not differ between sleep conditions for any group. Orientation, assessed by the MMSE and MoCA, showed the largest effect sizes ($d = .94$ and $d = .69$, respectively). This was followed by global cognitive function, also assessed by the MMSE ($d = .68$), executive function as measured by the Trails B task ($d = .31$), and memory as measured by the delayed logical memory test ($d = .22$).

2.7.1.1 Orientation

The finding that impairment in orientation showed the largest effect in terms of the presence of sleep issues in VaD is particularly noteworthy, as orientation is a cognitive domain that has implications for daily functioning and wellbeing in individuals with dementia (Razani et al., 2009). Orientation, which refers to an individual's awareness of themselves in relation to time, place, and person, is essential for navigating and making sense of one's environment

(Peer et al., 2015). Impairments in orientation have been shown to lead to significant distress, confusion, and difficulties in carrying out everyday activities. Previous research has highlighted the importance of orientation as a predictor of functional outcomes in dementia. A study by Razani et al., (2009) found that orientation was the single best predictor of daily function in individuals with dementia, even when compared to other cognitive domains such as memory and executive function. Specifically, the study found that poor MMSE orientation performance was significantly associated with poorer time orientation (e.g. orientation to person, place and time and the ability to accurately tell the time), communication skills (e.g. posting a letter, writing a cheque, dial a telephone), transportation skills (e.g. ability to read road signs and understand and implement driving rules), financial skills (e.g. count currency, balance finances), shopping skills (e.g. shopping from a 'mock' grocery shop and recall items givens), grooming abilities (e.g. using a toothbrush and combing one's hair), and eating ability (e.g. using utensils). This suggests that orientation plays a central role in an individual's ability to perform activities of daily living and maintain independence. The current study's finding that even mild sleep disturbances may exacerbate disorientation in VaD has important clinical implications. It suggests that addressing sleep issues in individuals with VaD may be a potential avenue for improving orientation and, consequently, daily functioning and future studies, particularly longitudinal or intervention designs, could help clarify whether sleep interventions might offer a viable approach to supporting orientation and daily living skills in people living with VaD.

2.7.1.2 Executive function

Executive dysfunction is a common and early feature of VaD (Román, 2003; Pantiou et al., 2018). Executive functions (EFs) are higher-order goal-oriented cognitive processes supported by frontal regions and their distributed networks, coordinating cognitive, affective, and motor abilities during the execution of complex tasks (Funahashi & Andreau, 2013; Pantiou et al., 2018). Put simply, EFs are important for performing everyday tasks such as performing task sequences such as getting dressed, cooking dinner, solving problems and making decisions (Sen & Tai, 2023). The prefrontal cortex (PFC) is a key structure for performing EFs (Funahashi & Andreau, 2013) and the results of this study found that individuals with VaD and sleep issues showed poorer performance in executive tasks (Trail Making Test-B) compared to those without sleep disturbances, align with the prefrontal

cortex vulnerability hypothesis (PFCVH; Muzur et al., 2002; Anderson & Horne, 2003; Funahashi & Andreau, 2013; Mander et al., 2013a). This hypothesis suggests that the PFC benefits from sleep, and sleep disruptions impair PFC function (Muzur et al., 2002).

Functional magnetic resonance imaging (fMRI) and EEG studies have shown that sleep deprivation leads to decreased activation in the PFC during cognitive tasks that require attention, working memory, and decision-making in healthy populations (Dai et al., 2012; Verweij et al., 2014). Wu et al., (2006) investigated frontal lobe metabolism following sleep deprivation and found that total sleep deprivation in healthy adults was associated with reduced glucose metabolism and blood flow to the PFC, which correlated with poorer performance on a serial addition and subtraction task. Furthermore, the authors found that even after a night of recovery sleep, participants showed reduced glucose metabolism compared to baseline, suggesting that the effects of sleep deprivation on brain metabolism may persist even after a period of recovery sleep. In another study, Anderson & Horne, (2003) found EEG correlations between increased slow-wave sleep (SWS) in left frontal channels and tasks involving the left PFC (verbal fluency and planning) for healthy older adults. They suggested that reductions in SWS in healthy adults directly affected the frontal cortex, resulting in reduced executive functioning. Additionally, a lack of SWS has been associated with a decline in extracellular serotonin (Bjorvatn et al., 2002), which has a complex role in sleep/wake regulation and maintenance, with one proposed mechanism being the promotion of SWS (Thomas et al., 2000). Moreover, Verweij et al., (2014) found that following total sleep deprivation compared to a day following normal sleep, in healthy young adults, sleep deprivation most strongly affected the functional connectivity of prefrontal cortical areas during a rested state as examined by high-density resting state EEG.

These findings collectively suggest that sleep deprivation and reduced SWS can lead to impairments in frontal lobe function, particularly in terms of executive functioning and sustained attention. The metabolic and neurochemical changes observed in the frontal regions following sleep deprivation, such as reduced glucose metabolism and decreased serotonin levels, may underlie these cognitive deficits (Muzur et al., 2002; Mander et al., 2013a). In the context of VaD, where frontal lobe function may already be compromised due to vascular pathology and white matter lesions (Calabrese et al., 2016), the additional burden of sleep disturbances could exacerbate executive dysfunction. Thus, a potential explanation for the observed results is that PFC vulnerability in VaD is compounded by sleep-related PFC

vulnerability, leading to more pronounced deficits in executive function. Moreover, this could translate into increased functional impairment and reduced independence in daily life. For example, Jefferson et al., (2006) found that for 24 patients with probable VaD, changes in executive function and memory abilities over the course of a year were most strongly associated with functional decline as assessed by the Dementia Rating Scale (DRS; Mattis, 1973) and informant based Instrumental Activities of Daily Living (IADL; Lawton & Brody, 1970). Given that executive dysfunction in both AD and VCI has been shown to significantly predict future decline in dementia (Boyle & Cahn-Weiner, 2004), addressing sleep issues in VaD may have important implications for cognitive and functional outcomes.

2.7.1.3 Language

The study found a significant main effect of group on language performance, with the hierarchy of performance being HOA>SCD>MCI>VaD, consistent with the expected pattern of cognitive decline across the spectrum from healthy ageing to mild cognitive impairment and dementia. Additionally, the study found a significant main effect of sleep condition, with participants experiencing sleep issues performing worse on the Category Fluency task than those without sleep issues. This finding aligns with previous studies showing an association between poor sleep and reduced cognitive performance, including verbal fluency (Zimmerman et al., 2012; Targa et al., 2021). Interestingly, our results revealed a significant interaction between group and sleep condition, suggesting that the effect of sleep issues on Category Fluency performance varies across the different cognitive groups. Specifically, post-hoc analyses showed that individuals with VaD and poor sleep were disproportionately affected compared to the other groups. This finding suggests that sleep disturbances may have a more pronounced effect on verbal fluency in individuals with VaD compared to those with MCI, SCD, or healthy older adults. This could be due to the specific pathophysiology of VaD, which often involves vascular lesions and white matter changes that can disrupt the neural networks supporting executive function and language (Funahashi & Andreau, 2013; d'Arbeloff et al., 2019).

2.7.1.4 Visuospatial

Interestingly, these results show that sleep issues were not associated with differences in visuospatial performance across all participants compared to those without sleep issues. Sleep-related visuospatial deficits have been shown in individuals with Alzheimer's Disease. For example (Shin et al., (2014), found that sleep latency was negatively correlated with visuospatial functions in AD but no other sleep parameters (e.g. quality, duration, SE, sleep disturbance, use of sleeping medication and daytime dysfunction). However, other research has found that sleep-related visuospatial deficits are linked to REM sleep behaviour disorder (Fantini et al., 2011), which includes complex motor behaviours during sleep and dream reenactment (Dauvilliers et al., 2018) are typically associated with Parkinson's disease or dementia with Lewy bodies (Fantini et al., 2011). These results support this work, suggesting that sleep-related impairments in visuospatial functioning are related to α -synucleinopathy (Dauvilliers et al., 2018).

2.7.1.5 Global functioning

Global cognitive function, as assessed by the MMSE, showed that those with VaD with sleep issues performed worse than those without after controlling for covariates, with a medium effect size ($d = .68$). This suggests a negative association between sleep issues and overall cognition, considering orientation, attention, verbal memory, language and visuospatial ability. Other studies have shown that poor sleep is associated with reduced performance in global cognitive function. For example, a meta-analysis of 24 studies found that reduced SWS and REM sleep, assessed by PSG, was negatively associated with MMSE performance in people with AD (Kim et al., 2011). Regarding VaD, these findings are supported by (Jiang et al., 2013), who found that for vascular mild cognitive impairment (vMCI), self-reported sleep quality as assessed by the Pittsburgh Sleep Quality Index (PSQI), sleep latency and arousal index (number of arousals), as assessed by PSG, were significantly negatively correlated with MoCA scores, compared to controls (Jiang et al., 2013). However, it is worth noting that there is a discrepancy between MoCA and MMSE findings. Contrary to the results regarding the MMSE global function, the study did not find a significant difference between sleep conditions for those with VaD and global cognitive function as assessed for the MoCA. However, this is likely due to the discrepancy in sample size between the two tests. The MMSE sample size was significantly larger as the MoCA was only introduced to the NACC-UDS version 3.

2.7.1.6 Memory

The study found that all memory measures indicated worse performance in individuals with VaD and poor sleep than those without sleep issues, except for the MoCA Memory Index Score (MIS) and the Craft-21 story. A likely explanation for this exception is that both measures were only introduced in UDS version 3, resulting in much smaller sample sizes (fewer than 60 participants per group) compared to the over 1,000 participants in other groups, likely rendering the analysis underpowered. Additionally, the digit forward task also showed no sleep-related effects for those with VaD. This task is simpler compared to the digit backward task and the logical memory (LM) task, both of which demonstrated significant sleep effects. This suggests that more complex memory tasks are more vulnerable to the detrimental effects of poor sleep than simpler tasks. More challenging memory tasks, which require greater cognitive resources and rely on other cognitive domains such as executive function and attention, may be more sensitive indicators of the impact of poor sleep.

2.7.2 MCI and SCD

This study found that those with SCD and sleep issues performed worse than those without sleep issues on specific cognitive domains, including orientation (MMSE-derived) memory (digit forwards task, logical memory immediate and delayed). These findings suggest that sleep disturbances may have a negative impact on orientation and memory in individuals with SCD. Interestingly, these results partially differ from a previous study that investigated the relationship between sleep issues and cognitive function in SCD (Exalto et al., 2022). In the previous study, no significant differences were found between those with and without sleep issues on measures of global cognition (MMSE), attention (TMT-A), memory (RAVLT immediate and delayed), language (category fluency animals), and executive functioning (TMT-B). However, it is important to note that the previous study did not specifically examine orientation or the digit forward task, which were found to be affected by sleep issues in the current study.

Furthermore, the previous study found that when specific sleep disorders were isolated, individuals with SCD and sleep apnoea performed significantly worse on global cognition and verbal fluency than those without sleep apnoea. The discrepancy in the findings related to

delayed memory between the current study and the previous study may be attributed to differences in the specific memory tests used (logical memory vs. RAVLT) or the characteristics of the study samples. The logical memory test used in the current study may be more sensitive to the effects of sleep disturbances on memory consolidation and retrieval processes in individuals with SCD.

2.7.2.1 *Category Fluency*

Previous research has consistently demonstrated associations between poor sleep and reduced cognitive performance, particularly in verbal fluency tasks, across various cognitive status groups. In healthy older adults and adults with SCD, Tsapanou et al., (2019) found that self-reported sleep problems were associated with poorer performance on category fluency tasks. In MCI, a study by Kim et al., (2011) found that the amount of SWS was positively correlated with the Boston Naming Test (BNT), a category fluency task and that sleep apnoea index scores were significant independent variables associated with BNT performance. This work is also supported by Targa et al., (2021), who found that in MCI patients, lower levels of SWS were associated with poorer verbal fluency performance and increased levels of neurofilament-light, a marker for neurodegeneration linked to cognitive decline. Given this body of evidence, our findings of no significant differences in cognitive performance between those with and without sleep issues in the MCI, SCD, and HOA groups are not in line with prior work. One potential explanation for this inconsistency could be the role of cognitive reserve. Some authors have suggested that older adults with lower education may be selectively vulnerable to the negative effects of sleep difficulties on verbal fluency tests (Zimmerman et al., 2012). However, this study controlled for years of education as a covariate in each analysis, so this factor alone does not fully account for our findings. Another potential explanation is that naming performance in healthy controls has been shown to have a ceiling effect (Laws, 2005), though this still would not explain the null findings for the MCI group.

A more likely explanation may lie in this study's sleep assessment approach. The study combined sleep disorders and disturbances in the analysis but did not specifically account for sleep duration or other parameters. Previous research has shown associations between sleep duration and category fluency performance, as well as with sleep disorders. For instance,

Low et al. (2019) found that short and long sleep durations were associated with poorer cognitive performance, including verbal fluency, in older adults. Additionally, Kim et al., (2011) found that sleep apnoea index scores were independent variables associated with performance in naming tasks. Thus, this study is not without limitations.

2.7.3 Limitations

The current study has several limitations that should be considered when interpreting the results. First, the use of all-cause MCI as a comparison group may have masked some effects, as the NACC database does not phenotype MCI into vascular mild cognitive impairment (vMCI) or amnesic MCI (aMCI)/non-amnesic MCI (na-MCI). As such, the study did not differentiate between VaD subtypes due to the unclear underlying pathology in the NACC database. Different pathologies are associated with differing cognitive presentations, suggesting that sleep may affect VaD subtypes differently. For example, research has shown sleep-related differences between aMCI and naMCI, suggesting that a more specific comparison group could have provided additional insights about the relationship between sleep and cognition in VCI.

Secondly, the sensitivity and specificity of the cognitive tests used in this study may have influenced the results. The Montreal Cognitive Assessment (MoCA) is more sensitive than the Mini-Mental State Examination (MMSE). At the same time, the MMSE has greater specificity and may be better suited for assessing VaD due to its focus on easier tasks. However, the study was likely underpowered for MoCA, limiting the ability to conclude test-related differences.

Thirdly, the sleep measures used in this study combined sleep disorders and sleep disturbances, which may have different effects and mechanisms on cognition, as previously highlighted in this discussion. The lack of objective sleep measures, such as PSG, is a limitation. However, the relatively lower prevalence of VCI compared to AD, coupled with participant burden and research costs, makes creating a large PSG and cognition database challenging. Sleep diaries or actigraphy would be more feasible for large data sets and could provide valuable information about specific aspects of sleep that may have differential effects on cognition.

Moreover, the cross-sectional design of this study is another significant limitation, as it fails to capture the dynamic nature of sleep and its potential impact on cognitive function over time. The inherent variability in sleep patterns raises concerns about the reliability of the ‘no sleep issue’ group classification, as the absence of reported sleep issues at a single time point does not necessarily equate to consistently good sleep quality. Some individuals in the ‘no sleep issue’ group may have experienced poor sleep before the assessment, while some participants with reported sleep issues may have had relatively good sleep quality during the same period, potentially minimising the observed differences in cognitive function between the groups.

Finally, small sample sizes for some measures introduced in the Uniform Data Set version 3 (UDS3), such as the MoCA and Craft 21 story recall, likely rendered those analyses underpowered for VaD, as the NACC is primarily an AD database. This limitation highlights the need for more focused studies on VaD and sleep but also provides valuable insights into the relationship between sleep and cognitive function in VaD. However, the above limitations should be considered when interpreting the results.

2.7.4 Future Research and Implications

Future research should incorporate several key improvements to address the current study's limitations and further investigate the relationship between sleep and cognition in VCI. These include using more specific comparison groups and a range of cognitive tests, considering individual variation, employing robust sleep measures such as sleep diaries, actigraphy, or PSG, differentiating between VaD subtypes, and using longitudinal and experimental designs with larger sample sizes. Longitudinal studies assessing sleep quality and cognitive function at multiple time points are important for understanding the long-term effects of sleep disturbances on cognition in VCI. This approach would help account for natural variability in sleep patterns and provide a more accurate representation of sleep's impact on cognitive trajectories.

Our study found that individuals with VaD show sleep-related impairments in orientation, global functioning, executive functioning, memory, and language. These findings have

significant implications for both research and clinical practice. They highlight the importance of considering sleep as a potential contributor to cognitive deficits in VaD. The large effect sizes for orientation and executive function domains are noteworthy, as these are strong predictors of subsequent cognitive decline in VaD. Furthermore, the impact of sleep on cognition in VaD has significant implications for quality of life and functional outcomes. Given that sleep is a modifiable risk factor, future studies need to determine the extent to which sleep accounts for the observed differences in cognitive performance. This could inform the development of targeted interventions to mitigate cognitive decline and improve functional outcomes in VCI.

The finding that narrative memory was negatively impacted in the VaD group with sleep issues warrants further investigation, particularly in sleep-dependent memory consolidation. While research has demonstrated the important role of sleep in memory consolidation in general and AD, its specific impact on VCI remains largely unexplored. Our findings may also influence the classification of VCI subtypes, particularly regarding using memory performance to differentiate between suspected AD and VaD. By clarifying the relationship between sleep and memory in VaD through experimental methods, we can improve the accuracy of diagnostic criteria and ensure that research studies appropriately classify participants based on their cognitive profile. This experimental exploration of memory consolidation in VCI will be the focus of the next chapter, aiming to provide insights into the mechanisms underlying sleep-related memory impairment in this population and potentially inform future interventions.

Chapter 3. Sleep-Dependent Emotional Memory Consolidation: Development of a Narrative Task, Preliminary Findings in Young and Older Adults, and Implications for Future Research for Individuals with Vascular Cognitive Impairment

3.1 Abstract

Sleep plays an essential role in memory consolidation, with research showing superior memory performance following sleep compared to an equal period of wakefulness. Our previous findings revealed that individuals with Vascular Dementia (VaD) and sleep issues showed poorer memory than those without prompted an exploration of sleep-dependent memory consolidation in Vascular Cognitive Impairment (VCI). This chapter presents five studies investigating sleep-dependent emotional memory consolidation. Studies 1 and 2 developed and validated a novel narrative memory task to assess sleep-dependent declarative and emotional memory consolidation. Study 3 used a within-participant crossover design with 24 young adults to examine sleep versus wake effects on memory performance. Results showed a general benefit of sleep for memory performance across all story types, though the anticipated preferential consolidation of emotional narratives was not observed. Study 4 addressed the time-consuming nature of manual scoring by developing and validating an automatic scoring tool using Python, significantly enhancing accuracy and efficiency for large-scale research. Study 5 aimed to extend the investigation to healthy older adults and individuals with VCI. However, due to COVID-19 disruptions and recruitment challenges, the sample size was limited ($n = 5$) for older adults, preventing definitive conclusions but offering interesting insights and highlighting the need for adapted methodologies in research involving older adults to improve recruitment in this population. Although the lack of VCI participants limited the examination of sleep-dependent memory consolidation, this chapter has made a significant contribution to methodological tools to examine sleep-dependent memory consolidation in future research.

3.2 Introduction

"You have to begin to lose your memory, if only in bits and pieces, to realise that memory is what makes our lives. Life without memory is no life at all.... Our memory is our coherence, our reason, our feeling, even our action. Without it, we are nothing." (Buñuel, 2013).

Memory is a fundamental cognitive function that refers to retaining information over time (Diekelmann & Born, 2010). It involves learning and making sense of information (encoding), transforming information into more stable and persistent forms which are integrated into pre-existing knowledge networks (consolidation) and accessing that information when needed (retrieval; (Diekelmann et al., 2009; Rasch & Born, 2013; McDermott & Roediger, 2018). Memory impairments are hallmark symptoms of various dementias, most notably Alzheimer's Disease (AD), and, to a lesser extent, Vascular Cognitive Impairment (VCI; Craft et al., 1996; Beekly et al., 2004; Mayda & DeCarli, 2009; Bir et al., 2021)). In AD, memory decline is often an early symptom due to the accumulation of amyloid- β plaques and hyperphosphorylated tau protein within neurons, leading to neuronal atrophy (Craft et al., 1996; Giannakopoulos et al., 2000). These pathological changes typically originate in regions critical for memory formation, such as the medial temporal lobe (MTL), specifically the hippocampus and entorhinal cortex, before progressing to other temporal and parietal regions (Traykov et al., 2005; André et al., 2019). While less prevalent than in AD, memory impairment is also observed in VCI (Traykov et al., 2005), though the underlying mechanisms differ where VCI-related memory issues stem from vascular damage and subsequent disruption of neural networks (Mayda & DeCarli, 2009). Memory impairment in dementia significantly impacts quality of life, wellbeing, and functional independence, underscoring its importance in daily functioning (Hawley & Cherry, 2008; Stites et al., 2018). Interestingly, an awareness of memory impairment appears to affect this relationship, as research has found that lower awareness of memory issues is associated with greater quality of life in those with dementia (Trigg et al., 2011). Furthermore, sleep disturbances are common comorbidities in dementia, particularly in AD and VaD, potentially exacerbating cognitive symptoms (Guarnieri & Sorbi, 2015; André et al., 2019) as a wealth of research suggests that sleep plays an essential role in memory formation (Walker et al., 2002;

Stickgold & Walker, 2005; Stickgold, 2005; Diekelmann et al., 2009; Mander et al., 2015; Guarnieri & Sorbi, 2015).

3.2.1 Sleep and Memory Overview

A breadth of evidence has shown that a critical function of sleep is to support memory consolidation, a process whereby weak memory traces are strengthened and stabilised from interference, supporting integration into long-term memory stores (Born et al., 2006; Diekelmann et al., 2009). For example, behavioural studies have demonstrated performance on memory tasks is superior following sleep compared to an equivalent period of wakefulness (Diekelmann et al., 2009), giving rise to sleep-dependent memory consolidation. This phenomenon has been observed across multiple types of memory, including memory involving motor skills (procedural memory; (Ghilardi et al., 2000; Walker et al., 2002; Marshall & Born, 2007), for event and fact information (episodic memory; (Van Der Helm et al., 2011; Inostroza et al., 2013; Oyanedel et al., 2019; Friedrich et al., 2020), and for experience and knowledge memory (semantic memory; Friedrich et al., 2020).

3.2.1.1 Theories of Sleep-Dependent Memory Consolidation

Historically, the role of sleep in memory consolidation was viewed as a passive process, sleep was thought to protect newly encoded memories from interference by providing a period of reduced sensory input (Ellenbogen et al., 2006). However, contemporary research supports a more dynamic role for sleep in memory processes, demonstrating that sleep protects information from retroactive interference and actively consolidates memories (Born et al., 2006; Inostroza et al., 2013; Rasch & Born, 2013). According to the Active Systems hypothesis (Born et al., 2006; Diekelmann et al., 2009; Diekelmann & Born, 2010), during sleep, particularly slow-wave sleep (SWS), recently encoded memories undergo a process of reactivation, stabilisation, and redistribution (Born & Wilhelm, 2012; Diekelmann et al., 2009). Specifically, memories initially stored in the hippocampus are repeatedly reactivated during sleep and are gradually transferred to neocortical networks for long-term storage (Born & Wilhelm, 2012). An orchestrated dialogue between neural oscillations and network dynamics supports this process. Evidence from human electroencephalography (EEG)

recordings and animal studies has supported this process (Born & Wilhelm, 2012; Köster et al., 2017). Slow oscillations (SOs) that predominate SWS (Mander et al., 2015), occurring at approximately 0.8Hz and originating in the neocortex, serve as a driving force for memory reactivations (Born & Wilhelm, 2012). These oscillations facilitate a dialogue between neocortical and hippocampal networks, crucial for the transfer of information whereby SOs group neuronal activity into distinct phases: hyperpolarising 'down-states' where neurons are temporarily silent, followed by depolarising 'up-states' where neuronal firing increases to levels comparable with wakefulness (Born & Wilhelm, 2012). A key finding in recent years has been the temporal coupling of these SOs with other sleep-specific neural events. For example, thalamocortical sleep spindles (brief bursts of oscillatory brain activity) and hippocampal sharp-wave ripples (high-frequency oscillations in the hippocampus) are synchronised with SOs, creating optimal windows for information transfer between brain regions (Born & Wilhelm, 2012; Fernández-Ruiz et al., 2019). This synchronisation is thought to be critical for the effective consolidation of memories during sleep.

Memory consolidation comprises two interconnected processes: cellular consolidation and systems consolidation (Rasch & Born, 2013; Klinzing et al., 2019). Cellular consolidation involves synaptic strengthening through molecular and cellular changes, while systems consolidation encompasses broader, system-level changes involving the redistribution of memory traces across neural networks (Dash et al., 2004). Sleep, particularly SWS, appears to play a crucial role in both these processes, facilitating the strengthening of synaptic connections and reorganising memory representations at a systems level (Mander et al., 2017). Functional neuroimaging studies have further supported these mechanisms, revealing activation in key memory-related brain regions during post-learning sleep (Peigneux, 2014). For instance, Takashima et al. (2006) found increased hippocampus and medial temporal lobe activity during sleep following a learning task correlated with memory performance. Importantly, Gais et al. (2007) found that hippocampal responses during word pair recall 48 hours after learning showed functional connectivity with the medial prefrontal cortex (MCPc). Furthermore, memories encoded before sleep activated the MCPc more strongly six months after learning. These findings indicate that sleep leads to long-lasting changes in memory representation at the systems level, showing a direct link between sleep-related brain activity and memory performance.

3.2.2 Sleep, Memory and Dementia

The co-occurrence of memory complaints and sleep disturbances, both common features of dementia, raises an important question: Is the process by which memories are consolidated during sleep further impaired in individuals experiencing this co-occurrence? Essentially, does poor sleep exacerbate memory issues via disruption to sleep-dependent consolidation mechanisms? In AD, several lines of evidence support this hypothesis. However, while direct research on sleep-dependent memory consolidation in VCI is limited, results from study 2 found that those with sleep issues and VaD showed poorer performance in memory tasks than those without sleep issues, suggesting that sleep-dependent consolidation mechanisms may be affected in those with VCI.

Regarding AD, research examining the relationship between oscillatory dynamics during sleep, subsequent memory performance and dementia-related pathology suggests that sleep-dependent memory consolidation mechanisms may be affected by underlying pathology (Mander et al., 2017). For example, research examining AD-related pathology suggests that non-rapid eye movement (NREM) sleep, and particularly SWS, is implicated in sleep-related memory impairment. Firstly, healthy older adults have been shown to have reduced Slow Wave Activity (SWA), generally across the head and across frontal regions where SWA is maximal, compared to younger adults (Mander et al., 2013a). This reduction in SWA in older adults is associated with impaired overnight episodic memory performance (Mander et al., 2013a). Moreover, both the disruption of SWA and experimentally increasing SWA are associated with decreased and improved performance in overnight memory consolidation, respectively. NREM SOs are generated in the medial Prefrontal Cortex (mPFC) and related structures, the same regions where amyloid beta aggregates (Mander et al., 2017).

Moreover, NREM sleep disruption is worse in early AD and MCI, correlating with elevated A β , predicting memory impairment (Traykov et al., 2005; Mander et al., 2013a, 2015). A study by Mander et al. (2015) found that beta-amyloid burden within the mPFC was correlated with SWA reduction in healthy older adults, and reduced SWA was associated with impaired overnight episodic memory consolidation. Moreover, one study found that in AD patients, sleep spindles were globally reduced compared to healthy controls and that the mean

intensity of fast spindles was positively correlated with immediate recall performance in an overnight episodic memory task examining post-sleep learning (Rauchs et al., 2008).

3.2.2.1 VCI

In VCI, while direct research on sleep-dependent memory consolidation is limited, several potential mechanisms may explain how poor sleep disrupts this process, particularly in relation to executive function, which is predominantly affected in VCI. White matter changes are a hallmark of VCI, especially in small vessel/subcortical subtypes (Smith et al., 2012; Wardlaw et al., 2013). White matter, comprising approximately half of the human brain, enables rapid and efficient information transfer, providing connectivity between neural networks and hemispheres to support cognitive function (Filley, 2012). Studies have shown that white matter lesions correlate with cognitive function in dementia (Cheng et al., 2013; Filley, 2012; d'Arbeloff et al., 2019). The disrupted white matter connectivity characteristic of VCI may interrupt the neural networks necessary for coordinating memory consolidation during sleep, such as the medial temporal lobe (MTL) and distributed networks (d'Arbeloff et al., 2019).

Moreover, executive function, which relies heavily on frontal-subcortical circuits, is particularly vulnerable to white matter damage in VCI (Funahashi & Andreau, 2013). Recent research has highlighted the importance of executive function in memory consolidation processes. For instance, Raj & Bell (2010) suggested that executive function plays a crucial role in tagging memories as important for future behaviour. In VCI, impaired executive function may lead to a less efficient selection of memories for consolidation during sleep, failing to prioritise and strengthen the most relevant information. Moreover, VCI is often associated with sleep disorders like sleep apnoea, insomnia and excessive daytime sleepiness, which are all associated with fragmented sleep and reduced SWS (Cheng et al., 2013; Hara et al., 2004; Bubu et al., 2017). This fragmentation could disrupt the cyclic nature of sleep stages necessary for optimal memory consolidation, in addition to SWS-mediated relationships outlined previously. Champetier et al. (2023) found that sleep fragmentation in older adults was associated with impaired overnight memory consolidation, particularly for declarative memories. These proposed mechanisms align with the findings from Study 2, which showed that individuals with sleep issues had poorer performance in memory tasks.

The disruption of sleep-dependent memory consolidation in VCI may contribute to the observed cognitive impairments, particularly in tasks requiring executive function and memory integration. Given the VCI and AD pathology overlap, many of these mechanisms may be shared between the two conditions. However, these are only proposed mechanisms as to how sleep-related memory impairments observed in study 2 may be explained.

3.2.3 Emotional Memory Overview

An additional aspect of sleep-dependent memory consolidated that may be particularly relevant to those with VCI, given our findings from Chapter 2, is the emotional content of information. Numerous studies have demonstrated that emotionally valenced stimuli, both positive and negative, are subject to less forgetting following a period of sleep compared to an equivalent period of wakefulness and compared to neutral material (Hamann et al., 1999; Lara-Carrasco et al., 2009; Bennion et al., 2015; Lipinska et al., 2019; Schäfer et al., 2020). This finding suggests that sleep may play a crucial role in the selective consolidation of emotionally salient memories, potentially prioritising their storage and retention over emotionally neutral memories (Hutchison & Rathore, 2015). For instance, Wagner et al., (2001) found that participants who slept after learning negative texts showed significantly better recall than those who remained awake, an effect not observed for neutral texts. Similarly (Hu et al., (2006) found that recognition accuracy for emotional images was superior after a period of sleep compared to wakefulness, while neutral image recognition remained unchanged. The preferential consolidation of emotionally salient memories during sleep may have adaptive significance, as emotionally charged experiences often carry important information for future behaviour and survival (Hamann et al., 1999). By selectively strengthening and stabilising emotionally relevant memories, sleep may help individuals better navigate their environment and respond appropriately to emotionally significant stimuli in the future (Hamann et al., 1999).

This adaptive function in the preferential consolidation of emotionally salient memories during sleep may have significant implications for individuals with VCI and other forms of dementia. While this process may serve as an adaptive function in healthy individuals by prioritising emotionally relevant information for adaptive future behaviour (Hamann et al., 1999), disruptions to this mechanism in relation to sleep in those with VCI could have

negative consequences beyond normal memory processing. Behavioural disturbances, mood disorders, and neuropsychiatric symptoms, which are common in VCI, may be influenced by alterations in emotional information processing during sleep. This hypothesis is supported by research in other clinical populations. For example, Hu et al., (2006) and Cunningham et al., (2022) proposed that sleep disruption in depression might lead to preferential consolidation of negative emotional memories, contributing to the maintenance of depressive symptoms. Disturbed sleep may, therefore, lead to an imbalance in the consolidation of positive versus negative emotional memories, potentially exacerbating depressive symptoms or anxiety in these individuals, suggesting that sleep disruption could have significant implications for mood effects in individuals with VCI.

Given the lack of research specifically in VCI populations, the next step in determining whether sleep-related mechanisms are preserved in those with VCI is to experimentally determine whether memory performance is superior following a sleep period compared to an equal period of wake in those with VCI and good sleep quality. Additionally, exploring how emotional content versus neutral content of information is processed across a period of sleep compared to an equal period of wakefulness in VCI patients is crucial. This line of investigation could build on work such as that of Baran et al., (2014), who examined sleep-dependent emotional memory consolidation in patients with AD, finding that while the overall benefit of sleep on memory was reduced, the selective benefit for emotional over neutral material was preserved. By examining the effect in VCI populations, this knowledge could inform targeted interventions aimed at improving both cognitive function and emotional wellbeing in individuals with VCI, potentially addressing not only memory deficits but also mood disorders and neuropsychiatric symptoms associated with the condition.

3.2.3.1 Methodological Considerations in Sleep-Dependent Emotional Memory Research

However, recent developments in sleep and memory research have challenged long-held assumptions about emotional memory consolidation during sleep. For example, while decades of studies suggested a preferential boost for emotional memories during sleep, more recent meta-analyses have questioned the strength and consistency of this effect (Hu et al., 2006). These findings suggest that specific circumstances may lead to more reliable effects on sleep and emotional memory (Cunningham et al., 2022). Consequently, it's crucial to

consider key methodological factors when designing robust sleep-dependent emotional memory studies. Given the limited research on emotional memory, sleep, and dementia, systematically addressing these factors is essential for developing robust studies and gaining a more accurate understanding of sleep's role in memory consolidation, particularly in the context of ageing and neurodegenerative diseases where studies are notably lacking.

A meta-analysis of 31 articles investigated sleep-dependent emotional memory enhancement and examined whether a sleep-filled interval, compared to a wake-filled interval, improves the strength of memory for emotional material over neutral material (Lipinska et al., 2019). Surprisingly, the authors noted that although emotional materials are generally more memorable, there was no overall difference between sleep and wake conditions, suggesting the absence of a sleep-specific effect on memory for valenced materials compared to neutral materials. However, when the authors conducted a moderation analysis, they found that sleep does enhance emotional memory but that this was only observed under specific conditions and identified key factors that appear to moderate the strength of sleep-dependent memory enhancement (Lipinska et al., 2019).

One of the key factors was the type of outcome measure used to evaluate memory performance, which affected the magnitude of the difference between sleep and wake conditions for emotional versus neutral performance. Studies reporting free-recall outcome measures showed significantly larger differences in performance and effect sizes compared to those using recognition measures. This finding is consistent with another recent meta-analysis that examined recognition paradigms within EEM research (Schäfer et al., 2020). Another important factor identified by Lipinska et al., (2019) was whether studies controlled for initial learning through the inclusion of retention measures (i.e., subtracting delayed recall performance from immediate recall performance). Studies that did not control for initial learning failed to show post-sleep evidence of preferential consolidation of emotional items. In contrast, studies that controlled for initial learning found that emotional material was selectively consolidated over neutral material. These findings underscore the importance of considering task-specific features of emotional memory paradigms when designing and interpreting emotional memory research.

3.2.3.2 Narrative Memory Tools

Narrative tools, the use of short stories or narratives, offer an approach to address the methodological considerations proposed by the meta-analysis conducted by Lipinska et al., (2019) and provide advantages over commonly used methods, such as pictorial stimuli like the International Affective Picture System (IAPS), which have been routinely used in emotional memory sleep studies. While the IAPS provides a standardised database of pictures varying in valence and arousal narrative memory tasks, they more closely resemble the structure of memory used in everyday experiences. Importantly, narrative tasks are better suited to assessing emotional memory and sleep using free-recall paradigms than picture tasks are. Moreover, the use of narratives in emotional memory research may better capture the richness and complexity of real-life emotional experiences and can provide context, sequential information, and emotional arcs that are more representative of how we encode and retrieve emotional experiences in daily life (León, 2016). Additionally, the use of free recall in narrative tasks may be more sensitive to the effects of sleep on emotional memory consolidation, as it requires a more active and effortful retrieval process compared to recognition tasks (Lipinska et al., 2019).

However, only a few studies have used story memory tasks to investigate sleep-dependent emotional memory. One of the earliest studies to use narratives was a study by Schürer-Necker, (1994), and the stories used here were later adapted by Wagner (2001) to investigate the effect of emotionality on sleep-dependent memory consolidation. However, several limitations to these stories need to be addressed. Firstly, the Schürer-Necker stories only included neutral and negative texts, lacking a positive text for comparison. The meta-analysis by Lipinska et al., (2019) also found that studies that included combined negative-positive stimuli versus neutral material showed greater strength of memory for emotional material compared to neutral. Moreover, age-related differences within emotional memory highlight the need to include bivalent stimuli when using narrative tools. For example, studies have shown that younger adults have better memory for negative items, whereas older adults show better memory for positive items following sleep (León, 2016). This finding suggests that the

emotional valence of memories preferentially consolidated during sleep may shift across the lifespan.

Socioemotional Selectivity Theory (SST; Carstensen et al., 2003) provides a framework for understanding this age-related shift in emotional memory processing. According to SST, as individuals age, they develop an increasing propensity to prioritise positive memories and information in pursuit of emotional regulation and wellbeing. This change in motivation is thought to be driven by the perception of future time as being increasingly limited with advancing age (Huan et al., 2020). Older adults, who perceive their future as more constrained, may therefore focus on optimising their emotional experiences and prioritise the consolidation of positive memories during sleep. In contrast, younger adults, who perceive their future as relatively open-ended, may prioritise knowledge acquisition and novel experiences over emotional wellbeing (Huan et al., 2020). As a result, they may selectively consolidate memories that support learning and growth, regardless of their emotional valence. In some cases, younger adults may even prioritise the consolidation of negative information during sleep, given its potential importance for survival and adaptation (Carstensen et al., 2003). The age-related differences in sleep-dependent emotional memory consolidation have important implications for understanding the relationship between sleep, emotion, and cognition across the lifespan, particularly when considering cognitively impaired older adults, such as those with VCI.

A limitation of one of the most cited studies using narrative tasks is that the negative text in Schröder-Necker task depicted the rape and murder of a child, which is not only concerning and inappropriate for many cohorts but also problematic for ethical clearance (Reid et al., 2022). To address these issues, Reid et al., (2022) developed three short stories: a positive story about a mother giving birth to a healthy baby girl, a neutral story about a day trip to a museum, and a negative story about a botched examination by a stressed dental student. These stories were piloted to ensure they were equally matched in terms of difficulty, memorability, and comprehensibility while also being rated as appropriately valenced. In their study, Reid et al., (2022) found that participants in the nap condition had better memory overall than those who did not nap, and that this effect occurred for negative and positive texts but not neutral texts. These findings demonstrate the potential benefits of using carefully designed narrative tasks in sleep-dependent emotional memory research and highlight the importance of including a range of valenced stimuli to better understand how

sleep may differentially affect the consolidation of emotional memories. Whilst this is an important contribution to the field of sleep and emotional memory consolidation, this study did not examine the full night of sleep (Lipinska et al., 2019). Research indicates that cycling through a full night of sleep, as compared to shorter architectural cycles in napping, may act differently.

Whilst this is an important contribution to the field of sleep and emotional memory consolidation, this study did not examine the full night of sleep. Research indicates that cycling through a full night of sleep, as compared to shorter architectural cycles in napping, may act differently. For example, (Van Schalkwijk et al., 2019) found that for 76 healthy adults, daytime naps protected procedural memories from deterioration, whereas a full night of sleep improved performance. Thus, it may be that for emotional memories to be properly consolidated, they need to be subject to full night of sleep. A night of sleep is different to a nap, because naps might include only some of the sleep stages (i.e. N1, N2, SWS and REM), in a typical night of sleep, all stages are included and subject to the naturalistic cycling of sleep stages. In the early half of the night SWS predominates whereas in the second half REM predominates (Fuller et al., 2006). This proportional change may reflect different neural processes compared to a nap. Another difference between the current study and the Reid et al. (2022) study is that the current study uses a within-subjects design: the 3 stories created by Reid et al., do not lend themselves to a repeated-measures design, in which participants learn materials over multiple days. To determine the impact of a full night of sleep on emotional memory consolidation, compared to wake-periods in a repeated measures design, multiple stories that are matched for equivalency, include positive, negative and neutral texts were produced. To explain the need of producing these new multiple stories, the other stories currently available will now be reviewed.

Aside from the problematic Schürer-Necker negative story mentioned above, the other prominent story tasks used in evaluating story memory are the Logical Memory (LM) task from the Wechsler Memory Scale-Revised (WMS-R) and the Craft-21 task, have limitations that make them unsuitable for the specific methodological requirements of sleep-dependent emotional memory research, particularly in the context of VCI. Both tasks are frequently used to assess memory, especially in cognitive impairment, and are featured as part of the National Alzheimer's Coordinating Centre (NACC) neuropsychological test batteries. They have been widely used across memory clinics in the United States to assess memory in

individuals with memory complaints. However, The LM task consists of two stories, each scored out of 25 units. With only two-story versions available, it is unsuitable for studies requiring multiple valenced stimuli. The Craft-21 task, on the other hand, reportedly has 22 story versions available, according to the NIH working group (Beekly et al., 2004). However, the accessibility of these versions to the general research community remains unclear, as they may have only been presented to the working group and not made publicly available.

The working group also reported that the 22 versions of the Craft-21 task were validated using a pilot study on younger adults and were matched for equal difficulty, comprehensibility, and memorability. However, the lack of publicly available data makes it difficult for researchers to independently assess the suitability of these stories for their specific study requirements. Furthermore, out of the 22 versions, the working group determined that only three were most closely related to the LM task. Of those 3, only one was chosen for the NACC test battery due to its appropriate content for NACC cohorts. The criteria used to make this judgment are unclear, raising concerns about the transparency and replicability of the selection process. In addition to the limitations mentioned above, both the LM and Craft-21 tasks are scored out of 25 units, which may not be sensitive enough to detect the subtle memory changes often seen in VCI, particularly when considering early impairment or prodromal stages. Given the lack of research on sleep-dependent consolidation in dementia, especially VCI, it is crucial to develop tasks that address the methodological concerns outlined and consider the specific factors concerning memory associated with VCI.

To address the concerns highlighted in this review relating to methodological considerations of emotional memory research with a specific focus on those with VCI, narrative memory tests should develop a story task that can be tested across multiple days to examine the impact of sleep on performance and account for natural variability in sleep. This requires multiple story sets with positive, neutral, and negative valences, piloted with transparent data to ensure equivalency in memorability, difficulty, comprehensibility, and appropriate valence. These sets should be more sensitive to capture subtle changes in memory for those with VCI. To account for individual differences, story tasks require multiple versions of the same valence for testing across multiple days and enabling within-participant testing.

3.2.4 Aims of the Chapter

The first aim of this chapter is to develop a novel story task, building on and incorporating the three stories developed by Reid et al., (2022) to create a total of 12 stories (positive, neutral, and negative) with four story versions per valence. The stories will be piloted using healthy younger adults and matched for equivalency in terms of being equally memorable and difficult and rated as appropriately valenced. Moreover, the scoring system will be amended from Reid's in developing the narrative tool, increasing the number of scored words, thus enabling better sensitivity in memory assessment. Once piloted and matched for equivalency, the second aim is that the stories will be used in a sleep versus wake within-participant crossover design using healthy young and older adults and individuals with VCI to determine sleep-dependent memory effects and emotional sleep-dependent memory effects. It is important to note that the increased sensitivity of the story tasks results in longer scoring times. Considering the potential clinical utility of the tool in research and for assessing subtle memory deficits, lengthy scoring times may reduce the likelihood of the tool's adoption. To address this issue, an final aim of this chapter is to develop, pilot, and demonstrate the use of an automatic scoring tool using Python. This tool will enable researchers to quickly, accurately, and efficiently score lengthy recalls.

The chapter is structured as follows:

1. Study 1: A set of 9 stories (3 positive, 3 neutral, and 3 negative) will be developed, piloted, and matched for equivalency. The results will be presented and discussed.
2. Study 2: An additional 3 stories will be developed, totalling 12 stories (4 positive, 4 neutral, and 4 negative), to account for day-to-day variability and the potential for multiple days of testing. These stories will be piloted, and the full method, results, and discussion will be presented.
3. Study 3: 9 stories will be tested on 24 young adults using a within-participant design over 3 days to determine emotional sleep-dependent memory consolidation for narratives. Day 1 will serve as a practice session, and on the following day, participants will be randomly allocated to either a sleep-first or wake-first condition in

a counterbalanced crossover design. Participants will complete initial and delayed recall to determine a measure of forgetting. They will read, evaluate, and recall the stories during each testing session.

4. Study 4: In response to the longer scoring times found in Study 2, the development and evaluation of a novel automatic scoring tool will be presented, outlining how it was developed, amended, and improved. The tool's functionality and data concerning its accuracy and efficiency compared to manual scoring will be discussed.
5. Study 5: It was intended for 24 healthy older adults (HOAs) to complete the study, following the same protocol as in Study 4. This group would serve as a comparison for individuals with vascular cognitive impairment (VCI). However, significant methodological issues arising from COVID-19 disruptions meant that older adults struggled to complete the study online, resulting in only 4 completed participants presented as case studies. Methodological issues are discussed in Chapter 7 in response to these challenges. Moreover, a study involving 50 older adults with vascular dementia (VaD) was planned to follow the same protocol as Studies 4 and 5, in collaboration with researchers in Saudi Arabia. Stories were translated into Arabic, and ethical approval was obtained from King Abdul-Aziz University Hospital and Swansea University. However, the study could not commence within my candidature period due to recruitment delays. This will form part of the discussion in Study 5.

3.3 Pilot Study 1

3.3.1 Method

3.3.1.1 Participants

Participants were 12 psychology students from Swansea University (7 women) aged between 18 and 25 (mean age=21.34, SD=2.1). All participants were native English speakers, with normal or corrected-to-normal vision and had no history of psychiatric, neurological, or sleep-related disorders and were non-smokers. Participants were conveniently recruited; eleven were recruited via advertising within a university participant pool and were awarded participant pool credits for their participation. One participant was recruited by word-of-mouth from a postgraduate cohort. Ethical approval was obtained Swansea University's Psychology Department Research Ethics Committee (Ethics number=4898).

3.3.1.2 Materials

A total of 9 short stories were presented to participants using Qualtrics. The texts differed in their emotional tone (valence); 3 were positive, 3 were neutral and 3 were negative. Moreover, 3 of the texts were drawn from a previous study by Reid et al., (2022). The remaining six stories were developed for this study.

Table 23: Stories Developed for Pilot Study 1 with Corresponding Authors

Story	Valence	Author
The Birth	Positive	Reid et al.,
The Date	Neutral	Reid et al.,
The Dental Exam	Negative	Reid et al.,
The Paris Trip	Positive	Tulip
The Cinema Trip	Neutral	Tulip
The Skateboard Race	Negative	Tulip

The Radio Contest	Positive	Tulip
The Car Purchase	Neutral	Tulip
The Work Meeting	Negative	Tulip

The texts developed for this study aimed to address some limitations of the Schürer-Necker emotional texts (Schürer-Necker, 1994), while adopting a similar framework. The Schürer - Necker texts have been used in sleep studies (Wagner et al., 2001, 2006), however they lack positive valence stories and are written exclusively in German with varying narrative styles. Additionally, the negative story contains graphic content featuring rape which inappropriate for many study populations. To build on this prior work, the current texts were modelled after those created by Reid et al. (2022). The texts include positive, neutral and negative stories with comparable third-person, linear narratives and, in accordance with those created by Reid et al., buffer sentences were added to the beginning and end of each story to minimise primacy and recency effects. The texts were matched on key characteristics including total words, scored words (excluding buffers), and number of sentences.

Table 24: Total Word Count, Number of Sentences, Scored content and Total Buffer Words
Per Story

Story	Valence	Total Word Count	Sentences	Unscored buffer words	Scored content words	Total Scored Words	Developed by
Hospital Visit	Positive	162	11	14	80	94	Reid et al.,
The Dental Exam	Negative	162	11	17	78	95	Reid et al.,
The Date	Neutral	162	11	18	69	87	Reid et al.,
The Cinema	Neutral	162	11	15	79	94	Tulip et al.,
The Job Interview	Negative	161	11	18	78	96	Tulip et al.,
Buying a Car	Neutral	161	11	15	83	98	Tulip et al.,
The Contest	Positive	161	11	13	83	96	Tulip et al.,
The Paris Trip	Positive	162	11	16	72	88	Tulip et al.,
The Skateboard Race	Negative	160	11	11	79	90	Tulip et al.,

The texts developed for this study are as follows:

The Cinema Trip

Jemma and her friend Beth are making plans for the evening. The pair decide to go to the cinema to watch a documentary about space engineering. It is raining so the women decide to wear waterproof coats on the way to the cinema. In the queue, Beth sees a poster for the film which shows a team of people working at computers in a command centre. A cinema worker wearing a red and blue striped shirt ushers the women to screen number 8. The opening scene

shows a rocket being propelled into space. Suddenly, the screen goes black and the audio for the film cuts out. A message appears on the screen informing the audience that there is a technical difficulty. Jemma and Beth walk to customer service and are told that they can attend another viewing in 10 minutes. The pair agree to go to the second viewing. After the film, the women head home chatting about parts of the film.

The Work Meeting

Sarah is a marketing assistant at a large graphic design firm. The company usually holds group meetings on Monday's at 9 am. Instead, the head of the company, Jack, asks to meet with her alone. Sarah is worried as she knows she has not been performing well. Jack walks Sarah to his office and puts her employee file on a glass table. He pulls out her record from the file and says she has not met her targets for the last six months. Sarah fills up with tears and Jack angrily asks her why she should deserve another chance. Jack has no sympathy for her and tells her that because she has not improved since her last warning, she is being fired immediately. Sarah feels sick and worries about paying her rent. Jack firmly instructs Sarah to collect her things and leave. On her way out, she calls her best friend Rosie and plans to meet her at a local pub.

The Car Purchase

Grace wants to use her savings to purchase a used car. She looks online and finds a small blue car with low mileage. She books an appointment to view the car on Saturday at 9 am. When Saturday arrives, Grace catches a train and then a bus to a small housing estate. Grace knocks on a door and meets a middle-aged woman with blonde hair called Sandra. Sandra asks Grace to wait outside whilst she collects the keys to the car so that they can both go for a test drive in the car. The pair drive to the local shops. Grace notices that the air conditioning does not work and asks Sandra if this can be fixed. Sandra gives the name of a small local business which repairs air conditioning for a low cost. Satisfied with the car, Grace agrees to purchase the car and drives home. Once home, Grace makes a hot cup of tea and calls her father.

The Radio Contest

Emma begins her commute in the car after a long day at work. She puts on her favourite radio station, Sun FM. The radio host tells listeners that it is time for a competition. Listeners must identify two songs in a row that are only played for two seconds each. Emma recognises both and calls the station immediately. Surprisingly, Emma is connected straight away and the host asks her for her answers. With both correct, the host congratulates her and tells her she has won the biggest prize the station has ever given away – a huge cash prize and a luxury holiday to Bali. Thrilled, Emma starts crying and thanks the host. Emma tells the host that she will spend some of the money on a new car and kitchen and will be able to save the rest. The host congratulates her again gives her instructions about how to collect her prize. Emma calls her husband to tell him the news.

The Paris Trip

Bella has earned some holiday allowance at work and books a short trip to Paris. After landing at the airport, she gets a taxi to her hotel and brings in her bags. Strolling around the centre of the French city, Bella spots an old school friend that she hasn't seen in years. She shouts to her old friend who turns around with a warm smile. Bella runs along the cobblestone street excitedly and embraces her friend. Grinning, the women are both shocked and surprised that they have bumped into each other in Paris. Her friend is very pleased to see Bella and is eager to tell her about her life since school. The pair decide to go to a wine bar and catch up over dinner. They tell each other fond stories of their childhood, laughing over funny stories. Later, they part with plans to meet up the next day. Bella hails for a taxi to take her back to her hotel.

The Skateboard Race

Josh decides to meet his friends at a park. His friend, Billy, invites him to race down a steep hill on their skateboards. Josh makes a quick start and is in the lead. As he gets faster, his board starts wobbling and suddenly slips from underneath him. Josh crashes to the ground and painfully slides over concrete, shredding his jeans. Coming to a stop, Josh feels a strong jolt of pain in his leg which is covered in blood. He tries to wipe some of the blood away to see where it is coming from and notices a large white lump in the middle of his shin. Josh screams as he realises his bone is poking out through his blood covered jeans. He calls for Billy who rushes over and gasps at the sight of his broken and bloody leg. Billy frantically

calls for an ambulance and tries to keep Josh calm. Billy is silent and waits patiently with Josh.

Evaluation Rating Matrix

To evaluate the stories according to specific factors using in the study by Reid et al., (2022) and Wagner et al., (2001), the following rating matrix was used to ensure that the stories were evaluated using the same metrics. Participants evaluated the stories in the same way using the 11-item, 7-point scale ranging from -3 to 3.

Figure 18: Rating Matrix Used to Evaluate Narrative Texts

	Rating Score							
	-3	-2	-1	0	1	2	3	
Incomprehensible								Comprehensible
Uninteresting								Interesting
Difficult								Easy
Neutral								Emotional
Unrousing								Startling
Unimportant								Important
Abstract								Concrete
Serious								Amusing
Boring								Arousing
Unfamiliar								Familiar
Negative								Positive

3.3.1.3 Design and Procedure

The study used a within-subject cross-sectional design. Participants completed the study procedures using Qualtrics surveys that were sent via email links. The study took place over 3 consecutive days. Each day, participants received 3 emails spaced throughout the day, morning (10am), afternoon (2pm) and evening (6pm), containing links to the Qualtrics

surveys. Each survey contained 3 stories, one positive, one neutral and one negative that participants completed one after the other. For each story, participants were given 3 minutes to read and remember the story. Afterwards, participants completed a 7-point rating matrix to evaluate the text on 11 dimensions. At this point, participants had to wait a minimum of 40 seconds before proceeding to a free recall tasks. This was to ensure participants did not rush the evaluation procedure. During the free recall tasks, participants typed a word-for-word account to the best of their ability, which was untimed. This process was then repeated until participants completed all 3 stories contained in a single link.

The presentation of the texts was counterbalanced across participants such that each participants read a one positive, one neutral and one negative story in each link, in a randomised order. Free recall responses were scored by calculating the percentage of correct words recalled out of the total scorable words in the original text. Synonyms of target words were counted as correct, as were different tenses and contractions of target words.

3.3.2 Analysis

To examine whether the stories differed in memorability and across the evaluation rating matrix based on their emotional valence and specific story version within each valence, a series of 3 (Valence: Positive, Neutral, Negative) x 3 (Story Version: 1, 2, 3) repeated measures ANOVAs were conducted. These were conducted on both the memory scores (percentage of correct words recalled) to determine memorability, and then were conducted on each of the 11-point rating matrix to determine whether the valences or versions differed according to each factor on the evaluation matrix.

3.3.3 Results

3.3.3.1 Memory Score

In terms of memory score, a 3x3 repeated measured ANOVA was conducted. Recall means (SE) measured in percentage of correct words recalled over the total number possible for each story were as follows: Negative story, mean = 48.72 (2.34); Neutral story, mean= 45.25 (2.63) and; Positive story, mean = 47.33 (2.62). Assumption checks confirmed that there was no violation of sphericity. The results showed that there was no main effect of valence of memory score, $F(2,22)=1.145$, $p=0.34$. Similarly, there was no main effect of version of memory score, $F(2,22)=1.08$, $p=0.36$ and no interaction between Version and Valence on memory score, $F(4,44)=2.36$, $p=0.07$. Overall, these results show that memory performance did not differ across valence or version, suggesting that the narratives were equally memorable.

3.3.3.2 Text ratings

Texts were rated by the 12 participants on 11 dimensions using a 7-point scale (-3 to 3). A series of 3 by 3 repeated-measures ANOVAs were conducted on these ratings using with the within participant variables of Valence and Version. Where assumptions of sphericity were violated, a Greenhouse-Geisser correction was applied. The rating matrix indicates that the texts were deemed to be equally matched on several key characteristics, while different on dimensions intrinsic to emotional valence manipulation. The stories showed no differences among versions on all dimensions suggesting that all versions were matched according to all 11 factors. Across valences, the stories showed no differences in familiarity, difficulty or comprehensibility. Moreover, the stories differed significantly on emotionality and valence ratings such that evaluations matched intended valence and emotionality (e.g. positive-positive, negative-negative, neutral-neutral). According to valence, the negative text was rated as more interesting, emotional, arousing, concrete, serious and boring than the other texts. These findings are similar to those found in studies by Reid et al., (2019) and Wagner et al., (2001) and are considered intrinsic to valence manipulation. Additionally, the positive texts were rated as more important and having a stronger valence than the other texts.

Table 25: Results of Repeated Measures 3x2 Factorial ANOVAs, Including Assumption Test Statistics and Post-hoc Comparisons

	Negative		Neutral Text		Positive		F(2,22)			P			Sphericity	Comparisons
	M	SE	M	SE	M	SE	Valence	Versi on	V*V	Valence	Version	V*V		
Comprehensibility	1.556	0.329	1.61	0.286	1.916	0.253	1.239	1.264	1.144	0.31	0.30	0.35	YES	
Interestingness	1.222	0.237	-0.72	0.3252	0.333	0.352	16.970	0.405	3.211	<.001	0.67	0.02	YES	Neg>Pos>neutral
Difficulty	0.833	0.254	0.86	0.021	1.278	0.252	2.457	2.496	2.426	0.11	0.11	0.07	YES	
Emotionality	1.333	0.228	-1.47	0.223	0.222	0.389	53.794	2.568	1.769	<.001	0.10	0.15	YES	Neg>Pos>Neutral
Arousal	1.111	0.264	-1.55	0.202	-0.36	0.311	19.557	0.872	3.324	<.001	0.43	0.21	YES	Neg>Pos>Neutral
Importance	0.333	0.432	-1.25	0.2756	-0.27	0.430	12.322	0.048	2.225	<.001	0.95	0.08	YES	Neg>Pos>Neutral
Concreteness	1.000	0.298	0.528	0.337	0.611	0.317	3.876	1.043	0.463	0.04	0.37	0.76	YES	Neg>Pos>Neutral
Seriousness	-1.02	0.354	-0.277	0.2386	0.167	0.282	7.735	0.933	6.689	0.01	0.41	<.001	NO	Neu>Pos>Neg
Boringness	0.977	0.264	-1.278	0.242	-0.11	0.332	19.557	0.872	3.239	<.001	0.43	0.02	YES	Neutral>Pos>Neg
Familiarity	0.417	0.228	-0.027	0.251	0.417	0.305	0.874	2.985	4.447	0.43	0.07	<.001	YES	
Valence	-1.77	0.144	0.3611	0.166	2.111	0.264	126.453	2.171	2.76	<.001	0.16	0.04	YES	Pos>Neg>Neut

3.3.4 Discussion

This pilot study aimed to develop and standardise a set of emotional and neutral texts for use in future research, ensuring that they were comparable in terms of difficulty, memorability, and comprehensibility, irrespective of their intended valence. Crucially, adding six newly developed for use in conjunction with three developed by Reid et al., (2022) would enable future studies to employ within-participant designs using sleep-first or wake-first crossover designs over multiple days. The results of this pilot study indicate that the texts were equally memorable and were perceived with similar levels of difficulty and comprehensibility. Moreover, the subjective ratings confirmed that the positive, neutral and negative stories matched their intended emotionality and valence. These characteristics are essential for exploring sleep-dependent emotional memory consolidation.

Consistent with Reid et al.'s (2022) findings, negative texts were rated more arousing, interesting, and important than neutral and positive texts. This likely stems from their perceived highly negative valence, as more extreme valences are associated with higher arousal (Kousta et al., 2009; Guasch et al., 2016). Specifically, the relationship between arousal and valence is stronger for unpleasant versus pleasant stimuli, with unpleasant words showing less variability in arousal (Vieitez et al., 2021). Additionally, negative texts being perceived as more important aligns with the automatic vigilance hypothesis whereby unpleasant stimuli receive attentional priority due to their potential threat value (Pratto & John, 1991). This negativity bias is supported by evidence showing faster recognition of negative versus neutral words (Kanske & Kotz, 2007), along with an inhibitory effect on processing speed unique to negative stimuli (Kanske & Kotz, 2007; Estes & Verges, 2008; Kuperman et al., 2014). As proposed by Vogt et al., (2008), preferentially assigning resources to unpleasant stimuli is explained by their significance as potential threats. Consequently, negative stimuli rated as arousing are also deemed more interesting and important, reflecting the automatic vigilance hypothesis. Reid et al., (2022) also found that negative texts were rated as more arousing, important and interesting in their study, but the observed characteristics may be inherent to valence manipulation. Despite this, the consistent scores across the difference valence indicate that these intrinsic characteristics did not affect the memorability of the texts.

Moreover, all texts were rated as equally difficult. Thus, despite inherent differences between valences, the comparable memory and equal difficulty enable the texts to isolate the effects of sleep on emotional memory consolidation without the confounding influence of varying memorability due to emotional content. In conclusion, the characteristics within these texts indicate they are suitable for research on sleep-dependent memory consolidation using within-participant designs.

3.4 Pilot Study 2

3.4.1 Introduction

The previous pilot study, which involved the development and validation of 9 short stories with positive, neutral, and negative valence, validated a narrative tool for studying emotional memory. A separate team within the university sought to use this tool to investigate how dietary choices, specifically sugary drinks, impact insulin sensitivity, sleep quality, and memory. To meet the unique needs of this interdisciplinary collaboration, an expansion of the narrative set was necessary as the team required an additional day of cognitive testing. Thus, 3 new additional stories were developed, creating a set of 12 short stories (4 positive, 4 neutral and 4 negative). This extension is designed to enhance the capacity of the narrative tool to examine sleep and memory dynamics across multiple conditions, including a familiarisation night, two study nights under varying dietary influences, and a wake condition for comparison.

The development of the 3 new stories will follow the criteria established in the original pilot study and the framework provided by Reid et al., (2022), aiming for consistency in terms of memorability, difficulty, and intended valence across stories. The aim of this second pilot study is to develop and validate these additional stories for use in varied research settings, demonstrating the adaptability and effectiveness of the narrative tool in addressing diverse hypotheses and study designs, especially those involving multiple nights of testing.

The potential of this study is particularly relevant to dementia research, where day-to-day and week-to-week variability in performance is of significant interest in VCI (Sachdev et al., 2019). This variability is pertinent to both sleep, where day-to-day fluctuations have been observed across research cohorts including older adults and those with dementia, and cognition, where variability in day-to-day and week-to-week performance is also present (Van Someren, 2007; Kuan et al., 2022). Creating a research tool that allows for more testing days using a within-participant crossover design will enable future studies to examine this variability in more detail potentially accounting for intra-individual variability.

3.4.2 Method

3.4.2.1 Participants

Thirteen participants were recruited for the study, with 10 from Swansea University using participant pool, and 3 from the public through Facebook using convenience sampling. The participant's ages ranged from 19-68 years (Mean= 27.92, SD= 17.02). All participants were fluent English speakers with normal or corrected to normal vision and hearing and had no history of psychiatric, neurological, or sleep-related disorders. Participants recruited from university's participant pool received credits for their participation, while those from the public did not receive any compensation. Ethical approval for the study was granted by the Department of Psychology's Research Ethics Committee at Swansea University (4898).

3.4.2.2 Materials

Nine of the stories presented in Pilot Study 1 were used in this study. An additional 3 were developed for this study with one being positive, one neutral and one negative. The stories were identical to the prior 9 in terms of length, scored words, narrative style and incorporated buffer sentences to account for primacy and recency effects. The three additional stories developed are follows:

(Positive) The Birthday Present

Annie had just finished her last day of school at Woodfield Primary School. It was Annie's tenth birthday, so she was eager to return home to her family for celebrations. At home, there was a large, wrapped, multicoloured box placed in the middle of the living room with a bow on top. Her mother said she could open the present, so she rushed over in excitement and ripped off the wrapping paper enthusiastically. In the box, Annie saw a tiny Labrador puppy with large brown eyes. It was no bigger than a football. The puppy seemed very happy to see Annie as it wagged its little, white, tail and jumped up at her. She gently lifted the Labrador up into her chest and cuddled it. She cried joyously as the puppy licked her face excitedly.

Annie was so pleased as she had always wanted a dog. Annie's mother collected all of the discarded wrapping paper and put it into a black plastic bag.

(Neutral) The Return

Fiona was getting ready to go to town on a rainy afternoon. She needed to return some winter clothes and gardening tools that she had bought online on Friday, the week prior. She laid out her items on her living room floor, ready to package them. Fiona noticed that a thread from her carpet had become loose which created a loop that stuck out. She took her scissors and cut away the thread. One by one, she then put her items into plastic parcel bags and taped them closed. The only pen she could find to write the addresses was a large marker. Once she had packaged all of the items, she searched for her car keys, they were nowhere in sight. She lifted the sofa cushions to check underneath but still could not find them. Suddenly, she remembered that she had left them in the fruit bowl in the kitchen. After, Fiona got her coat and loaded her packages in the car.

(Negative) The Presentation

Richard was wearing a blue shirt and a black striped tie. He wanted to look smart as he was about to give a presentation to hundreds of people. He was feeling extremely nervous as he wanted to make a good impression on his colleagues. As Richard walked anxiously across the stage to begin his speech, he tripped on a loose cable and fell headfirst into the audience. He was in excruciating pain as the fall had caused his shoulder to dislocate. The audience laughed, not realising that Richard had seriously hurt himself. To make matters worse, the fall had caused a table to tip over spilling boiling, hot drinks over people. Richard then climbed onto the stage to continue his presentation in an attempt to improve the situation. However, he found it difficult not to cry due to the pain and embarrassment. Tearful, he apologised to his peers and left the stage. Richard immediately called his wife to ask her to collect him.

3.4.2.3 Design and Procedure

The study followed an identical design and procedure to study 1, with the inclusion of an additional study day. That is, a within-subject design where all participants read, evaluated

and recalled a total of 12 stories with different valences: 4 positive, 4 neutral and 4 negative. The study also followed the scoring protocol as outlined in Pilot study 1. The study took place over 4 days and was conducted using Qualtrics. Participants were sent links that were systematically released at equal times (10am, 2pm and 6pm). Participants were asked to read and remember a story which was displayed for 3 minutes, evaluate the story using the rating scale (in study 1) and recall the story by typing a word-for-word account of the story to the best of their ability.

3.4.3 Analysis

A series of 3 by 4 repeated measures ANOVAs were conducted to compare the effect of valence (positive, neutral and negative) and Version (1,2, 3, or 4; there were 4 story versions for each valence) on scores (percentage of correct words over total number of scored words) and text evaluation ratings.

3.4.4 Results

Table 26: Recall Means and Standard Error of the Total Score (%) for Each Story

Story	Valence	Total score (%)	
		Mean	Standard Error
The Hospital Visit	Positive	47.70	2.97
The Radio Contest	Positive	61.34	3.56
The Paris Trip	Positive	56.06	3.92
The Birthday Present	Positive	57.98	4.31
The Cinema Trip	Neutral	53.64	3.99
The Car Purchase	Neutral	58.42	3.62
The Date	Neutral	59.87	3.82
The Return	Neutral	52.43	4.52
The Dentist	Negative	55.88	4.53
The Work Meeting	Negative	59.46	3.48
The Presentation	Negative	55.35	3.95
The Skateboard Race	Negative	52.31	3.99

In terms of memory score means (SE, they were as follows: Negative story, mean = 55.75 (3.61); Neutral story, mean= 56.09 (3.31) and; Positive story, mean = 55.78 (3.01). There was no main effect of valence on scores for all 12 stories $F(2,22)=0.03$, $p= 0.96$, however, there was a main effect of version on recall scores $F(3,33)=4.83$, $p<.001$), suggesting that the versions were not of equal memorability. Additionally, there was a significant interaction between valence and version for all 12 stories [$F(6,66)=2.26$, $p=0.48$]. Consequently, 3 stories with the lowest scores from each valence category were removed (e.g. The Hospital Visit, The Return and The Skateboard Race).

Table 27: Recall means (SE) in Analysis 1, including all 12 stories, and recall means (SE) in Analysis 2

Analysis 1			Analysis 2		
Valence	Total score (%)		Valence	Total score (%)	
	Mean	Standard Error		Mean	Standard Error
Positive	55.78	3.01	Positive	58.47	3.59
Neutral	56.09	3.31	Neutral	57.31	3.28
Negative	55.75	3.61	Negative	56.90	3.58

Note 2: These reflect the removal of the removal of the lowest scores (e.g. The Hospital Visit, The Return and The Skateboard Race).

3.4.4.1 Recall Means

A 3x3 repeated measures ANOVA were conducted on the remaining 9 stories. As the assumption of sphericity was violated for valence, a Greenhouse-Geisser correction was applied and revealed no main effect of valence $F(1.34,14.77)=0.693$, $p=0.460$, suggesting that positive, neutral and negative stories were equally memorable. Similarly, there was no main effect of version on recall scores $F(2,22)=2.23$, $p=0.13$ and there was no significant interaction between valence and version $F(4,44)=0.95$, $p=0.08$. These results indicate that the 9 remaining stories are equally memorable according to both valence and version.

3.4.4.2 Ratings

To reflect the removal of 3 of the stories with the lowest scores, a series of 3x3 (valence x version) repeated measures ANOVAs were conducted on the ratings (Table 28). Where main effects or interactions were significant, post-hoc comparisons using a Bonferroni Correction were conducted. Moreover, for the purposes of analysis, values were recoded from the original scale ranging from -3 to 3 to a 1-7 scale. On this revised scale, lower values correspond to evaluations that were previously negative, while higher values represent those

that were previously more positive. The midpoint value of 4 on this scale represents a neutral midpoint between extremes

Table 28: Main effects and interactions of Evaluation ratings along with Sphericity checks and significant pairwise comparisons using a Bonferroni Correction.

	Negative Text		Neutral Text		Positive Text		F(2,22)		P				Sphericity assumed	Sig Comparisons
	M	SE	M	SE	M	SE	Valence	Version	V*V	Valence	Version	V*V		
Comprehensibility	6.14	0.25	6.00	0.29	6.00	0.29	0.92	0.024	0.21	0.40	0.98	0.93	N Y Y	None
Interestingness	5.33	0.28	3.11	0.25	4.64	0.29	44.41	0.72	3.20	<0.01	0.50	0.02	Y Y Y	Neg+pos>neu.
Difficulty	5.14	0.37	5.39	0.34	5.31	0.36	1.35	6.13	0.28	0.28	<.001	0.89	Y Y N	1>2
Emotionality	5.58	0.25	2.44	0.26	4.56	1.98	45.13	0.59	5.21	<.001	0.56	<.001	YYY	Neg>pos>neut V=not sig
Arousal	5.11	0.19	2.17	0.23	3.33	0.23	44.61	2.36	1.08	<.001	0.12	0.38	YYY	Neg>pos>neut
Importance	4.86	0.26	2.64	0.25	3.69	0.19	27.07	1.48	3.12	<.001	0.25	0.02	YYY	Neg>Pos>neut
Concreteness	5.06	0.29	4.78	0.37	4.81	0.27	0.94	1.24	0.83	0.40	0.31	0.52	YYY	
Seriousness	3.08	0.37	3.72	0.23	4.81	0.17	8.03	2.42	0.85	<.001	0.11	0.50	YYN	Pos>neg
Boringness	4.58	0.20	2.36	0.25	4.08	0.25	32.58	3.88	2.88	<.001	0.04	0.03	YYY	Neg+ pos>neut -no other sig diffs 1>2
Familiarity	3.67	0.26	4.25	0.43	4.25	0.30	2.67	0.00	1.59	0.09	1.00	0.19	YYY	
Valence	2.50	0.46	4.72	0.17	6.22	0.24	28.625	0.22	2.93	<.001	0.80	0.08	NYN	Pos> >neg>neutral
Relatable	4.69	0.32	4.89	0.24	4.39	0.22	0.76	6.70	2.15	0.48	<.001	0.14	YYN	3>1

Note: The column titled ‘Sphericity Assumed’ contains responses indicated as ‘Y’ or ‘N’. ‘Y’ represents a confirmation (yes) of sphericity assumed, and ‘N’ represents sphericity has been violated and a Greenhouse-Geisser correction is applied. The sequence of these codes corresponds respectively for checks for sphericity related to Valence, Version, and Interactions.

3.4.4.3 Ratings

Valence

In terms of the rating valence, there was a main effect of valence, but not version. Post-hoc comparisons revealed that negative texts were rated as negative, neutral as neutral and positive as positive with a significance difference between all such that positive was rated as most strongly, then negative and then neutral. This suggests that participants rated all texts as having the same valence as intended and versions did not differ.

Emotionality

A similar pattern was seen in the emotionality rating where there was a main effect of valence, but not version, with a significant difference between all 3 valences, as shown by post-hoc comparisons. However, the negative text was rated as more emotional, followed by the positive text and then neutral.

Arousal

In terms of the arousal ratings, there was a significant main effect of valence, but not version, nor a significant interaction. Post hoc comparisons revealed a significant difference between positive, neutral and negative, such that the negative was rated more startling followed by positive whereas the neutral texts were appraised as being the least arousing.

Interestingness

In terms of interestingness, there was a significant main effect of valence, but not version, and a significant interaction. Post hoc comparisons reveal that there was a significant difference between all 3 valences, such that the negative texts were evaluated to be the most interesting, followed by the positive text, and neutral was rated to be the most uninteresting.

Importance

There was a significant main effect of valence for importance rating, but not version, and there was a significant interaction. Similarly, post-hoc comparisons revealed that there was a significant difference between valences in the order that the negative text was rated as the most important followed by the positive and then the neutral.

Seriousness

There was a significant main effect of valence on seriousness ratings, but not of version, nor an interaction. Post hoc comparisons reveal that only the difference between positive and negative texts was significant, such that the positive texts were rated as more amusing than the negative texts, which were rated as more serious.

Boringness

There was a significant main effect of valence on boringness ratings, as well as a significant main effect of version and a significant interaction. Post hoc comparisons reveal that for valence, the neutral texts differed significantly to positive and negative, but the negative and positive texts did not differ significantly in terms of boringness. The negative and positive texts were appraised to be more arousing than the neutral. In terms of version, post-hoc comparisons revealed that version 1 within each valence was more arousing than version 2.

Difficulty

There was no main effect of valence on difficulty ratings, however there was a significant main effect of version, but not interaction. Participants perceived version 1 (The Radio Contest, The Cinema Trip, The Dentist) to be more difficult than version 2 (The Paris Trip, The Car Purchase, The Work Presentation). However, no significant difference in scores occurred suggesting that this difference in subjective difficulty did result in these stories being more or less memorable than each other.

Relatable

The relatability dimension was introduced following participant feedback, which indicated variability in how relatable different stories were perceived. For example, some participants specifically mentioned the dental exam story describing how they could vividly imagine themselves in the dental chair and falling victim to an inexperienced student dentist. They noted that the experience of learning and recalling the story felt visceral due to prior unpleasant experiences at the dentist. It was hypothesised that if a story was more relatable, it would be more memorable as it would have personal salience to the individual.

As such, the inclusion of relatability sought to investigate whether some stories are more relatable than others. The results reveal that according to Valence, all stories are equally relatable [$F(2,22) = 0.76, p = .48$]. However, there was a significant difference between story versions [$F(2,22) = 6.70, p = .005$]. Post hoc analysis with a Bonferroni adjustment revealed that version 3 for each valence was more relatable than version 1 ($p < .001$).

Comprehensibility, Concreteness, Familiarity

In terms of comprehensibility, concreteness and familiarity, there was no main effect of version, or valence, nor a significant interaction, suggesting that these subjective characteristics of the texts did not differ for valence or version.

3.4.5 Discussion

Building on the work of the initial pilot study involving 9 short stories, this additional pilot study was created in response to an interdisciplinary research need. The overall aim of the study was to broaden the methodological scope of the story task by developing and standardising 12 short stories, 4 positive, 4 neutral and 4 negative for use in future research requiring longer study durations. In addition to enhancing the applicability of the tool in wider research, the inclusion of an additional set enables an additional day of sleep-dependent testing. In terms of dementia research, this inclusion may be of particular use where day-to-day variability in cognitive performance is of interest.

The results of the study confirmed that after the removal of 3 stories, which could be used in a practice day and therefore unscored, the remaining 9 stories did not differ significantly in terms of memorability. Moreover, the texts were deemed to match their intended valence and emotional texts were perceived as appropriately emotional. Similar to findings in the original pilot study, negative texts and positive texts were perceived as more arousing than neutral, with the negative text being perceived as the most startling. All texts were deemed to be equally comprehensible. Moreover, intrinsic to valence manipulation, the perceived importance did vary across valences, but not versions, with negative and positive stories perceived as more important than neutral.

However, there were minor differences in the results seen in those of the original pilot. For example, whilst perceived difficulty was not different across valences, they did differ across versions meaning that some versions were perceived to be more difficult than others. Additionally, whilst relatability did not differ across valence, there were difference in how relatable some versions were perceived. As recall scores did not significantly differ across valences and versions, it appears that these disparities in difficulty and relatability did not affect the overall memorability of the stories.

This study involved creating 3 new stories, each designed to be in line with the framework created by Reid et al., (2022) and the original pilot study, to ensure equal memorability, difficulty and intended valence. Whilst intended valence and memorability was consistent across all valences and versions, some story versions were perceived to be more difficult than

others. Overall, these differences did not affect memorability, as there was no difference in recall scores across all texts. Thus, these 12 stories developed, with 3 for use as practice and therefore ungraded, demonstrate suitability for exploring sleep-dependent memory consolidation. This additional pilot study broadens the methodological scope of the story memory task, but also highlights how the expanded set of stories could be adapted for future research that might require longer study durations and allows research to use the tool in conjunction with designs that are more tailored to their specific hypothesis. This could be particularly useful in studies where the effects of interventions or variables over time are of interest.

3.5 Study 3: Examining the Effect of Sleep-Dependent Memory Consolidation on Emotional Memory Performance Using Narratives in Young Adults

3.5.1 Method

3.5.1.1 Participants

This study used a within-participant repeated measures crossover design, with sleep and wake conditions counterbalanced. Participants were 24 young adults aged between 18-25 (8= male, mean age= 23.04, SD age= 9.38), all of whom were students at Swansea University. All participants were native English speakers, with normal or corrected-to-normal vision and hearing. Participants had no history of psychiatric, neurological, or sleep-related disorders and were non-smokers. Participants were convenience samples recruited using a participant pool system and were awarded credits for their participation. Ethical approval for this study was obtained from the Research Ethics Committee at Swansea University (approval no. 4898).

3.5.1.2 Eligibility and exclusion criteria

Table 29: Eligibility and Exclusion Criteria

Inclusion	Exclusion
Native English speakers	Smokers
Aged between 18-25 years	Medications for sleep
No neurological, psychiatric or sleep disorder	Diagnosis of mental health condition
Good sleeper (fall asleep within 30 mins or less, SE of 70% or above	Moderate or above for depression (≤ 13), anxiety (≤ 9), and stress (≤ 19) as scored by the DASS-21 short form questionnaire

3.5.1.3 *Materials and Procedure*

Questionnaire	When Used	Reason for Use
Pittsburgh Sleep Questionnaire Inventory (PSQI; 2 items, SE + SL)	Screening	Test for good sleeper
DASS-21- short form	Screening	No mood disturbances
Morning-Eveningness Questionnaire (MEQ)	Equivalency	Distribute chronotypes over groups evenly
Napping Behaviour Questionnaire (NBQ)	Equivalency	Distribute nappers evenly
Epworth Sleepiness Scale (ESS)-trait	Equivalency	Even trait sleepiness across groups
Stanford Sleepiness Scale (SSS)-State	Equivalency	Even state sleepiness across groups and testing sessions
Stories	Testing	Evaluate sleep-dependent narrative memory
Evaluation Matrix	Testing	Determine subjective equivalency and appropriateness of stories

3.5.1.4 *Recruitment, Screening and Group Allocation*

Participants initially received consent forms and, upon returning these completed forms, were asked to fill out a screening questionnaire. This screening process involved assessing sleep quality using the Pittsburgh Sleep Quality Index (PSQI; Buysse et al., 1989) with criteria including taking no more than 30 minutes to fall asleep and maintaining a Sleep Efficiency (SE) of 70% or higher. As the encoding, consolidation and retrieval process of memories have been shown to be susceptible to factors like stress (Trammell & Clore, 2014; Meir Drexler & Wolf, 2017), depression (Hornung et al., 2008) and anxiety (Kizilbash et al., 2002) participants were screened for mood disturbances using the Depression, Anxiety and Stress Scale-21 short form questionnaire (DASS-21; Lovibond & Lovibond, 2011). This ensured the inclusion only of individuals with scores indicating mild or no symptoms of depression (≤ 13), anxiety (≤ 9), and stress (≤ 19). Moreover, as nicotine has been shown to temporarily increase

cognitive functioning (Campos et al., 2016), such as components of attention and memory, and withdrawal has been shown to disrupt cognitive performance (McClellon et al., 2016) and nicotine affects sleep quality (J.-T. Liu et al., 2013), criteria also excluded smokers. Additionally, participants were required to have no history of psychiatric, neurological, or sleep-related disorders.

Eligible participants were then required to complete the Morning-Eveningness Questionnaire (MEQ; Adan & Almirall, 1991) and the Napping Behaviour Questionnaire (NBQ; Lovato et al., 2014). These questionnaires were used to identify participants' chronotypes and napping habits, respectively, ensuring an even distribution of chronotypes and napping preferences across groups (i.e. sleep-first or wake-first) during the study's counterbalancing phase. This group allocation process was designed to minimise potential confounding variables related to sleep patterns and circadian rhythms.

3.5.1.5 Story Sessions

Participants read, evaluated, and recalled 9 short stories across 3 testing sessions over 3 days. Day 1 was an unscored practice day to familiarise participants with the study protocol and address any questions. Days 2 and 3 were scored sessions. All stories were presented using Qualtrics with stories being available in both text and audio formats. This allowed participants to simultaneously read and listen to the stories, enhancing accessibility and engagement.

During each session, participants were given 3 minutes to read and memorise a story. Immediately after, they evaluated the story using the evaluation matrix. Subsequently, participants completed an untimed free recall task, where participants were asked to verbally recall the story to the researcher. This procedure was repeated for 3 stories in each session so that participants completed 1 positive, 1 neutral and 1 negative story each session. Twelve hours after the initial recall, participants were asked to recall the same stories to get a delayed recall, before proceeding to learn and recall 3 new stories. Thus, participants completed both an initial and delayed recall for a total of 9 short stories, 3 from each valence category, across 3 days.

Participants were randomly assigned to either a sleep-first or wake-first group to examine the effect of sleep on memory recall. Those in the wake-first group started their sessions in the morning and performed their delayed recall 12 hours later in the evening, thus having a wake-filled interval. Conversely, participants in the sleep-first group began their sessions in the evening, with the delayed recall taking place 12 hours later, after a sleep-filled interval. All participants completed both sleep and wake conditions. To accommodate individual chronotypes, participants were given the flexibility to choose their testing times, provided they kept to a strict 12-hour interval between sessions and maintained these times across all testing sessions (e.g. 9am/9pm, 10am/10pm).

A randomised counterbalancing strategy was used to ensure an even distribution of chronotypes and nappers/non-nappers between sleep-first and wake-first conditions. The order of sleep-first and wake-first conditions was also counterbalanced to avoid sequence effects. Additionally, as there were two versions of each story valence, the allocation of story versions was balanced so that half of the participants received each set 2 first, and half received set 3 first. Finally, the sequence of story valence (positive, negative, and neutral) was counterbalanced, ensuring all possible order permutations were equally represented across the participant pool. This counterbalancing approach aimed to mitigate potential biases related to group condition assignment, story version assignment, and valence sequence.

Table 30: Participant Randomisation and Counterbalancing

Subject	Randomisation	Day 1	Day 2	SET 1	SET 2	Valence order
1	12	Sleep first	Wake second	2	3	ABC
2	4	Sleep first	Wake second	2	3	ACB
3	21	Sleep first	Wake second	2	3	BAC
4	2	Sleep first	Wake second	2	3	BCA
5	5	Sleep first	Wake second	2	3	CAB
6	11	Sleep first	Wake second	2	3	CBA
7	18	Sleep first	Wake second	3	2	ABC
8	9	Sleep first	Wake second	3	2	ACB
9	15	Sleep first	Wake second	3	2	BAC
10	16	Sleep first	Wake second	3	2	BCA
11	1	Sleep first	Wake second	3	2	CAB
12	7	Sleep first	Wake second	3	2	CBA
13	22	Wake first	Sleep second	2	3	ABC
14	13	Wake first	Sleep second	2	3	ACB
15	20	Wake first	Sleep second	2	3	BAC
16	24	Wake first	Sleep second	2	3	BCA
17	14	Wake first	Sleep second	2	3	CAB
18	10	Wake first	Sleep second	2	3	CBA
19	17	Wake first	Sleep second	3	2	ABC
20	23	Wake first	Sleep second	3	2	ACB
21	3	Wake first	Sleep second	3	2	BAC
22	8	Wake first	Sleep second	3	2	BCA
23	19	Wake first	Sleep second	3	2	CAB
24	6	Wake first	Sleep second	3	2	CBA

Note 3: (A=positive, B=neutral, C=negative)

3.5.2 Analysis

A series of analyses were conducted to compare memory consolidation across a period of sleep versus an equivalent period of wakefulness (12 hours) using JASP, (JASP, 2024). Specifically, this study examined whether sleep preferentially consolidates emotional narratives compared to neutral narratives. To ensure equivalency at baselines across the sleep-first and wake-first conditions, independent samples t-tests were performed to ensure that there were no differences in sleep quality, as assessed by the PSQI (specifically SOL and SE), chronotype distribution, as measured by the MEQ, daytime sleepiness (ESS) and trait sleepiness (SSS) between groups. A chi-squared test was also performed to determine an equal distribution of those who frequently nap compared to those who do not across conditions. To explore whether the texts were rated appropriately, a series of 3x2 ANOVAs (valence; positive, neutral, negative; version; story 1, story 2) were conducted across all rating variables. To evaluate sleep-dependent consolidation effects, a 3x2x2 repeated measures ANOVA was conducted. The factors included valence (positive, neutral and negative), condition (sleep and wake) and story version (version 1 and version 2). The dependent variable was the percentage change in recall performance of the content words (does not include buffer sentences) from T2-T1. Effect sizes are reported with partial eta squared for ANOVAs, Cohen's d for t-tests, and rank biserial correlations for Chi-Squared. Post hoc tests used Bonferroni corrections and alpha levels were set at $p < .05$.

3.5.3 Results

3.5.3.1 Equivalency

Table 31: Equivalency Statistics Including Assumption Checks

Test		Mean (SD)		p-value (Cohen's d/*rank biserial correlation)	Normality (shapiro-wilk)	
		Sleep-first	Wake First		Sleep-first	Wake-first
MEQ (independent t-test)		45.83 (11.44)	54.92 (10.75)	.06 (-.82)	.90 (p=.18)	.94 (p=.49)
PSQI	SE	91.08 (5.87)	87.78 (5.53)	.17 (.58)	.97 (p=.93)	.93 (p=.39)
	SOL	15.63 (8.13)	17.29 (8.88)	.65 (-.11*)	.78 (p<.001)**	.88 (p=.08)
NBQ		Napper=5, Non- napper=7	Napper=6, non- napper=6	.78		
ESS (independent samples t-test)		5.83 (3.07)	6.17 (2.95)	.79 (-.11)	.95 (p=.62)	.97 (p=.87)

Firstly, there were no differences between sleep-first (M=45.88, SD= 14.8) and wake-first (M=54.92, SD=10.75) groups in terms of chronotype distribution as measured by the MEQ, $t(22)=-2.00$, $p=.06$, Cohen's $d=-.82$. Similarly, there were no differences between groups according to the PSQI subscales such as Sleep Efficiency (SE) and Sleep Onset Latency (SOL). For SE, an independent t-test was used and found no significant differences between groups ($t(22)=1.42$, $p=.17$, Cohen's $d=.58$). For SOL, a Mann-Whitney U test was used because the homogeneity of variance assumption was violated. Similarly, there were no significant differences between groups for SOL ($U=64.00$, $p=.65$, rank biserial correlation =-

.11). Moreover, the proportion of participants who napped versus those that didn't were similar across conditions, $\chi^2(3, N=24)=1.09, p=.78$. Next, to ensure that trait sleepiness was even across sleep-first and wake-first groups, an independent t-test revealed that there were no differences between trait sleepiness, as measured by the Epworth Sleepiness Scale, $t(22)=-.27, p=.79$, Cohen's $d=-.11$.

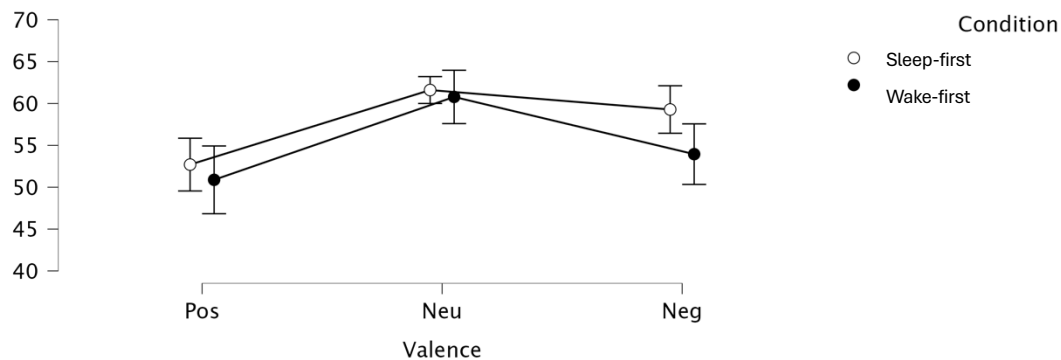
To determine whether state sleepiness (as measured by the Stanford Sleepiness Scale; SSS), measured at each testing session, differed across groups and testing sessions, a mixed ANOVA with a 2 (group: sleep-first vs. wake-first) $\times$ 3 (testing sessions; 1, 2 and 3). The assumption of sphericity was violated, $W(2) = .27, p = .04$, thus a Greenhouse-Geisser correction was applied ($\epsilon = .58$). The analysis revealed no significant between-subjects effect of group, $F(1, 6) = .03, p = .88$, partial $\eta^2 < .001$, indicating that subjective sleepiness scores did not differ between the sleep-first and wake-first groups. Similarly, there was no significant main effect of session, $F(1.16, 6.95) = 1.10, p = .34$, partial $\eta^2 = .016$, suggesting that subjective sleepiness scores were not different across testing sessions. Additionally, the interaction between group and session was not significant, $F(1.16, 6.95) = .83, p = .41$, partial $\eta^2 = .012$. These results suggest that subjective sleepiness did not significantly differ across both groups and testing sessions.

To account for Process S (time spent awake) given that those in the sleep-first condition have an additional 12 hours of sleep drive built up compared to those in the wake condition, two separate factorial repeated measures 2 (sleep-first versus wake-second; wake-first versus sleep second) $\times$ 3 (positive, neutral, negative stories) ANOVAs were conducted with the DV being % correct words recalled at initial testing. When comparing the wake-first, sleep-first group, the results showed no significant main effect of condition $F(1, 11)=1.85, p=.20, \eta_p^2=.14$, nor a main effect of valence $F(2,22)=1.85, p=.18, \eta_p^2=.14$, nor a significant interaction between condition and valence $F(2,22)=2.07, p=.15, \eta_p^2=.16$. This suggests that for this group, process S does not appear to have an effect on initial recall performance across the two conditions, nor across recall for valences.

When comparing the sleep-first, wake-first group, the results revealed that there was no main effect of condition $F(1, 11)=1.25, p=.29, \eta_p^2=.10$, suggesting that the additional sleep pressure built up at first testing did not have an effect on initial recall performance. However, there was a significant main effect of valence $F(2, 22)=4.64, p=.02, \eta_p^2=.30$. Post-hoc tests

using a Bonferroni correction revealed that recall for positive stories was significantly poorer than neutral stories (mean difference=-9.4%), $t(3)=-3.04$, $p=.02$, Cohen's $d=-.59$. There was no interaction between condition and valence $F(2, 22)=.25$, $p=.78$, $\eta_p^2=.02$.

Figure 19: Percentage of correct words recalled at initial recall for the sleep-first, wake-first group according to story valence (Positive, Neutral and Negative)



3.5.3.2 Text Ratings

A series of 3 by 2 repeated measures ANOVAs were performed to evaluate differences of story ratings across the 11 dimensions (see table 32). The results show that all texts were rated appropriately for valence (i.e. positive stories rated as positive) with no differences across versions. Similarly, positive and negative stories were rated as more emotional than neutral. All texts were rated as equally difficult, comprehensible and concrete irrespective of valence and version. Negative and positive texts were rated as more arousing than neutral. Neutral texts were considered more boring than positive and negative texts. Whereas positive and neutral texts were considered more serious than the neutral. All rating subscales did not differ across versions. These findings are in line with those found by Reid et al., (2020).

Table 32: Rating Matrices Results, Including Main Effects of Valence and Version and Interactions

	Positive Text		Neutral Text		Negative Text		F(2,94)			P			Sphericity assumed	Sig Comparisons
	M	SD	M	SD	M	SD	Valence	Version	V*V	Valence	Version	V*V		
Comprehensibility	6.31	.83	6.31	.85	6.27	.79	0.08	3.39	.59	0.92	0.07	.55	YN	
Interestingness	5.35	1.60	4.17	1.84	5.48	1.43	8.80	0.09	0.731	<.001	0.77	.44	YN	Pos>Neutral Neg>Neutral
Difficulty	5.69	1.49	5.39	1.23	5.04	1.82	2.87	.01	.43	.08	.91	.65	NY	
Emotionality	4.90	1.48	3.17	1.40	5.30	1.58	27.54	.056	1.02	<0.001	0.46	.37	YY	Neg>Neutral Pos>Neutral
Arousal	3.88	1.33	3.15	1.43	5.10	1.79	16.56	2.98	0.05	<0.001	0.10	.95	YY	Neg>Neutral Neg>Pos
Importance	4.04	1.32	3.17	1.34	5.29	1.37	28.25	.91	1.36	<.001	.035	.27	YY	Neg>Neu Neg>Pos Pos>Neu
Concreteness	5.33	1.42	5.02	1.73	5.38	1.36	1.20	0.66	0.12	0.31	0.43	0.88	YY	
Seriousness	5.06	1.51	4.13	1.25	2.77	1.98	21.00	0.97	3.87	<.001	0.34	0.03	NY	Neg>Pos Neg>Neu
Boringness	4.63	1.38	3.29	1.44	4.50	1.82	9.79	1.59	1.20	<.001	0.22	0.31	YY	Neu>Pos Neu>Neg
Familiarity	4.48	1.46	4.71	1.74	3.83	1.40	3.70	0.09	1.51	.03	.76	.23	YY	Neg>Neu
Valence	6.29	1.18	4.31	1.31	2.02	1.68	101.41	0.73	5.99	<0.001	0.40	0.51	YY	Pos>Neg Pos>neu Neg>Neu

*Sphericity assumptions were checked for Valence and Version, with respective columns indicating each in order (first column= valence, second= version). Y indicates sphericity assumed, N indicates a violation and a Greenhouse-Geisser correction is applied.

3.5.3.3 *Story Analysis*

Table 33: Descriptives (mean, SD, with measure of forgetting content words T2%-T1%)

Condition	Valence	Version	N	Mean (content T2-T1%)	SD
Sleep	Positive	1 (Radio)	12	-7.02	9.85
		2 (Paris)	12	-6.92	11.84
	Neutral	1 (Cinema)	12	-8.76	6.58
		2 (Date)	12	-6.44	5.44
	Negative	1 (Dental)	12	-4.28	6.27
		2 (Work)	12	-8.65	12.03
Wake	Positive	1 (Radio)	12	-12.15	11.56
		2 (Paris)	12	-7.91	9.4
	Neutral	1 (Cinema)	12	-13.65	9
		2 (Date)	12	-17.41	14.79
	Negative	1 (Dental)	12	-10.78	9.88
		2 (Work)	12	-9.43	12.3

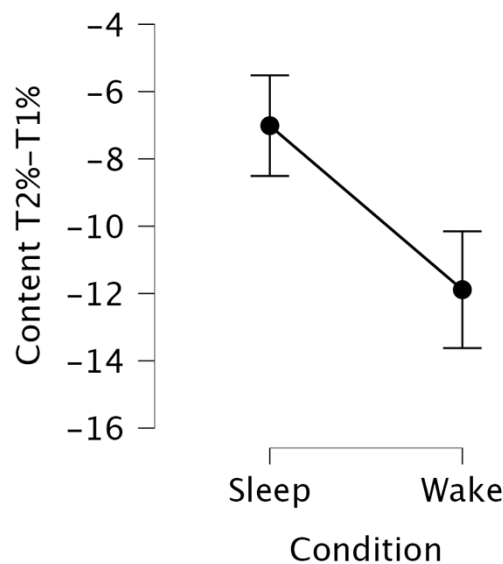
Table 34: Sphericity Checks for Main Effects and Interactions of Main Analysis

Factor	Mauchly's W	Approx. X²	df	p- value	Greenhouse- Geisser ϵ	Huynh- Feldt ϵ	Lower Bound ϵ
Valence	0.86	1.51	2	0.47	0.88	1	0.5
Condition * Valence	0.79	2.36	2	0.31	0.83	0.95	0.5
Valence * Version	0.86	1.56	2	0.46	0.87	1	0.5
Condition * Valence * Version	0.99	0.14	2	0.93	0.99	1	0.5

A 2 (condition: sleep vs. wake) x 3 (valence: positive, neutral, and negative) x 2 (story version per valence: 1 and 2) repeated measures factorial ANOVA was conducted. Sphericity checks confirmed that this assumption was met for all factors and interactions. The measure of forgetting, calculated as the difference in the percentage of correct content words from delayed recall to initial recall (where more negative values indicate greater forgetting), was used as the dependent variable. The analysis revealed a significant main effect of condition, $F(1,11) = 6.01$, $p = .03$, partial $\eta_p^2 = .35$. Post hoc analyses, adjusted by the Bonferroni correction and averaged across valence and version levels, indicated that participants in the wake condition forgot more content words than those in the sleep condition, with an average of 4.88% more content words being forgotten, $t(1) = -2.45$, $p = .03$, Cohen's $d = -0.47$.

Figure 20: Forgetting (T2%-T1%) Across Sleep and Wake Conditions

The analysis revealed no significant main effect of valence, $F(2, 22) = 1.37$, $p = .27$, $\eta_p^2 = .11$, indicating that the extent of forgetting was not influenced by the emotional valence of the stories in either condition. Similarly, no significant main effect of story version was observed, $F(1, 11) < .001$, $p = .99$, $\eta_p^2 = .11$, suggesting that the degree of forgetting was not different across different story versions. Furthermore, there were no significant interaction effects among the conditions: between condition and valence, $F(2, 22) = 1.17$, $p = .33$, $\eta_p^2 = .10$; between condition and story version, $F(1, 11) = .14$, $p = .72$, $\eta_p^2 = .01$; and between valence and story version, $F(2, 22) = .35$, $p = .71$, $\eta_p^2 = .03$. Additionally, the three-way interaction between condition, valence, and story version was not significant, $F(2, 22) = 1.58$, $p = .23$, partial $\eta_p^2 = .13$.



3.5.4 Discussion

Using a within-participant design, this study aimed to determine whether emotional narratives are preferentially consolidated across a full night of sleep, compared to an equal wake-filled interval compared to neutral texts on 24 young adults. Contrary to our hypothesis that memory performance for emotional texts would be superior in general and particularly for sleep conditions, we did not find an effect of valence on memory performance. However, in line with previous literature suggesting that sleep serves to boost declarative memory, we found that performance for participants after they had slept was superior to when they were awake, with the wake-condition forgetting on average 4.88% more content words than in the sleep condition, suggesting that sleep may have provided consolidation benefits (Takashima et al., 2006; Hu et al., 2006; Gais et al., 2007).

The literature on sleep-dependent emotional memory consolidation has highlighted inconsistencies in findings (Lipinska et al., 2019; Schäfer et al., 2020). A meta-analysis by Lipinska et al., (2019) highlighted key methodological considerations resulting in stronger associations between sleep and valenced materials. These included considering types of outcome measures, as free recall studies showed stronger associations. The second methodological condition that the meta-analysis highlighted as an important factor was whether studies used a measure of retention and controlled for initial learning, as studies that did not control for this did not find emotional enhancement of material across sleep. Thirdly, studies that used bi-valent stimuli (i.e. both positive and negative) in addition to neutral material showed a stronger emotional memory effect than studies that compared a single valenced category. As such, this study incorporated the methodological considerations by using bi-valent, free-recall and measures of forgetting (i.e. controlling for initial learning) as an outcome measure and using within-participant design, which mitigates between-participant differences. Thus, the finding that emotional texts did not confer a benefit from sleep in this young adult sample is surprising.

One potential explanation for the lack of an emotionality effect is that in this sample, the positive texts were rated as having a greater valence tone than the negative texts. Prior research has shown age effects on emotional memory consolidation, with younger adults exhibiting better memory for negative texts than positive texts following sleep (Jones, 2002; Huan et al., 2020). The socioemotional selectivity theory accounts for this by proposing that

younger adults are still learning and navigating life's challenges. Thus, it serves an adaptive function by having an inherent bias towards potential threat sources, such as negative stimuli (Carstensen et al., 1999, 2003). In contrast, older adults are biased towards more positive stimuli, as they prioritise emotional wellbeing and meaningful experiences due to their limited time horizon (Carstensen et al., 2003; Huan et al., 2020). Given this potential bias and considering that the negative stimuli were rated as having a weaker valence tone, this may account for some of the null effects of emotionality on sleep-dependent memory performance in our study. It is possible that the difference in valence tone between the positive and negative texts was not sufficient to elicit a strong emotional response, thus reducing the potential for selective consolidation of emotional content during sleep.

Interestingly, a study by Jones et al., (2016) examined the emotional bias of sleep-dependent processing across 51 healthy older adults (mean age=64.08) and 81 young adults (mean age=20.39). They found that compared with waking, sleep enhancement memory for positive but not negative pictures in older adults, but not young adults and negative but not positive pictures in young adults, in line with previous research. However, they also found that memory for neutral pictures was enhanced differentially such that in young adults, recognition of neutral pictures benefits from sleep when presented with negative but not positive pictures, and in older adults, recognition of neutral pictures benefits from sleep when learned with positive but not negative pictures. Thus, they suggest that the influence of emotional items may strengthen neutral stimuli as a byproduct of emotional enhancement during sleep, such that reactivations of emotional items may also have a 'bleed-over' effect. Given that our study found a general memory boost for all types of stimuli following sleep, regardless of emotional content, it's possible that a similar "bleed-over" effect occurred. The weaker valence ratings for negative texts may have reduced the potential for strong emotional responses, thus minimising the differential consolidation of emotional content during sleep. However, the general memory enhancement observed could still be beneficial, particularly for older adults and those with dementia.

A primary limitation of this study is the scoring of the narratives. As no previous studies have used a within-participant design using bi-valent narratives, this study sought to overcome this. However, nine narratives were required to achieve a within-participant design (3 for each valence per condition and an additional set of 3 for familiarisation day). Ultimately, this meant that with nine stories and around 120 words per story, a complete participant set could

give rise to a maximum of just over 51,000 words to be manually scored. Given that the scoring rules mean that synonyms are scored in the place of the target word and the exact word order does not matter so long as participants recall the content with its intended meaning, scorers must keep track of word order, potential synonyms and place-hold previously scored synonyms as some words appear more than once. This is highly cognitively demanding and is a lengthy process, resulting in the potential for human error. Scoring systems were created with tally charts and corresponding words to be ticked off to reduce error. However, the usability of this task remains limited due to the labour-intensive nature of scoring. Thus, future studies should aim to develop faster and more accurate methods of scoring to improve accuracy and reduce the researcher's burden.

This study, whilst not finding an emotional enhancement of sleep for emotional texts in young people, has found that sleep benefits declarative narrative memory. Given that the texts positive texts were rated as having a stronger valence, this may be of particular benefit to exploring the enhancement of emotional memory across sleep for older adults and adults with VCI as they show a bias towards positively toned information during sleep (Jones, 2002; Huan et al., 2020). Moreover, a potential 'bleed-over' effect found in prior studies suggests that even in the absence of emotional memory enhancement, these narratives may be a valuable tool in exploring memory issues in those with more pronounced impairment, such as Vascular Dementia, as the contextual emotional information may improve performance for neutral texts. Future studies should aim to enhance scoring efficiency and investigate whether emotional texts over neutral texts are preferentially consolidated in healthy older adults following sleep.

3.6 Study 4: Automatic Narrative Scoring Tool

3.6.1 Introduction

The task of scoring in the emotional memory study poses considerable methodological challenges, mainly because it is time-consuming, meticulous, and, as such, highly prone to human error. When scoring a typical sample size of 24 participants, each participant must recall nine different stories, which contain around 120 words. In a typical crossover design, which includes three testing days, including one familiarisation day, participants must recall each story twice, one initial recall and one after a 12-hour delay to measure memory deterioration. This is calculated as the percentage of correct responses at the initial recall minus the percentage of correct responses at the delayed recall ($T1\% - T2\%$). This procedure means that 432 stories are recalled across all participants, giving rise to a maximum of 51,840 (120 words $\times$ 2 $\times$ 9) words generated by the recall tasks. The researcher must then manually count these to identify the percentage of correct words recalled.

The sheer volume of words increases the potential for human error when manually counting recalled narratives. Moreover, the scoring protocol allows participants to recall target words out of order and accepts synonyms for target words, making the scoring process highly complex for several reasons:

1. Target word recurrence: Some target words appear multiple times within a story. The scorer must carefully count how many times the participant correctly recalls each target word, ensuring that all repetitions are accurately scored. For example, if the word 'house' appears three times in the original story, the scorer must track whether the participant correctly recalls the word "house" once, twice, or all three times, and adjust the score accordingly.
2. Non-sequential recall: Participants often recall words out of their original sequence. This requires the scorer to maintain a mental record of each target word's occurrences while simultaneously evaluating the rest of the passage for any further appearances. For instance, if the participant recalls a target word in the middle of the story at the beginning of their response, the scorer must remember this occurrence and continue searching for any additional instances of the word throughout the remaining response.

3. **Synonym allowance:** The scoring protocol accepts synonyms for target words, adding another layer of complexity. Scorers must continuously track previously scored words, their frequencies, and potential synonyms while ensuring that the count for each target word does not exceed the maximum limit. For example, if the target word is 'house', the scorer must also consider synonyms such as 'home', 'residence,' or "dwelling" when counting the participant's score.
4. **Cognitive load:** The scoring process demands significant attention to detail and imposes a high cognitive load on the scorer. It requires the meticulous management of multiple cognitive tasks simultaneously, such as tracking target words, their occurrences, and synonyms and ensuring accuracy in counting. This mental juggling act can lead to fatigue and increase the likelihood of human error.

Combining these factors makes the manual scoring process highly challenging and prone to human error. The scorer must maintain high focus and concentration throughout the process to ensure accurate results, which can be mentally taxing and time-consuming.

Thus, this scoring method's labour-intensive and error-prone nature significantly limits its practical application in narrative, emotional memory research and broader applications such as clinical settings. Given that research using narratives in emotional memory research is limited and that the potential to create tools with such high sensitivity to detect memory changes over time could be of clinical utility, these factors highlight a need for a more streamlined and efficient method of scoring narrative tasks to enhance their utility and reliability in the field. To overcome these challenges, this study introduces a novel automatic scoring tool, developed using Python programming to improve the speed and accuracy of narrative scoring. This tool aims to refine text data analysis in sleep and memory research, demonstrating its practical application and significantly improving the manual method. This study aims to validate this automated approach and showcase its feasibility in practical scenarios. The aims and objectives of the study are fourfold:

1. *Development:* the study aims to design and build an automatic scoring tool to streamline the scoring process by reducing human effort and error, thereby facilitating greater efficiency and accuracy.
2. *Functionality:* the study aims to explain how the tool works, describing essential features and functionalities. This includes how the tool identifies and counts target

words and synonyms within a given narrative and how the tool should be used to ensure maximum accuracy.

3. *Validation:* A core aim of the study involves evaluating the performance of this automated tool and, therefore, assessing its accuracy and reliability to provide evidence of its efficacy in scoring narratives. This assessment will involve testing the tool against manually scored narrative data and comparing the count outcomes.
4. *Potential Impact:* Lastly, the study aims to explore the implications of this tool within the memory research field. With the potential to detect subtle changes in memory over time due to the high sensitivity of the narratives, this tool may have significant applications in clinical settings, particularly in aiding memory assessments, where conventional assessments have lower sensitivity.

3.6.2 Development

3.6.2.1 Refining the Scoring Procedure

To develop an automatic scoring tool that is both efficient and accurate, a thorough evaluation of the existing scoring rules was conducted. This evaluation aimed to identify potential improvements that could enhance the tool's effectiveness in terms of target word identification and categorisation.

Previously, target words were initially identified using OneNote Immersive Reader. This software automatically identifies verbs, adjectives, nouns, and adverbs, marking them with different font colours and categorising them by their respective word classes (see fig 1.). This approach was chosen for its objectivity, offering a more reliable and precise method than manual text inspection for identifying target words.

Figure 21: A sample of The Dental Exam with class words automatically identified and coloured using OneNote Immersive Reader.

Once target words were identified, a list of synonyms were created using Merriam-Webster Thesaurus since synonyms of target words are accepted. The manual scoring rules were as follows:

- Exact target words receive 1-point.
- Synonyms of target words receive 1 point.
- Contractions of the target word or associated synonym receive 1 point.

- Suffix changes of target word or associated synonyms receive 1 point.
- The order and syntax of target words and associated synonyms do not matter.

Moreover, to avoid primacy and recency effects where items at the start and end of a list are more likely to be recalled than those the middle of a body of text (C. Li, 2009), the first and last sentences were scored separately from the main body of the text, giving rise to three separate scores: first sentence, main body and last sentence.

After reviewing the initial scoring procedure, copula and modal verbs will be removed from the scored word list. These include words like ‘and’, ‘are’ and ‘is’ (see figure 35 for full list). These words will be removed due to their contextual dependency which can lead to ambiguity in automatic detection. Consider the sentence: ‘A mother and her son are leaving home in the morning’. Here, ‘are’, functions as a copula verb and is identified as such by OneNote Immersive Reader, making it eligible for scoring. However, if the sentence is recalled as ‘A mother and her son leave home in the morning’ the essential meaning of the sentence is preserved. The primary change here is the verb tense (from ‘leaving’ to ‘leave’), which does not significantly alter the sentences’ overall meaning. Being as the scoring rules state that the tense does not matter, the inclusion of modal and copula verbs contradicts the total amount of potential scored words achieved by a participant recalling the story in another tense.

This adjustment in the scoring criteria aims to focus more on content that carries substantial meaning and reduce emphasis on elements that do not alter the content of the story. Equally, if these modal and copula verbs were left in the target list, participants could recall common words such as ‘and’ and ‘is’ and receive points, though they may not be recalled in the context of the stories meaning and therefore would inflate scores erroneously. Finally, the exclusion of words like ‘and’, ‘is’, and ‘are’ is beneficial because these words often form parts of other words. Their removal simplifies the detection and separation of complete words, enhancing the accuracy and efficiency of the automatic scoring process. A copula verb, or a linking verb, primarily serves to link the subject with the complement in a sentence. Since these verbs can be omitted without majorly altering the meaning, they are excluded from the recall score. Similarly, modal verbs, which express modalities such as likelihood, ability,

permission, obligation, and advice, are also omitted. The removal of these verbs does not significantly impact the overall meaning of a sentence or statement.

Table 35: Examples of Modal and Copula Verbs

Modal verbs	Copula verbs
Can	Be
Could	Is
May	Are
Might	Was
Shall	Were
Should	Been
Will	Being
Would	Seem
Must	Appear
Ought to	Become
Had/has	Look
	Feel

To demonstrate the impact of the revised scoring procedure, consider the case of the story titled ‘The Hospital’. Originally, the total word count for this story was 162 words, comprising of 14 buffer words (the combined score for the first and last sentences) and 78 content words, leading to a total of 92 scored words. However, with the exclusion of all modal and copula verbs, the revised count for ‘The Hospital Visit’ stands at 13 buffer words, 70 content words and 83 scored words in total. Despite the reduction, the text maintains a high level of sensitivity for scoring purposes.

This updated scoring method was systematically applied to all 12 stories in the study, resulting in new target word counts for each (see table 36). To ensure consistency with this updated approach, all recall data in the study were manually re-scored, taking the exclusion of modal and copula verbs into account.

Table 36: New Word Count for Stories

	Previous count				New Count				Total Change			
Story	First	Main	Last	Total	First	Main	Last	Total	First	Main	Last	Total
The Hospital Visit	5	80	8	93	5	73	8	86	0	7	0	7
The dental Exam	8	75	9	95	7	68	7	82	1	7	2	10
The date	8	69	10	87	6	61	9	77	2	8	1	11
The cinema	7	75	11	93	6	72	7	78	1	3	4	8
The Work Meeting	8	78	10	96	7	69	10	84	1	9	0	10
The Car Purchase	8	83	8	99	7	75	8	89	1	8	0	9
Radio Contest	7	82	5	94	7	65	5	78	0	17	0	17
The Paris Trip	10	72	6	88	9	63	6	78	1	9	0	10
The skateboard race	5	79	6	90	5	69	5	81	0	10	1	11
The Return	8	75	6	89	7	62	5	75	1	13	1	15
The Birthday Present	10	75	10	95	8	63	9	80	2	12	1	15
The presentation	8	81	6	95	7	67	6	81	1	14	0	15

In light of rescoring the texts to reflect the removal of certain words, a list of new synonyms for each of the 12 stories were created for each target word. Synonyms of target words were created using a combination of Thesaurus by Merriam-Webster (The Merriam-Webster Thesaurus, 2023), and Thesaurus.com (Thesaurus.Com, 2023) to identify associated synonyms.

3.6.3 Designing the tool

Python was chosen to develop the scoring tool for its versatility, open-source nature, and accessibility. Being open-source encourages collaboration and ensures adjustments can be made easily, which is beneficial for adapting the tool to future research needs. The core functionality required from the tool is the ability to count the presence and frequency of predefined target words and their associated synonyms within a given narrative. While counting word frequencies in a text is a relatively simple task, this tool would need to be more complex in order to account for the numerous features required by the scoring protocol. In building the automatic scoring tool, the following design considerations were prioritised:

1. **Text specification:** The tool should allow researchers to input a specific sample text for analysis.
2. **Target Word Count:** The tool must count all target words present in the sample text.
3. **Synonym Count Limit:** The tool should provide functionality that allows the researcher to set a maximum count for each synonym associated with a target word.
4. **Synonym Handling:** If the exact target word is not present in the text, then the tool should count an associated synonym in its place.
5. **Text Segmentation:** The tool should segment the text into three distinct parts: the first sentence, the main body, and the last sentence, producing separate counts for each.
6. **Output Visualisation:** To aid in visual inspection and validation:
 - a. The tool should print the full sample text and highlight all counted words and synonyms for visual inspection by the researcher.
 - b. The tool should print a list of all counted words and synonyms and number of occurrences these have been identified for cross-referencing against the highlighted print of the full text.

- c. All synonyms counted in the place of a target word should be labelled according to their associated target words as some synonyms are present across multiple target words.
7. **Order disregard:** The tool's design should ensure that it disregards the order in which the target words appear in the text, focusing purely on their presence and frequency.

3.6.4 Implementation and Functional Testing

3.6.4.1 Code Development

Based on the needs of the tool, the code first imports libraries from python for improved efficiency when counting and to add colour formatting to the text. These include 'defaultdict' from the 'collections' module and 'fore' and 'style' from the 'colorama' module, respectively.

Next, the code enables the researcher to input a sample text, such as a particular story by placing it inside the "text" = ' function. As python uses 'strings' to represent text data, which are comprised of sequences of text characters, the counting function is case sensitive, meaning that if a specific word is 'Mother', for example, and the string 'mother' is present in the sample text, it will not return the count of 1 because they are not the same strings. Therefore, the text in the sample narrative is converted into lower case to ensure consistent matching regardless of the original case. This also ensures that if researchers amend the sample narratives, then case entries will not result in an incorrect count.

To ensure that first sentence, main body and last sentence words produce separate counts, they have been separated into 3 separate sets; set 1 (first sentence), set 2 (main body), and set 3 (last sentence). Within each set, the specified target words and maximum count for that word and a list of synonyms with their respective maximum counts are housed. The code then counts each occurrence of each set of target words using the 'set1_count', 'set2_count', 'set3_count' function. To prevent any word from being over-counted and to ensure that the count does not exceed the predefined limit, the 'max_count' feature specifies within each how many times a word may be counted within each tuple. For example, in the 'Dental

Exam', the word 'father' appears twice in the original story. The tuple is set at a maximum count for the target word and corresponding synonyms as follows: '("father", 2, [("dad", 2), ("daddy", 2), ("pa", 2), ("papa", 2), ("poppa", 2), ("parent", 2)])'. If any further occurrences of the word 'father' are present in the sample text, they are not included in the final count.

The code then loops through each set and within each set, it loops through each word-synonym group. If a target word is found, it is then highlighted in a specific colour and printed in the output, depending on which set it belongs to. This was designed for easy identification of counted words from sets, to aid the researcher in determining a correct count per set. The sample story is finally printed with a total count for each set, along with highlighted colours.

3.6.4.2 First iteration of the code

```
from collections import defaultdict
from colorama import Fore, Style
```

```
# Sample text
```

```
text = "mother and son walking to victoria memorial hospital where the father works as a
laboratory consultant. they check before crossing a busy road. on the way the mother gets a
call from her sister who has just given birth. she tells her son that he has a new baby cousin
called Sophie. they race to the hospital and the son holds his new baby cousin, who is making
cute baby noises babbling and gurgling, she is happy bubbly and rosy, the nurses take a photo
of the smiling duo. the mum leaves her son with the aunt and father to go collect someone.
she caught the number 9 bus."
text = text.lower()
```

```
# Sets of target words and synonyms
```

```
set1 = [("mother", 1, [("mom", 1), ("parent", 1), ("mammy", 1), ("mam", 1), ("mommy", 1),
("mama", 1)]),
        ("son", 1, [("boy", 1), ("offspring", 1), ("child", 1), ("dependent", 1), ("junior", 1)]),
        ("leaving", 1, [("going", 1)]),
```

("home", 1, [("house", 1), ("residence", 1), ("abode", 1), ("dwelling", 1), ("lodging", 1)]),
 ("morning", 1, [("morn", 1), ("daybreak", 1), ("dawn", 1)])

set2 = [("taking", 1, [("taking", 0)]),
 ("visit", 1, [("see", 1)]),
 ("father", 2, [("dad", 2), ("daddy", 2), ("pa", 2), ("papa", 2), ("poppa", 2), ("parent", 2)]),
 ("workplace", 1, [("factory", 1), ("studio", 1), ("workshop", 1), ("plant", 1), ("works", 1),
 ("workroom", 1), ("work", 1), ("shop", 1)]),
 ("morning", 1, [("morn", 1), ("daybreak", 1), ("dawn", 1)]),
 ("laboratory", 1, [("laboratory", 0)]),
 ("technician", 1, [("specialist", 1), ("consultant", 1), ("professional", 1), ("expert", 1),
 ("operator", 1)]),
 ("victoria", 1, [("victoria", 0)]),
 ("memorial", 1, [("memorial", 0)]),
 ("check", 1, [("glance", 1), ("peek", 1), ("glimpse", 1), ("inspect", 1), ("audit", 1),
 ("examine", 1), ("survey", 1), ("scan", 1), ("scrutinise", 1)]),
 ("crossing", 1, [("traverse", 1), ("navigate", 1), ("cross", 1), ("walk", 1), ("travel", 1)]),
 ("busy", 1, [("buzzing", 1), ("vibrant", 1), ("crowded", 1), ("thriving", 1), ("humming", 1),
 ("lively", 1)]),
 ("road", 1, [("highway", 1), ("street", 1), ("throughfare", 1), ("freeway", 1),
 ("expressway", 1), ("route", 1), ("roadway", 1), ("boulevard", 1)]),
 ("walking", 1, [("treading", 1), ("walk", 1), ("strolling", 1), ("stepping", 1),
 ("wandering", 1), ("marching", 1), ("sauntering", 1)]),
 ("along", 1, [("forward", 1), ("on", 1), ("onward", 1), ("forth", 1)]),
 ("receives", 1, [("get", 1), ("gets", 1), ("recieves", 1), ("obtain", 1), ("gain", 1),
 ("acquire", 1), ("came by", 1), ("recieve", 1)]),
 ("phone", 3, [("dial", 3), ("telephone", 3), ("call", 3)]),
 ("call", 1, [("dial", 1), ("phone", 1), ("ring", 1), ("rings", 1), ("call", 1)]),
 ("say", 1, [("tell", 1), ("express", 1), ("state", 1), ("put", 1), ("describe", 1), ("saying", 1),
 ("say", 1), ("mention", 1)]),
 ("sister", 1, [("sibling", 1)]),
 ("given", 1, [("give", 0), ("giving", 1)]),
 ("birth", 1, [("labour", 1), ("deliver", 1), ("mother", 1), ("produce", 1), ("bore", 1)]),

("mother", 3, [("mom", 3), ("parent", 3), ("mammy", 3), ("mam", 3), ("mommy", 3),
 ("mama", 3), ("ma", 3)]),
 ("excitedly", 1, [("eager", 1), ("interested", 1), ("enthusiastic", 1), ("keen", 1),
 ("anxious", 1)]),
 ("told", 1, [("said", 1), ("told", 1), ("state", 1), ("report", 1), ("recount", 1), ("describe",
 1), ("narrate", 1)]),
 ("son", 1, [("boy", 1), ("offspring", 1), ("child", 1), ("dependent", 1), ("junior", 1)]),
 ("new", 1, [("novel", 1), ("fresh", 1), ("original", 1), ("newborn", 1)]),
 ("baby", 3, [("child", 3), ("infant", 3), ("newborn", 3), ("kid", 3), ("babe", 3), ("neonate",
 3), ("girl", 3)]),
 ("cousin", 2, [("relative", 2), ("family", 2), ("relation", 2), ("relative", 2), ("kin", 2)]),
 ("called", 1, [("dubbed", 1), ("named", 1), ("termed", 1), ("labelled", 1), ("nicknamed",
 1), ("titled", 1)]),
 ("sophie", 1, [("Sophie", 1)]),
 ("hospital", 2, [("clinic", 2), ("infirmary", 2), ("medical center", 2), ("medical centre",
 2)]),
 ("boy", 2, [("kid", 2), ("lad", 2), ("teenager", 2), ("adolescent", 2), ("son", 2)]),
 ("rushes", 1, [("hurries", 1), ("hurry", 1), ("scurry", 1), ("scurries", 1), ("trot", 1),
 ("speed", 1), ("sped", 1), ("travel", 1), ("drives", 1), ("flies", 1), ("chase", 1), ("race", 1),
 ("jump", 1), ("zip", 1), ("run", 1), ("buzz", 1)]),
 ("auntie", 2, [("aunty", 2), ("aunt", 2)]),
 ("bedside", 1, [("bed", 1)]),
 ("time", 1, [("moment", 1), ("occasion", 1), ("minute", 1), ("second", 1)]),
 ("yawned", 1, [("yawn", 1)]),
 ("making", 1, [("make", 1), ("produce", 1), ("create", 1), ("producing", 1), ("creating",
 1), ("manufacture", 1), ("manufacturing", 1)]),
 ("cute", 1, [("beautiful", 1), ("lovely", 1), ("gorgeous", 1), ("pretty", 1), ("handsome", 1),
 ("charming", 1), ("stunning", 1)]),
 ("babbling", 1, [("babble", 1)]),
 ("noises", 1, [("noise", 1)]),
 ("healthy", 1, [("well", 1), ("robust", 1), ("wholesome", 1), ("strong", 1), ("hale", 1),
 ("sturdy", 1), ("whole", 1), ("fit", 1), ("thriving", 1), ("health", 1)]),
 ("happy", 1, [("pleased", 1), ("delight", 1), ("satisfied", 1), ("satisfy", 1), ("glad", 1),
 ("glee", 1), ("thankful", 1)]),

("rosy", 1, [("glow", 1), ("ruddy", 1), ("red", 1), ("tanned", 1), ("warm", 1), ("bright", 1)]),
 ("ward", 1, [("ward", 0)]),
 ("staff", 1, [("workforce", 1), ("personnel", 1), ("manpower", 1), ("crew", 1), ("employee", 1), ("worker", 1), ("nurse", 1), ("team", 1)]),
 ("took", 1, [("got", 1), ("caught", 1), ("take", 1), ("takes", 1), ("snapped", 1)]),
 ("photograph", 1, [("photo", 1), ("picture", 1), ("pic", 1), ("snap", 1), ("snapshot", 1), ("print", 1), ("photos", 1), ("shot", 1)]),
 ("smiling", 1, [("laughing", 1), ("giggling", 1), ("chuckling", 1), ("giggle", 1), ("chuckle", 1), ("laugh", 1), ("beam", 1), ("amuse", 1), ("jovial", 1)]),
 ("duo", 1, [("pair", 1), ("couple", 1), ("twain", 1), ("twosome", 1), ("two", 1)]),
 ("left", 1, [("went", 1), ("depart", 1), ("exit", 1), ("part", 1), ("leaves", 1), ("leaving", 1), ("leave", 1)]),
 ("other", 1, [("different", 1), ("diverse", 1)]),
 ("child", 2, [("kid", 2)]),
 ("preschool", 2, [("pre-school", 2), ("nursery", 2), ("kindergarten", 2), ("school", 2)]),
 ("morning", 1, [("morn", 1), ("daybreak", 1), ("dawn", 1)]),
 ("feeling", 1, [("emotion", 1), ("sense", 1)]),
 ("elated", 1, [("ecstatic", 1), ("giddy", 1), ("thrilled", 1), ("excited", 1), ("delight", 1), ("please", 1)]),
 ("tell", 1, [("said", 1), ("stated", 1), ("report", 1), ("recount", 1), ("describe", 1), ("inform", 1), ("narrate", 1)]),
 ("soon", 1, [("shortly", 1), ("momentarily", 1), ("promptly", 1)]),
 ("pick", 1, [("collect", 1), ("round up", 1), ("gather", 1), ("picking", 1)])

set3 = [("pick", 1, [("collect", 1), ("round up", 1), ("gather", 1)]),
 ("heading", 1, [("going", 1), ("goes", 1), ("lead", 1)]),
 ("child", 1, [("kid", 1)]),
 ("hails", 1, [("summon", 1), ("call", 1), ("asks", 1), ("request", 1), ("order", 1), ("beckon", 1)]),
 ("taxi", 1, [("go", 1), ("goes", 1)]),
 ("number", 1, [("number", 0)]),
 ("bus", 1, [("car", 1), ("automobile", 1)]),
 ("stop", 1, [("stop", 0)])


```

# Counters for each set
set1_count = 0
set2_count = 0
set3_count = 0

# A dictionary to keep track of counted synonyms
counted_synonyms = defaultdict(int)

# Loop through each set
for set_info in [set1, set2, set3]:
    for word_info in set_info:
        if len(word_info) == 2:
            # Target word without associated synonyms
            word = word_info[0]
            max_count = word_info[1]
            count_word = text.count(word)
            count = min(count_word, max_count)
            if count > 0:
                if set_info == set1:
                    set1_count += count
                    text = text.replace(word, Fore.RED + word + Style.RESET_ALL, count)
                elif set_info == set2:
                    set2_count += count
                    text = text.replace(word, Fore.GREEN + word + Style.RESET_ALL, count)
                elif set_info == set3:
                    set3_count += count
                    text = text.replace(word, Fore.BLUE + word + Style.RESET_ALL, count)
            else:
                # Target word with associated synonyms
                word = word_info[0]
                max_count = word_info[1]
                count_syn = 0
                for syn_info in word_info[2]:

```

```

synonym = syn_info[0]
if synonym in text:
    continue # Ignore synonym if it's already been counted as the target word
count_syn += max(0, text.count(synonym))
count_word = text.count(word)
count = min(count_word + count_syn, max_count)
if count > 0:
    if set_info == set1:
        set1_count += count
        text = text.replace(word, Fore.RED + word + Style.RESET_ALL, count)
        for syn_info in word_info[2]:
            synonym = syn_info[0]
            count_syn = min(max(0, text.count(synonym)), max_count - count_word)
            if count_syn > 0:
                set1_count += count_syn
                text = text.replace(synonym, Fore.RED + synonym + Style.RESET_ALL,
count_syn)
        elif set_info == set2:
            set2_count += count
            text = text.replace(word, Fore.GREEN + word + Style.RESET_ALL, count)
            for syn_info in word_info[2]:
                synonym = syn_info[0]
                count_syn = min(max(0, text.count(synonym)), max_count - count_word)
                if count_syn > 0:
                    set2_count += count_syn
                    text = text.replace(synonym, Fore.GREEN + synonym +
Style.RESET_ALL, count_syn)
        elif set_info == set3:
            set3_count += count
            text = text.replace(word, Fore.BLUE + word + Style.RESET_ALL, count)
            for syn_info in word_info[2]:
                synonym = syn_info[0]
                count_syn = min(max(0, text.count(synonym)), max_count - count_word)
                if count_syn > 0:

```

```

set3_count += count_syn
text = text.replace(synonym, Fore.BLUE + synonym + Style.RESET_ALL,
count_syn)

print(text)
print(Fore.RED + "Set 1 Count: " + str(set1_count) + Style.RESET_ALL)
print(Fore.GREEN + "Set 2 Count: " + str(set2_count) + Style.RESET_ALL)
print(Fore.BLUE + "Set 3 Count: " + str(set3_count) + Style.RESET_ALL)

```

3.6.5 Functionalities and Features

Firstly, a narrative sample text is present within the code. This is then converted into lower case, ensuring that all word matches are not case-sensitive and is crucial to enable accurate word matching and counting. Subsequently, the tool uses three sets of data, each containing specific word information related to distinct parts of the narrative that need to be scored. Each set contains tuples, each of which represent a target word, its maximum count, and any associated synonyms. As the tool processes each set, it scans for each target word within the sample text. If a target word is found, the tool records its frequency. If a target word has associated synonyms, the tool performs an additional step. It scans for each of these synonyms in the text and counts their frequencies, ensuring not to double-count any word already recorded as a target word.

A defaultdict is used to efficiently track and manage these word counts. In the absence of a predefined count, a defaultdict automatically assigns a default value of zero, thus ensuring that every word has an associated count, even if it doesn't appear in the text. Without this, any words that are not predefined would result in an error since they have not been assigned a value. Once the tool completes the scanning and counting process for all sets, it prints out the modified text with colour-marked words and the total counts for each set. This output provides a clear report on the scored narrative.

3.6.6 Initial testing and Iterations

To first test the tool, all original stories were used as sample texts to examine whether the total counts for each set (i.e. first sentence, main body and last sentence) were correct. This initial testing phase revealed that the tool was consistently overcounting, resulting in total counts that exceeded predefined limits for each set. This overcounting was especially prevalent when synonyms were shared between the first sentence, main body, and last sentence. Given that participants' recall does not necessarily follow an ordered sequence and therefore may recall main body words in the first sentence and vice versa, it was essential to modify the code to overlook sequencing and not solely seek target words in the actual first and last sentence. Another challenge arose due to the tuple structure when the code returned an error if some target words did not have associated synonyms.

A potential workaround was to limit the number of synonyms, but this was impractical for maintaining the accuracy of the tool. Instead, the code was amended so that suffix and contraction changes were counted, whilst keeping the number of allowed synonyms the same. The rationale was that in order to limit the number of accepted synonyms to reduce the possibility of shared synonyms across sets, but adhere to the scoring rules, accepting suffix changes such as 'play' to 'played', would overcome this issue. This provision, however, led to complications when dealing with other target words that included the target word. For instance, if 'man' was a target word with 'he' as a synonym, the code's inclusion of the string variable 'he' would inadvertently include words containing 'he,' such as 'then.' This led to an inflated word count as 'then' is neither a target word nor a synonym.

Various iterations of the code were tested to address the overcounting issue, ultimately leading to several modifications. The rule of contractions and suffix changes were removed from the loop code, and instead, they were manually added to each tuple. This ensured that each variation of a target word that are specified are counted, eliminating the risk of a conflated count. Additionally, a section of the code was introduced so that the tool would skip target words without synonyms, or empty strings.

Furthermore, the initial design intended to colour-code counted words from different sections, highlighting words from the first sentence in red, the main body in blue, and the last sentence in green. This was aimed at aiding visual inspection to distinguish between sections. However, it did not function as expected, with colours bleeding into unintended sections. This

was due to the sequence of operations within the code and when a target word is identified. If a target word is shared across sections, the first identification of that word will be applied to all future instances. For example, if the word ‘walk’ is in the first and last section, it will be first coloured according to the first sentence rules, but all future occurrences will be highlighted in that colour.

To simplify the tool and to ensure accuracy in target word and synonym identification and counting, the decision was made to manually separate the first sentence, the main body, and the last sentence. For this purpose, a user-friendly widget was integrated into the code. This graphical interface allows the user to divide each section of the text and assign the corresponding target words and associated synonyms to each respective section, as depicted in Figure 22.

Figure 22: Sample Story Segmentation Entries

First sente...	
Target words:	fiona f 1 getting
Main body:	
Target words:	needed required,necessary,essential,d
Last sente...	
Target words:	fiona f 1 coat
Analyze	

Figure 23: Output Of An Analysed Sample Story With Respective Counts, Highlighted Words And Counted Synonyms

```
fiona was getting ready to go to town on a rainy afternoon.
Set 1 Count: 7
Word/Synonym "fiona" (from "fiona") was found 1 time(s)
Word/Synonym "getting" (from "getting") was found 1 time(s)
Word/Synonym "ready" (from "ready") was found 1 time(s)
Word/Synonym "go" (from "go") was found 1 time(s)
Word/Synonym "town" (from "town") was found 1 time(s)
Word/Synonym "rainy" (from "rainy") was found 1 time(s)
Word/Synonym "afternoon" (from "afternoon") was found 1 time(s)
she needed to return winter clothing and gardening tools that she had bought online on friday, the week prior. fiona laid out all the items on the living room floor, ready to be packaged. she noticed that a thread of carpet had come loose and the thread created a loop that stuck out. fiona got her scissors and cut the thread. one by one, she placed her items into plastic parcel bags and sealed them with tape. the only pen she had to write the labels was a large marker. fiona tried to find her car keys, but they were nowhere to be found. she looked under cushion covers then remembered she had left them in the fruit bowl in the kitchen.
Set 1 Count: 51
Word/Synonym "needed" (from "needed") was found 1 time(s)
Word/Synonym "return" (from "return") was found 1 time(s)
Word/Synonym "winter" (from "winter") was found 1 time(s)
Word/Synonym "clothing" (from "clothes") was found 1 time(s)
Word/Synonym "gardening" (from "gardening") was found 1 time(s)
Word/Synonym "tools" (from "tools") was found 1 time(s)
Word/Synonym "bought" (from "bought") was found 1 time(s)
Word/Synonym "online" (from "online") was found 1 time(s)
Word/Synonym "friday" (from "friday") was found 1 time(s)
Word/Synonym "week" (from "week") was found 1 time(s)
Word/Synonym "prior" (from "prior") was found 1 time(s)
Word/Synonym "laid" (from "laid") was found 1 time(s)
Word/Synonym "items" (from "items") was found 2 time(s)
Word/Synonym "living" (from "living") was found 1 time(s)
Word/Synonym "room" (from "room") was found 1 time(s)
Word/Synonym "floor" (from "floor") was found 1 time(s)
Word/Synonym "ready" (from "ready") was found 1 time(s)
Word/Synonym "parcel" (from "package") was found 1 time(s)
Word/Synonym "fiona" (from "fiona") was found 1 time(s)
Word/Synonym "noticed" (from "noticed") was found 1 time(s)
Word/Synonym "thread" (from "thread") was found 2 time(s)
Word/Synonym "carpet" (from "carpet") was found 1 time(s)
Word/Synonym "loose" (from "loose") was found 1 time(s)
Word/Synonym "created" (from "created") was found 1 time(s)
Word/Synonym "loop" (from "loop") was found 1 time(s)
Word/Synonym "stuck" (from "stuck") was found 1 time(s)
Word/Synonym "got" (from "took") was found 1 time(s)
Word/Synonym "scissors" (from "scissors") was found 1 time(s)
Word/Synonym "cut" (from "cut") was found 1 time(s)
Word/Synonym "placed" (from "laid") was found 1 time(s)
Word/Synonym "plastic" (from "plastic") was found 1 time(s)
Word/Synonym "bags" (from "bags") was found 1 time(s)
Word/Synonym "sealed" (from "taped") was found 1 time(s)
Word/Synonym "pen" (from "pen") was found 1 time(s)
Word/Synonym "find" (from "find") was found 1 time(s)
Word/Synonym "write" (from "write") was found 1 time(s)
Word/Synonym "large" (from "large") was found 1 time(s)
Word/Synonym "marker" (from "pen") was found 1 time(s)
Word/Synonym "packaged" (from "package") was found 1 time(s)
Word/Synonym "car" (from "car") was found 1 time(s)
Word/Synonym "keys" (from "keys") was found 1 time(s)
Word/Synonym "nowhere" (from "nowhere") was found 1 time(s)
Word/Synonym "cushion" (from "cushions") was found 1 time(s)
Word/Synonym "under" (from "underneath") was found 1 time(s)
Word/Synonym "remembered" (from "remembered") was found 1 time(s)
Word/Synonym "left" (from "left") was found 1 time(s)
Word/Synonym "fruit" (from "fruit") was found 1 time(s)
Word/Synonym "bowl" (from "bowl") was found 1 time(s)
Word/Synonym "kitchen" (from "kitchen") was found 1 time(s)
she then loaded the packages into the car.
Set 1 Count: 3
Word/Synonym "loaded" (from "loaded") was found 1 time(s)
Word/Synonym "packages" (from "packages") was found 1 time(s)
Word/Synonym "car" (from "car") was found 1 time(s)
First sentence total count: 7
Main body total count: 51
Last sentence total count: 3
```

The code automatically populates the input widgets with the predefined sets of target words and synonyms for the three text segments. This eliminates the need for users to copy and

paste the target words and synonyms which simplifies the process and reduces the potential for errors. Moreover, the approach eliminates the need for the user to copy and paste the sample text into the code as users can simply copy the respective sections directly into the widget. Users can now simply copy their recalled text, whether it's the first sentence, the main body, or the last sentence, directly into the corresponding widget box. This interface, being more intuitive to use and similar to standard data entry forms, is likely to be more user-friendly, especially for those lacking programming experience. Thus, this modification not only simplifies the counting process but also significantly enhances the tool's usability and accessibility.

3.6.7 Validation

Thus, to validate the tool, previously unused pilot data was used. This pilot data was unused because it was not properly counterbalanced in the original study design. The original data consisted of 12 stories recalled twice over a total of 4 days (3 stories recalled twice per day). Participants ($n=10$, mean age = 20.23, SD age = 4.65), were recruited from Swansea University Psychology Participant pool. Ethical approval was given by Swansea University's Psychology department.

Given that the cognitive and labour-intensive process of scoring the narratives can increase the likelihood of human error and thus that manual coding may not be the most accurate, in order to validate the tool and compare the tool's accuracy and reliability, a benchmark dataset was created. This included creating a reliable and accurately coded subset of the pilot data which included 3 participant recalls per valence randomly selected from the dataset. This equates to a total 36 story counts (30% of the original dataset for 10 participants). The data was coded over 5 days with each story being counted per day using blind coding, giving rise to 180 story counts.

Each coding session was treated as though the data was coded for the first time, ensuring that each coding session was independent. Moreover, prior counts of the data were not visible when coding to ensure that previous counts did not influence future counts. At the end of each coding session an error analysis was performed which sought to identify and record any discrepancies between coding sessions and understand their causes. This ensured that future

coding sessions would be more accurate since a log of discrepancies in counting were used to avoid future discrepancies. This temporal separation, blind coding and error analysis approach was preferred over a consensus dataset which would include multiple coders to achieve inter-rater reliability because ultimately the aim of the tool is to replace human coding due to the error-prone likelihood. Therefore, inter-rater agreement reflects consistency among different coders, rather than accuracy in coding per se.

Table 37: Manual Scoring Table Results

		Day (Count)															Main body M, (±SD)
		1			2			3			4			5			
Story Name	Participant Recall	First	Main	Last	First	Main	Last	First	Main	Last	First	Main	Last	First	Main	Last	
The Hospital Visit	1	2	32	2	2	34	2	2	34	2	2	35	2	2	35	2	34.00 (±1.22)
	2	3	39	4	3	36	5	3	35	5	3	37	5	3	37	5	36.80 (±1.48)
	3	2	34	3	3	32	3	2	33	3	3	37	2	3	37	2	34.60 (±2.30)
The Dental Exam	1	6	33	6	6	33	6	6	33	6	6	33	6	6	33	6	33.00 (±0.00)
	2	7	48	5	7	45	5	7	44	5	7	44	5	7	44	5	45.00 (±1.73)
	3	6	32	4	6	33	4	6	34	4	6	34	4	6	34	4	33.40 (±0.89)
The Cinema Trip	1	4	49	4	4	51	4	4	51	4	4	51	4	4	51	4	50.60 (±0.89)
	2	2	28	3	2	30	3	2	30	3	2	30	3	2	30	3	29.60 (±0.89)
	3	3	22	5	3	25	4	3	25	4	3	25	4	3	25	4	24.40 (±1.34)
The Date	1	6	51	9	6	52	9	6	53	9	6	53	9	6	53	9	52.40 (±0.89)
	2	6	20	5	6	21	5	6	21	5	6	21	5	6	21	5	20.80 (±0.45)
	3	4	35	7	4	36	7	4	37	7	4	37	7	4	37	7	36.40 (±0.89)
The Paris Trip	1	9	48	6	9	49	6	9	48	6	9	49	6	9	49	6	48.60 (±0.55)
	2	7	35	5	7	37	5	7	37	5	7	37	5	7	37	5	36.60 (±0.89)

	3	8	20	3	9	20	3	9	20	3	9	20	3	9	20	3	20.00 (± 0.00)
The Skateboard Race	1	5	35	4	5	38	4	5	37	4	5	37	4	5	37	4	36.80 (± 1.10)
	2	5	63	5	5	63	5	5	61	5	5	60	5	5	60	5	61.40 (± 1.52)
	3	5	28	2	5	27	2	5	29	2	5	26	2	5	26	2	27.20 (± 1.30)
The Work Meeting	1	6	52	5	6	51	6	6	47	6	6	48	6	6	48	6	49.20 (± 2.17)
	2	6	44	5	6	44	5	6	45	5	6	45	5	6	45	5	44.60 (± 0.55)
	3	5	30	5	5	31	5	5	32	5	5	32	5	5	32	5	31.40 (± 0.89)
The Car Purchase	1	7	66	6	7	65	6	7	62	6	7	62	6	7	62	6	63.40 (± 1.95)
	2	7	58	6	7	58	6	7	58	6	7	58	6	7	58	6	58.00 (± 0.00)
	3	7	42	7	7	43	7	7	43	7	7	43	7	7	43	7	42.80 (± 0.45)
The Radio Contest	1	3	51	3	3	50	3	3	50	3	3	50	3	3	50	3	50.20 (± 0.45)
	2	6	50	5	6	49	5	6	48	5	6	48	5	6	48	5	48.60 (± 0.89)
	3	6	34	4	6	33	4	6	32	4	6	33	4	6	33	4	33.00 (± 0.71)
The Birthday Present	1	6	39	7	6	39	7	6	39	7	6	39	7	6	39	7	39.00 (± 0.00)
	2	6	25	0	6	25	0	6	27	0	6	27	0	6	27	0	26.20 (± 1.10)
	3	7	29	6	7	29	8	7	29	7	7	29	7	7	29	7	29.00 (± 0.00)
The Presentation	1	7	60	6	7	61	6	7	62	6	7	62	6	7	62	6	61.40 (± 0.89)
	2	7	31	3	7	29	3	7	29	3	7	29	3	7	29	3	29.40 (± 0.89)
	3	6	39	0	6	39	0	6	39	0	6	39	0	6	39	0	39.00 (± 0.00)
The Return	1	6	28	0	6	28	0	6	29	0	6	29	0	6	29	0	28.60 (± 0.55)
	2	6	25	0	6	25	0	6	26	0	6	27	0	6	27	0	26.00 (± 1.00)

	3	7	49	3	7	50	3	7	50	3	7	51	3	7	51	3	50.20 (± 0.84)

3.6.8 Error Analysis Post Count

Initially, there were discrepancies between the word counts on day 1 and day 2. Upon reflection, it became apparent that the inconsistencies arose from the difficulty in tracking allowed synonyms and their associated maximum counts when target words were absent. To address this issue, all story recalls were printed with target word and synonym counts. For subsequent counts on other days, a system was implemented where target words and synonyms were crossed off the list as they were counted. This visual inspection method made it easier to keep track of the remaining words and synonyms, leading to consistent scores. However, this process significantly increased the time required for scoring.

Despite the improvement, a few discrepancies persisted due to overlapping synonyms of target words, making it challenging to determine which associated synonym had been counted in place of a target word. To resolve this, a written note was made for each synonym-target word pair, specifying the number of occurrences present in the text. While this further increased the time required for scoring, it ensured that all counts were consistent once this system was in place.

Table 38: Final Manual Count Versus Final Python Code Count

Story Name	Participant Recall	Manual Count		Python Count				Total Difference
		First	Main	Last	First	Main	Last	
Hospital	1	2	35	2	2	35	2	0
	2	3	37	5	3	37	5	0
	3	3	37	2	3	37	2	0
Dental	1	6	33	6	6	33	6	0
	2	7	44	5	7	44	5	0
	3	6	34	3	6	34	3	0
Cinema	1	4	51	4	4	51	4	0
	2	2	30	3	2	30	3	0
	3	3	25	4	3	25	4	0
Date	1	6	53	9	6	53	9	0
	2	6	21	5	6	21	5	0
	3	4	37	7	4	37	7	0
Paris	1	9	49	6	9	49	6	0
	2	7	37	5	7	37	5	0
	3	9	20	3	9	20	3	0
Skate	1	5	37	4	5	37	4	0
	2	5	60	5	5	60	5	0
	3	5	26	2	5	26	2	0
Work	1	6	48	6	6	48	6	0
	2	6	45	5	6	45	5	0
	3	5	32	5	5	32	5	0

Car	1	7	62	6	7	62	6	0
	2	7	58	6	7	58	6	0
	3	7	43	7	7	43	7	0
Radio	1	3	50	3	3	50	3	0
	2	6	48	5	6	48	5	0
	3	6	33	4	6	33	4	0
Birthday	1	6	39	7	6	39	7	0
	2	6	27	0	6	27	0	0
	3	7	29	7	7	29	7	0
Presentation	1	7	62	6	7	62	6	0
	2	7	29	3	7	30	3	+1
	3	6	39	0	6	39	0	0
Return	1	6	29	0	6	29	0	0
	2	6	27	0	6	27	0	0
	3	7	51	3	7	51	3	0

3.6.9 Discussion

The automatic counting tool was validated against a carefully benchmarked dataset, which revealed substantial enhancements in the accuracy and consistency of manual counting. To achieve consistent manual counts for the final two days of the validation process, additional measures were incorporated into the counting process, such as using a printed checklist and marking each target word along with their synonyms. While these measures effectively increased the reliability of the manual counting, they also resulted in a longer time required to score each story. It is important to note that the validation was performed on only a subset of the data. In typical protocols investigating the effect of sleep on emotional memory, there are usually 24 participants with around 50,000 words to be manually scored. Thus, whilst this process revealed how to achieve more reliable and consistent manual counts, the increased time required for scoring narratives using the enhanced manual counting process would not be feasible in many research and clinical settings.

The automatic tool demonstrated remarkable accuracy, with a minimal difference of only +1 score out of the 36 scored stories when compared to the benchmark dataset. This finding highlights the tool's potential to significantly reduce the manual effort and time required for scoring narratives while maintaining high standards of accuracy. Furthermore, the tool's consistency in scoring, regardless of the inherent variability and subjectivity associated with manual counting, emphasises its utility in research settings where large volumes of data require efficient and reliable analysis. To put this into perspective, a manual count typically takes approximately 5 minutes to score one story, whereas the automatic tool requires only around 15 seconds to input 3 sections of text into the analysis boxes, making it roughly 20 times faster, more accurate, and more reliable than manual scoring.

However, it is important to acknowledge the limitations of the tool. The scoring rules allow points for contractions, suffixes and tense changes to target words and synonyms (e.g. the target word 'walk' would allow for changes such as 'walked', 'walking', 'walks', etc.), but not all permutations of these have been included in the tool. As a result, researchers will need to cross-reference the output of the analysis feature against sample stories to ensure that all words are counted correctly. To mitigate this limitation, the tool has been designed to allow

for the easy addition of words and synonyms to the analysis (refer to the ‘User Guidelines’ in the appendix for details), enabling researchers to adapt the code to their specific needs.

Despite these limitations, the development of this automatic scoring tool represents a significant step forward in emotional memory research. By providing a more efficient and reliable means of analysing narrative data, this tool has the potential to facilitate discoveries and insights into the relationship between emotion and memory.

Finally, given that the code is open access, researchers can amend it for their needs. Future iterations of the code could incorporate word order analysis, which would provide further insights into specifics regarding emotional memory consolidation. By considering the sequence in which words appear in the narrative, the tool could potentially assess temporal order memory, which involves remembering the order in which events or information are processed. This aspect of memory is important for understanding how individuals process and recall experiences in a structured manner.

Overall, the development of this faster, more accurate, and reliable scoring tool has the potential to significantly advance our understanding of emotional memory. By enabling researchers to analyse large datasets quickly, accurately, and reliably, this tool may help to increase the use of narratives within memory research. Moreover, given the high sensitivity of the narratives, this tool could be employed in clinical settings to detect subtle changes in memory over time. Future research should examine sleep-dependent memory and emotional memory consolidation of emotional narratives in healthy older adults and those with Vascular Cognitive Impairment. This tool can help significantly reduce scoring time and improve accuracy and efficiency.

3.7 Study 5: Examining the Effect of Sleep-Dependent Memory Consolidation on Emotional Memory Performance Using Narratives in Older Adults: A Case Study of 5 Older Adults

3.7.1 Method

3.7.1.1 Participants

This study aimed to replicate the emotional memory study previously conducted with younger adults, focusing on healthy older adults aged 65, to recruit 24 older adults to participate in the study. However, despite extensive recruitment efforts, which included reaching out to 368 potential participants and successfully enrolling 10 participants, only 5 participants completed the study (2 males, 3 females) with a mean age of 71.20 ($SD = 4.66$). The reduced sample size can be attributed to various challenges specific to this demographic and the study protocol, which will be discussed in detail in Chapter 5. This study was granted ethical approval by Swansea University Psychology Ethics Committee (4898).

3.7.1.2 Recruitment Challenges and Protocol Amendments

Recruitment of older adults presented unique challenges, described in more detail in Chapter 5. These challenges included technological barriers, health constraints, and difficulties in adhering to scheduled session times. Specifically, the original protocol, designed for younger adults, proved impractical for older adults in the recruitment of this study. As previous data collection for younger adults took around four months to get the total 24 participants to complete the study, improvements to data collection efficiency were required due to the approaching end of candidature. Moreover, to ensure that participants were tested in the morning and evening windows to align with natural chronotypes (e.g. a morning window of 7am-10am and an evening window of 7pm and 10pm), the intended plan was to test 24 participants over 24 days, based on an idea scenario of back-to-back appointments (with 3 participants completing the study every 3 days). However, this was not possible due to the complexities of participants availability and health conditions, which extended data collection to several months.

To address these issues, the protocol was modified to allow participants to independently complete sessions, as opposed to completing sessions with a researcher present via Zoom, and submit their story recalls via recorded voice notes. Despite providing detailed instructions and offering flexibility in using various platforms, such as WhatsApp for story submissions, participants still found recording and sending recordings challenging. For example, 5 participants were excluded from the study, despite completing at least 2 testing days due to recording issues. Three of these participants attempted to re-record the sessions. Still, as the links in Qualtrics do not allow participants to return to the previous story (to stop re-rehearsals), further story recalls were lost. Thus, strict adherence to the schedule and the viewing stories only once was vital since any deviation could compromise the counterbalanced design and to avoid re-learning stories as they are meant to be viewed only once for a set 3 minutes.

Proactive measures were taken to improve compliance and adherence to the schedule, including telephone briefings on the procedure for voice recording submissions. Despite these efforts, only 5 participants completed the study (2 males, 3 females) with a mean age of 71.20 ($SD = 4.66$). These experiences underscore the need for protocol revisions to enhance feasibility and inclusivity for older adults. Recommendations for such amendments are discussed in Chapter 5, outlining the importance of adopting a methodology that accurately reflects the capabilities and preferences of the broader older adult population. This is crucial, as the current protocol may inadvertently exclude a subset of older adults who find specific research designs challenging, affecting the findings' representativeness.

3.7.1.3 Presentation of findings

Due to the reduced sample size, the planned $2 \times 3 \times 2$ (condition: sleep versus wake; Valence: Positive, neutral, negative; Story Version: 1 and 2) repeated measures ANOVA and other inferential statistical analyses were not feasible due to the high likelihood of committing a type 1 error. Given the small sample size, descriptive statistics will be presented in this chapter as a case study. This will include descriptive statistics of the percentage of correct content words recalled at delayed recall minus the initial recall and visual representations of the data. However, it is worth noting that the limited dataset is sensitive to individual

variations, and extreme scores can significantly affect the means and measures of distribution. Thus, given this study's constraints, it is impossible to draw conclusions from this data regarding the effect of sleep on emotional narratives for older adults. However, including this data provides a transparent account of the methodological challenges encountered and offers insights into the data limitations.

Ultimately, the value of this study lies in its contribution to understanding the complexities faced in gerontological emotional memory research and the importance of adapting research designs to accommodate the unique characteristics of this demographic. These reflections and methodological considerations are described in further detail in Chapter 5, created using reflections from this study. Consequently, this study and its challenges have helped create future recommendations and insights for improved protocols, along with a discussion on how future research can build upon these findings to achieve more statistically robust outcomes.

3.7.2 Results

Table 39: Change Scores From T2% To T1% as a Percentage Of Correct Content Words

Participant	Sleep			Wake		
	Positive	Neutral	Negative	Positive	Neutral	Negative
1	0.00	-1.39	0.00	-3.08	-5.56	-2.94
2	-24.62	-6.94	-26.47	0.00	3.28	-8.70
3	-3.08	-11.11	-2.94	-15.87	-9.84	-15.94
4	-4.62	-5.56	1.47	11.43	-9.84	5.80
5	-38.41	1.64	-10.14	-1.27	-31.15	-2.90
Median	-4.62	-5.56	-2.94	-1.27	-9.84	-2.94
IQR	21.52	5.55	10.14	3.08	4.28	5.80

Figure 24: Median Change in Recall Performance From Delayed Recall (T2%) Minus Initial Recall (T1%) Across Valence and Sleep and Wake Conditions

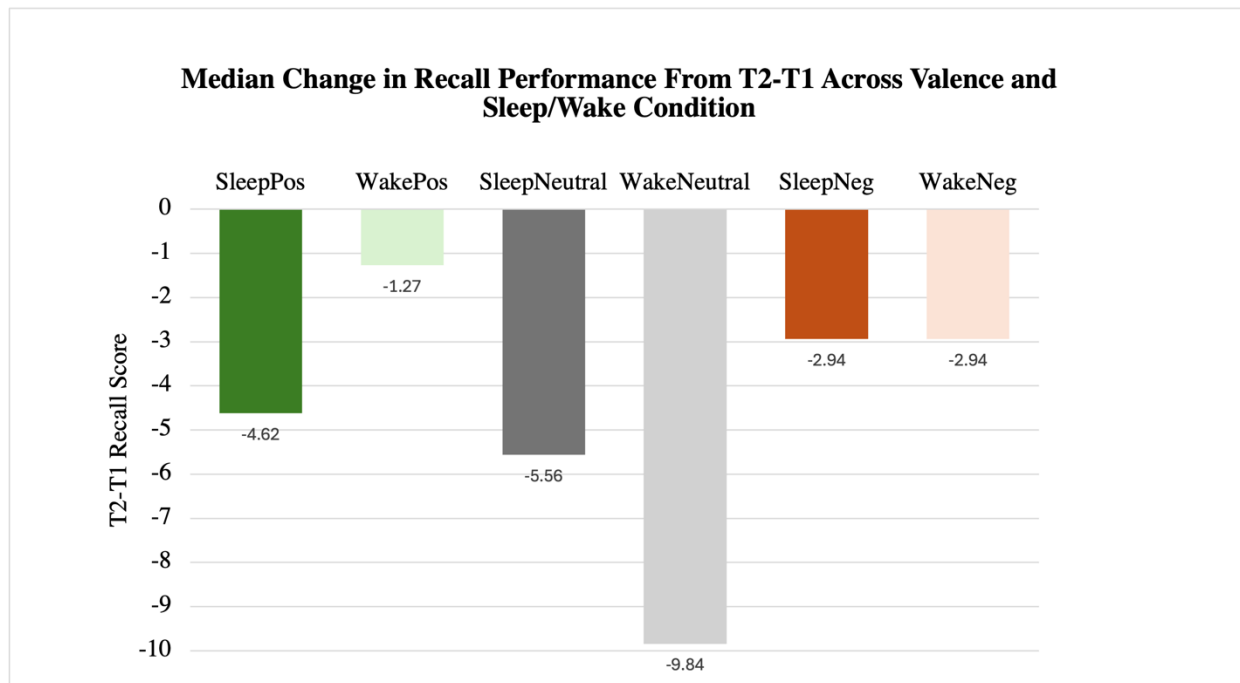


Figure 25: Median Change in Recall Performance From Delayed Recall (T2%) Minus Initial Recall (T1%) Across Sleep and Wake Conditions

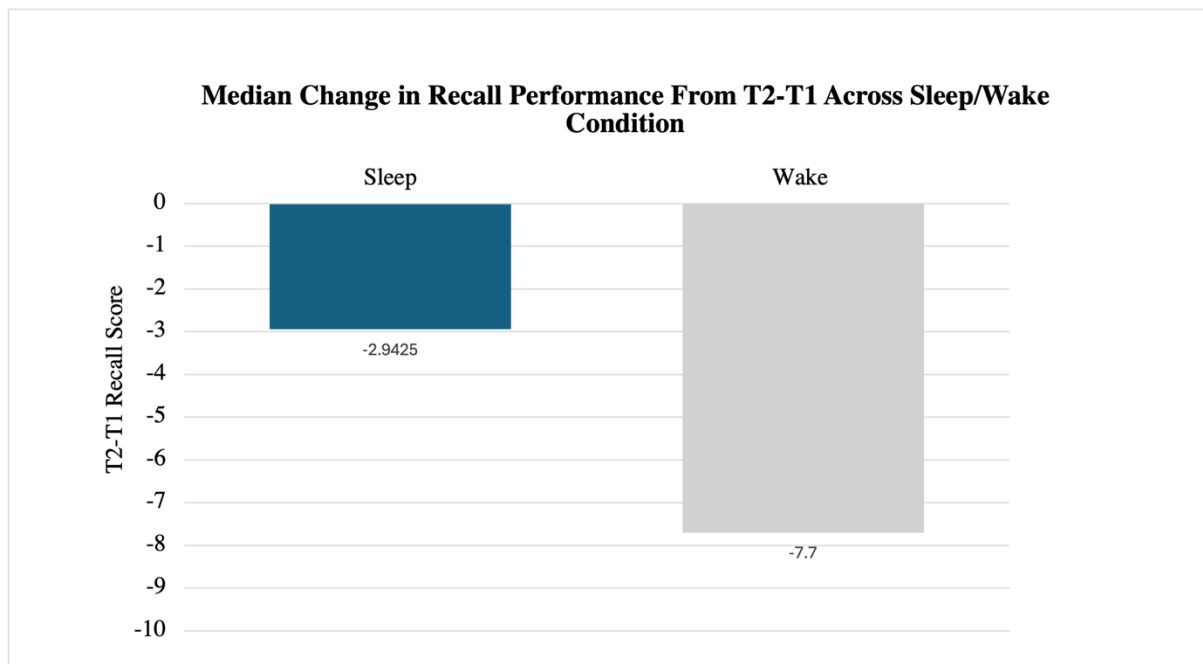
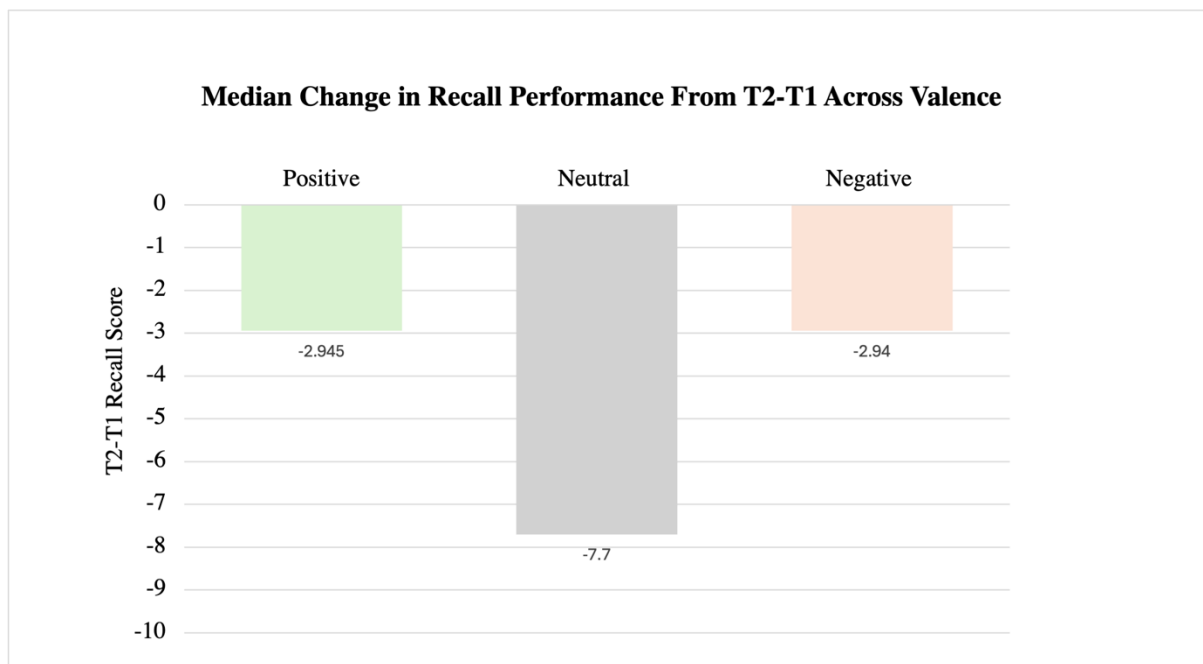


Figure 26: Median Change in Recall Performance From Delayed Recall (T2%) Minus Initial Recall (T1%) Across Valence



3.7.3 Discussion

This study aimed to examine sleep-dependent emotional memory enhancement of emotional and neutral narratives in 24 older adults using a within-participant design to compare this group against individuals living with dementia. However, due to methodological challenges, only five healthy older adults completed the study. The results from the current study, with its limited sample size, do not provide conclusive insights into emotional memory consolidation following sleep compared to wakefulness in older adults. In line with the hypothesis that sleep benefits memory consolidation, individuals in this particular sample showed greater forgetting when in the wakefulness condition than in the sleep condition.

However, the hypothesis that sleep specifically benefits emotional narrative consolidation and that older adults have better memory for positive narratives was partially supported (Jones et al., 2016; Huan et al., 2020). Overall, participants showed better memory for the positive and negative items compared to neutral. However, with regards to the effect of sleep or wake on the positive stories, participants showed better memory in the wake condition for positive items than in the sleep conditions. Given the small sample size and high variability in scores, the interpretation of the data is limited, and this study does not provide robust evidence regarding emotional memory consolidation across sleep and wake for older adults.

However, as the study intended to achieve 24 participants for testing, the protocol for completing the study with the full sample size has been developed and randomisation of participants along with counterbalancing of story valence, story set and story versions have been created. Future work can build upon this dataset to reach the intended sample size of 24. Moreover, this study and the methodological challenges encountered have informed the recommendations for protocol improvements outlined in Chapter 5. These recommendations aim to ensure better participant adherence and study completion in future research. Briefly, suggested protocol amendments include ensuring a researcher is present remotely during sessions to provide guidance on completion and conducting regular check-ins with participants. Additionally, given that some participants struggled with completing practice sessions even with a researcher present, future studies should consider using a cognitive screening test, such as the Montreal Cognitive Assessment, to either screen for mild cognitive impairment or to stratify participants according to test outcomes. This approach would help to

better represent healthy older adults in the sample and account for the impact of objective cognitive impairment on study results, and, potentially, study completion.

In conclusion, while the current study's results are inconclusive due to the limited sample size and high variability, the lessons learned from this research can inform future studies in emotional memory consolidation across sleep and wake in older adults. By implementing the suggested protocol improvements and increasing the sample size, more definitive conclusions can be drawn, contributing to our understanding of how sleep and emotion interact in memory consolidation in ageing populations.

3.8 Chapter 5: General Discussion

Sleep has been shown to enhance memory consolidation, with many studies demonstrating that a period of sleep, compared to an equal period of wakefulness, is associated with better memory performance (Born et al., 2006; Hornung et al., 2008; Born & Wilhelm, 2012; Lipinska et al., 2019; Huan et al., 2020; Reid et al., 2022). This effect has been observed in various populations, including young adults (Reid et al., 2022), healthy older adults (F. A. Jones, 2002), and individuals with dementia (Baran et al., 2014; Jones et al., 2016). Memory impairments are a common feature in dementia, particularly for those with Alzheimer's Disease (AD) and, to a lesser extent, those with Vascular Cognitive Impairment (VCI; Craft et al., 1996; Beekly et al., 2004; Baran et al., 2014; Bir et al., 2021). Since sleep disturbances are also prevalent in individuals with dementia (Ju et al., 2014; Bir et al., 2021), investigating whether sleep-dependent memory processes are preserved in those with VCI is important.

According to the Active Systems hypothesis (Born et al., 2006; Born & Wilhelm, 2012), during sleep, labile memory traces are protected from interference and are reactivated to facilitate their transfer from short-term stores, such as the hippocampus, to long-term stores, such as the neocortex (Klinzing et al., 2019). This process strengthens and stabilises memory representations and allows for their reintegration into existing knowledge networks (Klinzing et al., 2019). Chapter 2 of this thesis explored the role of sleep issues on cognitive performance in individuals with Vascular Dementia (VaD) and found that those with sleep disturbances exhibited poorer memory performance than those without, suggesting potential impairments in sleep-dependent memory processes. In addition to the general benefits of sleep for memory consolidation, research has shown that emotional material may receive a preferential boost, with better memory performance for emotional items compared to neutral items following sleep (Lipinska et al., 2019; Schäfer et al., 2020). This emotional enhancement of memory (EEM) is particularly relevant in the context of dementia, given the high prevalence of mood disturbances and other neuropsychiatric symptoms in this population (Ballard et al., 2008; Desai et al., 2012). However, the strength of the EEM effect has been debated, with meta-analyses suggesting that it may be more pronounced under specific conditions, such as studies using free-recall outcome measures, retention measures (i.e., controlling for initial learning), and bivalent stimuli (i.e., both positive and negative stimuli) alongside neutral stimuli (Lipinska et al., 2019). To address these methodological

considerations and investigate sleep-dependent emotional memory in VCI, we developed a set of short stories that included positive, neutral, and negative narratives. Using narratives in this context offers several advantages over traditional stimuli, such as word lists or pictures. Narratives more closely resemble everyday memory experiences and may better capture the natural structure of memory (León, 2016). Moreover, using narratives allows for incorporating free-recall measures and bivalent stimuli, essential for detecting EEM effects (Lipinska et al., 2019).

The primary aims of this chapter were to develop and pilot a set of emotional and neutral short stories, to examine sleep-dependent emotional memory in young adults using these stories, and to lay the groundwork for extending this research to older adults with and without VCI. Study 1 involved piloting 9 stories (3 positive, 3 neutral, and 3 negative) to ensure their suitability for the intended purpose. The results showed that the stories were equally memorable, comprehensible, and familiar across valences and versions. However, they differed in some dimensions, such as arousal and interestingness, which are intrinsic to valence manipulation. Study 2 expanded the story set to 12, allowing multiple testing sessions and increasing the task's utility for various research contexts. The pilot results for the additional stories were consistent with those from Study 1, confirming the suitability of the expanded set for investigating emotional memory. Study 3 tested the developed stories in 24 young adults using a within-participant crossover design with sleep and wake conditions. Contrary to our expectations based on prior literature, we did not observe a significant effect of valence on memory performance. However, we found a general sleep effect, with participants forgetting fewer content words following sleep than wakefulness. The lack of a valence effect may be due to the negative stories being rated less strongly valenced than the positive stories. Additionally, research suggests that in younger adults (Huan et al., 2020), presenting negative items alongside neutral items may strengthen memory for the neutral items, potentially diminishing the EEM effect (Jones, 2002).

Despite the absence of a valence effect, the finding that sleep benefited memory for narratives in general is noteworthy and provides a foundation for investigating sleep-dependent memory in older adults with and without cognitive impairment. The stronger positive valence in the stories may be advantageous for future studies in older adults, given the well-documented positivity bias in this population (Jones et al., 2016; Huan et al., 2020). Older adults tend to show better memory for positive information, and this bias may interact with the EEM effect,

potentially leading to more pronounced differences between memory for positive and neutral items following sleep. To extend this research to individuals with dementia, we established a collaboration between Swansea University and King Abdulaziz Hospital in Saudi Arabia. The narrative stories were translated into Arabic by native speakers, and ethical approval was obtained from both institutions. Unfortunately, due to time constraints faced by the Saudi team, data collection for the dementia arm could not be completed within the scope of this thesis. Despite this limitation, the established collaboration and the groundwork laid for this cross-cultural expansion demonstrate the feasibility and potential of the study protocol to be adapted for different populations and disciplines. The inclusion of this discussion serves to illustrate the research plans that were developed and the commitment to advancing our understanding of emotional memory processing in both healthy and clinical populations.

An additional aim that emerged during this research was developing an automated scoring tool to address the significant time and cognitive effort required to manually score the narratives. The high word count and multiple versions of the stories made manual scoring a challenging task. To overcome this issue, we developed a Python-based automated scoring tool demonstrating excellent efficiency and accuracy in scoring the narratives. All 12 stories were coded and tested to enhance the tool's usability. The open-source nature of the tool allows researchers to modify and adapt it to their specific needs, representing a novel contribution to memory research using narratives. Thus, this study developed a promising narrative-based task to investigate sleep-dependent emotional memory in VCI and demonstrated the feasibility of adapting the protocol for cross-cultural research. While the young adult findings did not show the expected EEM effect, the general sleep benefit for narrative memory provides a foundation for future studies in older adults with and without cognitive impairment. The development of the automated scoring tool represents a significant methodological advancement, enhancing the efficiency and accessibility of narrative-based memory research.

Limitations of the current study include the unexpected valence ratings of the stories and the inability to complete the dementia arm within the thesis timeline. Future research should aim to further optimise the emotional salience of the narratives and investigate sleep-dependent emotional memory in diverse clinical populations, including those with VCI and other types of dementia. Additionally, the automated scoring tool could be further refined, including accounting for word order and validated in different research contexts to maximise its impact

on the field. However, this chapter highlights the importance of investigating sleep-dependent memory processes in individuals with VCI. It presents a novel narrative-based task and automated scoring tool to facilitate future research. The findings contribute to our understanding of the role of sleep in emotional memory consolidation and lay the groundwork for future studies in clinical populations. By addressing the limitations and building upon the promising results of this study, researchers can continue to advance our knowledge of the relationship between sleep, emotion, and memory in the context of cognitive impairment and dementia.

Chapter 4. The Impact of Bedtime Fiction Reading on Sleep, Wellbeing, and Mood in Healthy Older Adults and Individuals with Vascular Dementia

4.1 Abstract

Sleep disturbances are common among older adults, especially those experiencing cognitive decline. Through two studies, this chapter explores fiction reading as a potential non-pharmacological intervention to enhance sleep quality and wellbeing in these populations. Study 1 employed an 8-week mixed-methods, within-subjects, pre-post-test design to investigate the effects of a 4-week fiction reading intervention on sleep quality, wellbeing, and mood in healthy older adults (HOA) and those with self-reported subjective cognitive decline (SCD). Participants ($n = 26$; aged 65-83 years) were stratified into HOA ($n=10$) and SCD ($n=16$) groups. Sleep quality was assessed using actigraphy, the Consensus Sleep Diary (CSD), and the Pittsburgh Sleep Quality Index (PSQI). Wellbeing and mood were measured using the PERMA-profiler and the Depression, Anxiety and Stress Scale-21 Item. Results showed significant improvements in subjective sleep quality across all participants from baseline to post-intervention, as measured by the CSD ($d=0.38$) and PSQI ($d=-1.26$). However, objective sleep quality remained unchanged. A significant interaction between group and study phase revealed differences in the SCD group and HOA regarding positive emotion and wellbeing. This suggests that the SCD group showed greater improvements in these factors. However, post hoc analyses were not significant. Study 2 adopted a case study approach due to recruitment challenges, applying the same protocol to three individuals with Vascular Dementia (VaD; mean age=72.46, SD=4.98) with support from study partners. Descriptive statistics are presented, and the feasibility of implementing the fiction reading protocol among older adults with VaD is discussed. This research highlights the potential of bedtime fiction reading as an accessible strategy to enhance subjective sleep quality and overall wellbeing, particularly for individuals with SCD who are at higher risk of developing dementia. The differential effects observed between HOA and SCD groups suggest that those with SCD may benefit more from solitary fiction reading.

4.2 Introduction

Sleep disturbances are a significant issue among older adults, particularly those with dementia. Research has shown a bidirectional relationship between sleep and dementia, with poor sleep being both a risk factor for and a consequence of cognitive decline (Bubu et al., 2017; Shi et al., 2018). A meta-analysis by Bubu et al. (2017) found that individuals with sleep disturbances had a 1.68 times higher relative risk of developing dementia compared to those without sleep issues. Moreover, the progression of dementia often exacerbates sleep problems, in some cases leading to a cycle of deterioration that impacts overall health and wellbeing (Shi et al., 2018). Sleep disturbances in dementia are associated with increased caregiver burden, decreased quality of life, and accelerated cognitive decline (Petrovsky et al., 2018; Gao et al., 2022). Given the high prevalence and significant consequences of sleep disturbances in older adults with and without dementia, effective interventions to improve sleep quality are vital for promoting healthy ageing and ameliorating sleep-related impact on cognitive decline and quality of life (Petrovsky et al., 2018).

While pharmacological treatments are commonly used to treat sleep disturbances in older adults (Pek et al., 2017; Luta et al., 2020), they often have limited efficacy and come with risks of unwanted side effects such as increased tolerance (Swift et al., 1984), anxiety and daytime sleepiness (Kales, 1990), polypharmacy and toxicity (Cho et al., 2020), an increased risk of falls and fractures (Sakshaug et al., 2017) and can even exacerbate cognitive symptoms (Glass et al., 2005; Sakshaug et al., 2017; Díaz-Gutiérrez et al., 2017). Given the limitations and potential risks of pharmacological treatments, there is a growing interest in non-pharmacological treatments (NPTs) as safer and more holistic alternatives for improving sleep and overall wellbeing in older adults (Montgomery, 2004; Blackman et al., 2021; Javed et al., 2023).

Non-pharmacological treatments encompass a wide range of approaches, including cognitive-behavioural therapy, exercise, light therapy, and sleep hygiene education (MacLeod et al., 2018). These interventions have shown promising results in improving sleep quality, reducing sleep disturbances, and enhancing overall wellbeing in older adults (Montgomery, 2004; Blackman et al., 2021; Javed et al., 2023). For example, cognitive-behavioural therapy for insomnia (CBT-I) is effective in improving sleep quality, reducing insomnia severity, and

decreasing depressive symptoms in older adults with insomnia (Montgomery, 2004; Huang et al., 2023) in addition to improving cognitive symptoms in those with Mild Cognitive Impairment (MCI; Cassidy-Eagle et al., 2018). Similarly, exercise interventions have enhanced sleep quality, increased sleep duration, and reduced sleep disturbances in middle-aged adults (Yang et al., 2012) and older adults (Solis-Navarro et al., 2023). Thus, NPTs help promote sleep quality in older adults with and without cognitive decline. However, despite these NPTs' effectiveness, many require trained professionals' guidance, which can limit their accessibility and scalability (Roberts & Ulmer, 2023). For example, while digital CBT-I platforms have improved accessibility (Riemann et al., 2023) many older adults, particularly those with cognitive impairment, may face challenges engaging with digital interfaces or implementing complex behavioural changes independently. Given the high prevalence of sleep issues among older adults with and without cognitive impairment (Canever et al., 2024) and constraints in accessing sleep treatments specific to this population, such as mobility issues, geographical constraints and health issues, there is a need for NPTs that can be self-administered and are widely accessible to this population (Canever et al., 2024).

Bibliotherapy is one potential NPT that has been underexplored in improving sleep quality and can be self-administered (Brewster, 2008; Brewster & McNicol, 2021). Bibliotherapy is an umbrella term that encompasses reading-based practices used to promote health and wellbeing (Brewster, 2008; McCulliss, 2012). Broadly, there are two overarching forms: non-fiction models, often based on self-help materials, and creative models that employ fiction and poetry (Brewster, 2008). Non-fiction bibliotherapy, such as self-help books and educational materials, has gained credibility in improving health literacy and management of specific health conditions, such as insomnia (Bjorvatn et al., 2002; Jernelöv et al., 2012) and dementia (Billington et al., 2013; Brewster & McNicol, 2021; Orrell et al., 2019). These interventions often provide practical strategies and information to manage symptoms and promote healthy behaviours. For instance, the UK's 'Books on Prescription' program offers curated reading lists providing information about specific health conditions, including dementia, by offering educational resources, practical tips, and strategies for managing symptoms, as well as guidance on promoting healthy ageing and supporting caregivers (Chamberlain et al., 2008). While this targeted approach has been shown to improve health literacy and management of specific conditions, with regards to sleep, the application of non-fiction bibliotherapy in practice is limited to addressing specific sleep conditions, such as

insomnia (Bjorvatn et al., 2002; Jernelöv et al., 2012) rather than promoting broader and generalised sleep enhancement.

In contrast, creative bibliotherapy, which uses fiction and poetry, may offer unique cognitive and emotional benefits that could be particularly advantageous for improving sleep quality and wellbeing (Brewster, 2008; Mar & Oatley, 2008; Mar et al., 2009, 2011). Engaging with fiction has been associated with many positive outcomes that extend beyond health literacy. For example, studies have found that reading fiction is associated with cognitive preservation during ageing (Wilson, 2002; Wilson et al., 2013), reduced psychological distress (Levine, 2020), improved empathy and theory of mind (Mar et al., 2009), reduced negative emotions (Sabatinelli et al., 2006), decreased feelings of loneliness (Pettigrew & Roberts, 2008), and enhanced social cognition (Altmann et al., 2012; Mar & Oatley, 2008). These wide-ranging benefits suggest that creative bibliotherapy may have the potential to positively impact sleep and wellbeing more holistically rather than focusing solely on treating specific sleep disorders such as insomnia. However, it is important to note that research specifically focusing on the relationship between reading fiction and sleep is extremely limited. Despite an extensive literature search, studies directly investigating the impact of fiction reading on sleep outcomes are scarce. This lack of empirical evidence highlights the need for further research to better understand the potential sleep-promoting effects of fiction reading, given that it is self-reported to be a common pre-sleep activity in adults (Carrigan et al., 2020).

Unlike non-fiction, fiction reading requires readers to create mental simulations of fictional worlds and characters, drawing on creativity and mental imagery (Mar & Oatley, 2008). This process encourages psychological transportation into the story world, which can be deeply immersive and emotionally engaging (Sabatinelli et al., 2006; Mar & Oatley, 2008; Mar et al., 2011; Isberner et al., 2019). When readers are transported into a narrative, they engage in perspective-taking and project themselves into the characters' minds to understand their thoughts, emotions, beliefs, motivations, desires, and goals, a process known as the theory of mind (ToM; Green & Brock, 2000; Sabatinelli et al., 2006; Mar & Oatley, 2008). This enables readers to empathise with characters and vicariously experience their struggles and triumphs, evoking genuine emotions (Mar & Oatley, 2008; Isberner et al., 2019; Sella et al., 2023). Research has demonstrated that engagement with fiction enhances ToM and social cognition, as readers consistently practice understanding and relating to diverse characters and their experiences (Mar et al., 2009; Kidd & Castano, 2013).

These unique cognitive and emotional processes involved in fiction reading may have important implications for both sleep and wellbeing. For sleep, the immersive nature of fiction may facilitate sleep onset by diverting attention away from real-world stressors and worries. This is supported by Molen et al. (2013) who found that for 42 adults with insomnia, introducing a calming book before bedtime improved both somatic and cognitive symptoms of insomnia. The authors suggested that pre-sleep reading acted as a worry-incompatible behaviour that reduced pre-sleep arousal. The cognitive engagement required for creating mental simulations and following narratives may also promote a sense of cognitive satisfaction and fulfilment, potentially reducing stress-related thought patterns that could interfere with sleep (Carrigan et al., 2020). Furthermore, fiction reading may benefit sleep by providing a structured and absorbing pre-sleep activity (Green & Brock, 2000) that helps establish a consistent and calming bedtime routine, which is known to be beneficial for sleep quality (Martin et al., 2000; Mindell & Williamson, 2018). The potential sleep-promoting effects of reading routines are well-documented in children, where bedtime story routines are associated with better sleep outcomes, including longer sleep duration, fewer night wakings, and reduced sleep anxiety (Burke et al., 2004; Galland & Mitchell, 2010; Hale et al., 2011; Krishnaswamy et al., 2017). These benefits are attributed to both the calming and predictable nature of the bedtime story routine and the emotional engagement it provides (McNally et al., 2021). The importance of pre-sleep routines may extend to adults, as demonstrated by Wickwire et al. (2009), who found that in adults with insomnia (mean age = 57.9), establishing rituals to unwind before sleep was associated with improved subjective sleep quality and better daytime functioning.

For wellbeing, these cognitive and emotional processes involved in fiction reading may offer several distinct benefits. The process of empathising with characters through theory of mind may foster meaningful emotional connections and vicarious experiences, which has been shown to reduce feelings of loneliness and social isolation (Mar & Oatley, 2008; Pettigrew & Roberts, 2008). This social-cognitive engagement may be particularly valuable as loneliness is often associated with reduced wellbeing (Golden et al., 2009; Tani et al., 2022). Beyond social benefits, the cognitive demands of creating mental simulations and following complex narratives may provide meaningful mental stimulation that promotes engagement and cognitive satisfaction. Simultaneously, the emotional involvement with characters and their stories can facilitate positive emotional experiences, stress reduction, and emotional

regulation (Sabatinelli et al., 2006; Mar et al., 2011). The combination of cognitive challenge and emotional engagement in fiction reading may also contribute to a sense of purpose and accomplishment, which are fundamental components of psychological wellbeing (Seligman, 2018). Moreover, by providing a structured and absorbing activity that can be independently pursued, fiction reading may help maintain autonomy and personal agency, factors that are particularly important for wellbeing in older adults and those with cognitive decline (Reis et al., 2010; van Loon et al., 2021).

Despite these promising indicators, research specifically investigating the impact of fiction reading on sleep and wellbeing remains surprisingly limited, especially among older adults and those with dementia. However, one study suggests that the hypothesised sleep-promoting effects of reading fiction may extend to people living with dementia (Billington et al., 2013; Claridge & Rimkeit, 2018). In a literature-based intervention called ‘Get Into Reading’, Billington et al. (2013) used a selection of prose material (i.e. short stories or short extracts from novels) that were read aloud in a group setting by individuals living with dementia. Each weekly session lasted no longer than an hour and was conducted over a 3- or 6-month period in a residential care or hospital setting. The study found that for all three care homes that participated in the study, neuropsychiatric symptoms were lower throughout the reading period than baseline as assessed by the Neuropsychiatric Inventory Questionnaire (NPI-Q; Cummings, 1997). The average NPI-Q scores indicated that for most participants, neuropsychiatric symptoms were not present for most of the intervention. Importantly, the NPI-Q includes measures of nighttime behaviours, capturing information related to circadian rhythm disruptions, such as waking too early, excessive daytime sleepiness, and sleep fragmentation. These are all markers of poor sleep quality (Abraham et al., 2017). Thus, the study by Billington et al. (2013) suggests that poor sleep improved across all participants, indicating that fiction reading may have sleep-enhancing effects. Furthermore, the study conducted semi-structured qualitative interviews with staff in all care settings. The qualitative findings suggested that reading sessions positively influenced quality of life and wellbeing, as denoted by the main themes identified by the authors, including enjoyment, authenticity, and meaningfulness of the reading-group experience, as well as a renewed sense of personal identity and enhancement of listening, memory, and attention skills

Given the prevalence and accessibility of reading (Gleed, 2013), there is a clear need for research investigating the impact of individual fiction reading on sleep, particularly among

older adults and those with dementia. The study by Billington et al. (2013) suggests that fiction reading may have sleep-enhancing effects, but the NPI-Q used in their research is not specifically designed to measure sleep quality. Additionally, their study was based on a shared-reading group model, making it difficult to determine whether the observed effects on ameliorating markers of poor sleep are due to fiction alone or the social aspect of shared reading. Research on children has shown that shared reading is important for promoting bonding and engagement with narratives (McNally et al., 2021), but the impact of individual fiction reading on sleep remains undetermined. This knowledge gap is important, as solitary reading could offer a more accessible, scalable, and personalised option than group interventions (Knechel, 2013). Moreover, the cognitive and emotional benefits of fiction reading, such as improved theory of mind, increased empathy, and reduced negative emotions, may be particularly relevant for older adults with dementia, who often experience social isolation, decreased quality of life, and sleep disturbances.

To address this gap, the present study aims to be the first to empirically investigate the effects of individual fiction reading on sleep quality and wellbeing in older adults with and without dementia, using a pre-post-test design and both objective (actigraphy) and subjective (sleep diaries and questionnaires) measures. The study will employ a 4-week fiction reading intervention before bedtime, a duration chosen based on research on habit formation (Gardner et al., 2022) which suggests that habits can research automaticity in as little as 18 days (Lally et al., 2010), and the recommended duration for actigraphy studies which is a minimum of 14 days (Grandner et al., 2006; Van Someren, 2007) ensuring that the intervention is long enough to establish a reading habit and account for day-to-day and week-to-week sleep variability. In addition to sleep quality, the current study will directly examine wellbeing using the PERMA-Profiler b(Butler & Kern, 2016) based on Seligman's PERMA wellbeing model (Seligman, 2010). This multidimensional assessment of wellbeing has not been explored in relation to fiction reading and sleep quality in older adults with and without dementia, representing another novel aspect of the current study. Finally, as research has shown that fiction is associated with reductions in negative emotions, the study will aim to assess mood disturbances to determine whether fiction reading before bedtime affects mood disturbances in these populations.

Moreover, individuals with Subjective Cognitive Decline (SCD), who perceive their cognition to be worse than in prior years but show no objective impairment on

neuropsychological tests, have been shown to have a higher prevalence of sleep issues compared to healthy age-matched counterparts (Jenkins et al., 2019; Liew, 2020). Given their increased risk of conversion to Mild Cognitive Impairment (MCI) and dementia, individuals with SCD are considered to have preclinical dementia. This study will additionally aim to determine the role of reading fiction on sleep quality for those with SCD, as they represent a unique opportunity to intervene at the earliest possible stage, given their increased prevalence of sleep issues and the relationship between sleep issues and subsequent cognitive decline.

The findings of this research could contribute to the development of accessible, scalable, and non-pharmacological interventions for enhancing sleep quality and wellbeing in older adults with and without dementia. If the results support the hypothesised benefits, the potential impact of this study could extend to promoting healthy ageing, enhancing quality of life and wellbeing, and reducing the negative consequences of sleep disturbances and cognitive decline. By examining the effects of a fiction reading intervention on sleep quality, overall wellbeing, and mood, this study aims to investigate the potential of creative bibliotherapy and provide evidence-based insights into the role of fiction reading in the context of sleep and quality of life in older adults with and without dementia. Thus, the following aims, objectives, research questions and hypotheses of this study are:

4.3 Aims

This study aims to determine whether four weeks of nightly reading affects sleep quality, wellbeing and mood disturbances for healthy older adults, older adults with Subjective Cognitive Decline (SCD) and adults living with Vascular Dementia (VaD).

4.4 Objectives

To achieve the study aims, this study will use a pre-post-test design, with a 4-week reading interval to determine whether there are differences across these three time periods according to subjective sleep quality (as measured by sleep diaries and questionnaires), objective sleep quality and quantity (as measured by actigraphy), wellbeing (as measured by self-report), and mood disturbances (as measured by self-report).

4.5 Research Questions

What is the impact of nightly fiction reading on sleep, wellbeing, and mood in healthy older adults (HOA), individuals with SCD and people living with vascular dementia (VaD)?

4.5.1 Additional research questions:

1. How does nightly reading affect objective and subjective sleep quality?
2. Does nightly reading influence self-reported wellbeing, and are any changes in wellbeing associated with changes in sleep quality?
3. What is the effect of nightly reading on self-reported symptoms of depression, anxiety, and stress?
4. Is the amount of time spent reading and engagement with fiction related to changes in objective and subjective sleep quality?
5. Are there differences in the effects of nightly reading on sleep, wellbeing, mood, and reading engagement between HOA, SCD, and VaD groups?

4.6 Hypotheses:

1. Objective and subjective sleep quality will improve during the reading intervention, but objective and subjective measures of sleep may differ significantly.
2. Self-reported wellbeing will improve during the reading intervention.
3. Self-reported symptoms of depression, anxiety, and stress will decrease during the reading intervention.
4. Greater reading time and narrative engagement will be associated with greater improvements in objective and subjective sleep quality and wellbeing during the reading phase.
5. The SCD group will show greater overall benefits from the reading intervention than the HOA group, and the VaD group will show greater overall benefits than both HOA and SCD groups.

This chapter presents two separate studies. The first study examines the association of fiction reading with sleep, wellbeing, and mood in healthy older adults and adults with self-reported Subjective Cognitive Decline (SCD). The second study follows the same protocol but focuses on individuals with Vascular Dementia (VaD). The findings and implications of both studies will be explored together in the general discussion section of this chapter.

4.7 Study 1: Healthy Older Adults and Adults with Self-Reported Subjective Cognitive Decline

4.7.1 Method

4.7.1.1 Design

The study used an 8-week mixed-methods, within-subjects, pre-post-test design to investigate the impact of a 4-week fiction reading intervention on sleep, wellbeing and mood in older adults with and without subjective cognitive decline (SCD). Participants completed baseline measures of sleep, wellbeing, and mood, followed by a 4-week reading intervention and measures of sleep, wellbeing and mood were collected every two weeks. Sleep quality was monitored objectively using actigraphy and subjectively using sleep diaries and questionnaires. Cognition was measured using rapid cognitive screening assessments, and wellbeing and mood were measured using self-report questionnaires.

4.7.1.2 Participants

Participants ($n = 29$) were community-dwelling healthy older adults aged between 65 and 83 years ($M = 71.55$, $SD = 5.46$), comprising 20 females and 9 males. All participants were fluent in English, had normal or corrected-to-normal vision and hearing, and had access to a computer with a video camera, which was necessary to complete cognitive assessments via Zoom calls. Three participants withdrew during the study (one lost to follow-up, one due to a family emergency and one due to a health issue), resulting in a final sample of 26 participants aged 65-83 years ($M = 72.88$, $SD = 5.67$; 18 females) with an average of 17.87 years of education ($SD = 4.55$). Ethical approval for this study was obtained by Swansea University's Psychology departmental ethics board (5305).

4.7.1.2.1 Recruitment

Participants were recruited using non-random convenience sampling using the Join Dementia Research (JDR) platform. The JDR is a collaborative effort led by the National Institute for Health and Care Research (NIHR) in partnership with Alzheimer Scotland, Alzheimer's Research UK, and Alzheimer's Society. The JDR platform is primarily focused on facilitating dementia research by connecting researchers with volunteers who have signed up to participate in dementia-related studies. The platform comprises a diverse pool of volunteers, including healthy individuals and those diagnosed with cognitive impairment. Researchers can use the JDR platform to identify and recruit suitable participants for their studies based on the volunteers' profiles, which include demographic information such as age, sex, ethnicity, and geographical location, as well as health-related data such as cognitive status and medical conditions.

4.7.1.2.2 Inclusion/Exclusion Criteria

Inclusion criteria were age: ≥ 65 years, community-dwelling, capacity to provide informed consent, fluency in English, and normal or corrected-to-normal vision and hearing. Exclusion criteria were: diagnosed sleep disorders, reading/writing impairments, moderate or severe depression/anxiety/stress on the Depression, Anxiety and Stress Scale-21 item (DASS-21), living in a care facility, and for the SCD group, other causes of cognitive impairment (see Table 1).

Table 40: Inclusion and Exclusion Criteria for SCD and HOA groups

	SCD	HOA
Inclusion	• Older adults (65+ years) • Capacity to provide informed consent • Fluency in English (as reading material will be given in English in addition to questionnaires/tests, which have not been validated in any other language) • Normal or corrected-to-normal hearing and vision • Access to a computer with a video camera (to conduct video calls) • CCI score (>16/80 on the first 12 items; individuals with <16 will be stratified to HOA group, providing all inclusion/exclusion of that group is met)	• Older adults (65+ years) • Capacity to provide informed consent • Normal or corrected-to-normal hearing and vision • Fluency in English • Access to a computer with a video camera (to conduct video calls)
Exclusion	• No other significant contributory cause of cognitive impairment (e.g. no other clinically significant neurological, psychiatric, or medical condition, no significant psychoactive drugs, no history of substance or alcohol dependency) • Diagnosed sleep disorder • Reading/writing impairment (e.g. dyslexia) • DASS-21 (cut-off scores for severity will be considered as moderate or above (i.e. depression ≥ 14, Anxiety ≥ 10, Stress ≥ 19). • Currently living in a care or assisted living facility	• Neurological, psychiatric or medical conditions that may affect cognition and mood • History of cognitive impairment Reading or writing impairment • A diagnosed sleep disorder (e.g. insomnia, sleep apnoea etc.) • DASS-21 (cut-off scores for severity will be considered as moderate or above (i.e. depression ≥ 14, Anxiety ≥ 10, Stress ≥ 19). • Currently living in a care or assisted living facility

4.7.1.3 Group Stratification

Participants were stratified into SCD (n=10) and Healthy Older Adults (HOAs; n=16) groups based on scores on the first 12 items of the Cognitive Change Index (CCI; Burke et al., 2004). The CCI is a self-report tool designed to assess perceived decline in memory, executive function, and language over the past five years. A score of ≥ 16 on the first 12 items, indicative of significant subjective memory changes (Risacher et al., 2015) was used to categorise participants as SCD, consistent with prior studies (Koppara et al., 2015; Verfaillie et al., 2019; Chen et al., 2020; Liew, 2020; Morrison et al., 2022).

Additionally, the SCD group classification aligns with the Subjective Cognitive Decline Initiative (SCD-I) working group's framework (Jessen et al., 2014), which proposes that individuals with SCD should show:

1. Self-experienced persistent cognitive decline compared to a previously normal status unrelated to an acute event.
2. Normal age, gender, and education-adjusted performance on standardised cognitive assessments used to screen for mild cognitive impairment (MCI) or prodromal Alzheimer's disease (AD).

Exclusion criteria, as per the SCD-I framework, included MCI, prodromal AD, dementia, or cognitive decline explained by psychiatric, neurologic, or medical disorders, medication, or substance use. Additionally, all participants demonstrated objectively normal cognitive functioning on the Montreal Cognitive Assessment (MoCA; ≥ 26), used as a screening measure for cognitive impairment. Table 41 presents group characteristics.

Table 41: Participant Demographics by Group Stratification

	HOA (n=10)	SCD (n=16)
Males/Females	3 males (30%), 7 females (70%)	5 males (31.25%), 11 females (68.75%)
Age (SD)	71.90 (4.91)	72.25 (6.19)
Age range	65-80	65-83
Years of Education (mean, SD)	16.80 (4.49)	17.94 (4.43)
Baseline MoCA (M, SD)	27.7 (2.54)	25.94 (2.38)
CCI first 12 items (M, SD)	13.6 (1.58)	25.00 (8.19)
CCI total (M, SD)	21.6 (1.577)	35.94 (10.96)
DASS total	2.3 (2.58)	4.31 (3.65)

4.7.2 Materials

To assess the impact of the reading intervention on various domains, several measures were used relating to sleep quality and quantity, cognition, mood and wellbeing and reading. Sleep was evaluated using both objective (actigraphy) and subjective (Pittsburgh Sleep Quality Inventory; PSQI (Buysse et al., 1989), consensus sleep diary, CSD (Carney et al., 2012)) measures. Cognitive function was assessed through a rapid screening tool (Montreal Cognitive Assessment; MoCA (Nasreddine et al., 2005) and a subjective measure of perceived cognitive change (Cognitive Change Index; CCI). Mood and wellbeing were captured using self-report questionnaires (DASS-21, PERMA-Profil) and semi-structured interviews. Reading engagement was measured using reading habit and attitude surveys, a reading diary, and the Story World Absorption Scale (SWAS). The specific measures used in each domain are detailed in Table 42 and described below.

Table 42: Materials and Measures According to Domain of Interest

Domain	Measure/Material	Primary Outcome
Sleep	Actigraphy (camntech Pro-Diary)	An objective measure of: a. Sleep Quality b. Sleep Quantity
	Pittsburgh Sleep Quality Index (PSQI)	A subjective measure of: a. Sleep Quality b. Sleep quantity
	Consensus sleep diary (CSD)	A subjective measure of: a. Sleep quality b. Sleep Quantity
Cognition	Montreal Cognitive Assessment (MoCA)	a. objective measure of cognitive function
	Cognitive Change Index (CCI)	a. subjective measure of cognitive change over the last five years
Mood	Depression, Anxiety and Stress Scale-21 Item (DASS-21)	a. Self-report of mood disturbance symptoms, including depression, anxiety and stress
Wellbeing	PERMA- Profiler	a. Subjective measure of wellbeing (positive emotions, engagement, relationships, meaning, achievement. Negative emotions and loneliness)
Reading	Reading Diary	Tracker for completed stories and frequency of reading during the reading period
	Story World Absorption Scale (SWAS)	Measures 4 dimensions of reading cognition: attention, emotional engagement, mental imagery, transportation
	Reading material	5 Dovetale Press dementia-friendly books to read over the reading period and a book of Haikus

4.7.2.1 Sleep Measures

4.7.2.1.1 Actigraphy

The study used wrist-worn actigraphy to objectively measure sleep quality and quantity (Pro-Diary, CamNTEch, Cambridge, UK). The Pro-diary includes a tri-axial accelerometer that records data based on physical movements. The pro-diary captures estimates of daytime activity and sleep parameters such as Total Sleep Time (TST), Sleep Onset Latency (SOL), Sleep Efficiency (SE), Wake After Sleep Onset (WASO), Number of Awakenings (NA) and Sleep Fragmentation Index (SFI). The data is sampled at 50Hz and measures movement in terms of peak acceleration, where values are compared to a minimum threshold of ‘not moving’ (0.1g). Values above the minimum threshold are summed over a 30-second epoch to produce activity counts.

4.7.2.1.2 The Consensus Sleep Diary

The Consensus Sleep Diary (CSD; Carney et al., 2012) is a paper-based tool used to measure subjective evaluations of overall sleep quality and quantity. The CSD is a product of collaboration between insomnia sufferers and sleep researchers to create a universally adopted and standardised subjective sleep diary. Historically, sleep research has used many different sleep diaries that measure different sleep parameters, leading to inconsistent and non-comparable metrics across studies (Carney et al., 2012). This has inevitably complicated comparisons and replications. As such, the CSD was chosen for this study due to the standardised nature of the diary, which facilitates future replications and comparisons, given that this is a novel study.

The CSD offers two versions: a core version encompassing nine items and an extended version with 15 items. For the sake of reducing participant burden in this study, the 9-item core version was used. This version records several aspects of sleep, such as time in bed, time attempted to sleep, sleep onset, time taken to fall asleep, number and duration of awakenings, wake time, time out of bed, and overall sleep quality rated on a 1-5 Likert scale (from very

good to very poor). An additional field for comments is also provided. From this information, metrics such as SE, TST, WASO, and SOL can be calculated.

4.7.2.1.3 Pittsburgh Sleep Quality Index Questionnaire (PSQI)

The Pittsburgh Sleep Quality Index Questionnaire (PSQI; Buysse et al., 1989) is a self-rated questionnaire to assess subjective sleep quality over the prior month. It can also be used to categorise individuals as either ‘good’ or ‘poor’ sleepers based on a global score. It comprises 19 items generating seven ‘component’ scores, including SOL, TST, SE, sleep disturbances, use of sleep medication, daytime dysfunction, and overall sleep quality. These scores are summed to provide a global score (range 0-21), with higher scores denoting poorer sleep quality. A global score of ≥ 5 characterises a ‘poor sleeper’, and ≤ 4 indicates a ‘good sleeper’. The PSQI has been validated for older adults (Spira et al., 2012; Landry et al., 2015).

In terms of reliability, the PSQI demonstrates good internal consistency with a healthy adult population ranging from $\alpha=0.80$ (Carpenter & Andrykowski, 1998) to $\alpha=0.83$ (Buysse et al., 1989) and adequate internal consistency with older adults ($\alpha=0.69$). For example, worse PSQI scores have been correlated with higher depressive symptomology on the Geriatric Depression Scale ($r=.13$, $p<.001$; GDS; Yesavage & Sheikh, 1986) and lower health-related quality of life on the SF-12 ($r=-.30$, $p<.001$; Ware et al., 1996). Concerning criterion validity, a study conducted on a non-clinical sample of older and younger adults found that the PSQI moderately correlates with sleep diary variables and the CESD depression scale (Radloff, 1977), but does not strongly correlate with actigraphic data (Grandner et al., 2006). This discrepancy may indicate that the PSQI captures more of an individual’s subjective dissatisfaction or attitudes towards their sleep rather than specific sleep-related disturbances per se.

Whilst the PSQI may not closely mirror objective sleep measures, it can provide insight into an individual’s perception of their sleep experience. For this reason, it has been suggested that the PSQI should not be used in isolation to measure sleep quality but rather in conjunction with objective measures such as actigraphy (Landry et al., 2015; Zitser et al., 2022). This dual approach has been adopted for this study as the insights into the perception of participant’s

sleep may provide valuable insights. For example, discrepancies between objective and subjective measures can reveal useful information about an individual's perception of their sleep quality. This, in turn, could be an important factor in their response to an intervention. Therefore, the use of both the PSQI and actigraphy offers a more comprehensive view of older adult's sleep experience.

4.7.2.2 Cognition Measures

4.7.2.2.1 Montreal Cognitive Assessment (MoCA)

The Montreal Cognitive Assessment (MoCA; Nasreddine et al., 2005) is a widely used and validated cognitive screening tool that assesses multiple domains of cognition including executive function, visuospatial abilities, attention, concentration, working memory, language, abstract reasoning, memory, and orientation. The assessment is intended to assist health professionals in detecting Mild Cognitive Impairment. The test is administered orally and takes approximately 10 minutes, with a maximum score of 30. An extra point is added to the total score of patients with 12 or fewer years of education to account for educational level. A score of ≥ 26 is generally considered normal, and the MoCA is more accurate than other screening tools in detecting mild cognitive impairment. The MoCA is available in several languages and is commonly used in research and clinical practice. The MoCA demonstrates good internal consistency ($\alpha=0.79$; Daniel et al., 2022).

4.7.2.2.2 Cognitive Change Index

The Cognitive Change Index-Self Report (CCI-S; Rattanabannakit et al., 2016) is a subjective tool for assessing perceived shifts in cognitive abilities over the past five years. Comprising 20 items, the instrument gauges self-reported changes across various cognitive domains such as memory, executive function, and language. Responses are captured using a Likert scale that ranges from 1 to 5, where higher scores denote greater perceived decline in cognition (1 = no change or normal ability, 2 = minimal change or slight/occasional problem, 3 = some change or mild problem, 4 = clearly noticeable change or moderate problem, 5 = much worse or severe problem).

The initial 12 items of the CCI-S focus on memory. Research has established that scores exceeding 16 on these first 12 items effectively differentiate individuals with subjective memory complaints from those without such complaints. This differentiation is corroborated through comparative analyses with other cognitive performance metrics, such as the Wechsler Logical Memory Delayed Recall (LM-Delayed) and the Mini-Mental State Exam (MMSE; Risacher et al., 2015; Jenkins et al., 2019). Consequently, in this study, participants who scored 16 or higher on the initial 12 items were classified as exhibiting Subjective Cognitive Decline (SCD), in contrast to those without, classified as Healthy Older Adults (HOA). The CCI-S shows good internal consistency ($\alpha=.96$; Risacher et al., 2015).

4.7.3 *Mood Disturbances*

Mood disturbances are measured using the Depression, Anxiety and Stress Scale 21-item (DASS0-21; Lovibond & Lovibond, 2011), which is a self-report tool that measures perceived symptoms of depression, anxiety and stress. It consists of 21 items with 7 questions pertaining to depression, anxiety and stress, respectively. Each item is scored on a 4-point Likert scale ranging from 0 ‘did not apply to me’ to 3 ‘applied to me very much’. The thresholds for normal, mild, moderate, severe and extremely severe symptoms for each subscale are listed in Table 43. The DASS-21 demonstrates excellent internal consistency in samples of older adults ($p = .94$) and acceptable discriminative validity, with significant differences observed between groups with and without mood disorders (β ranges from .54 to 1.52, $p < .05$ to $p < .001$; (Gloster et al., 2008).

Table 43: DASS-21 Symptom Severity Scoring Thresholds

	<i>Depression</i>	<i>Anxiety</i>	<i>Stress</i>
<i>Normal</i>	0-4	0-3	0-7
<i>Mild</i>	5-6	4-5	8-9
<i>Moderate</i>	7-10	6-7	10-12
<i>Severe</i>	11-13	8-9	13-16
<i>Extremely Severe</i>	14+	10+	17+

4.7.3.1 Wellbeing (PERMA-profiler)

The PERMA-Profiler (Butler & Kern, 2016) is a validated 15-item scale designed to measure the five pillars of wellbeing according to Seligman's PERMA theory (Seligman, 2010). The theory proposes that wellbeing consists of five key elements: Positive emotions, Engagement, Relationships, Meaning, and Accomplishment. The PERMA-profiler scale includes three items per subscale, assessing each of the five pillars. Additionally, the PERMA-Profiler incorporates eight 'filler' items that capture negative emotions, loneliness, and overall happiness, providing a more comprehensive evaluation of an individual's well-being. Respondents rate each item on an 11-point Likert scale ranging from 0 to 10, with all items worded in a positive direction. Higher scores on the PERMA-Profiler indicate better wellbeing. To calculate subscale scores, the three items corresponding to each subscale are averaged. The overall wellbeing score is determined by calculating the mean of the five PERMA subscale scores.

4.7.3.2 Reading Measures

4.7.3.2.1 The Story World Absorption Scale (SWAS)

The study used the Story World Absorption Scale (SWAS; Kuijpers et al., 2014) to measure story world absorption. The SWAS is an 18-item self-report questionnaire that assesses four dimensions of absorbed reading: Attention, Transportation, Emotional Engagement, and Mental Imagery. Participants rate each item on a 7-point scale ranging from -3 (completely disagree) to 3 (completely agree). The Attention subscale measures the degree to which readers are focused on the story, while the Transportation subscale assesses the extent to which they feel immersed in the story world. The Emotional Engagement subscale assesses readers' emotional involvement with the characters, and the Mental Imagery subscale evaluates their ability to visualise the story's settings and events. The SWAS has demonstrated strong internal consistency, with Cronbach's alpha values ranging from .88 to .95 for the overall scale and from .66 to .91 for the individual subscales (M. M. Kuijpers, 2020).

4.7.3.2.2 Reading Material and Diary

The study provided participants with a curated selection of reading materials, including four adapted classic novels and one poetry book. The adapted novels were created by Dovetale Press and designed to be dementia-friendly. These adaptations included "A Christmas Carol" by Charles Dickens, "Little Women" by Louisa May Alcott, "Sherlock Holmes" by Arthur Conan Doyle, and "The Garden Party and Doll's House" by Katherine Mansfield. The poetry book, "Poetry for The Restless Heart," was co-authored by Dr B Sally Rimkeit and Dr Gillian Claridge.

To make the reading experience more accessible and engaging for individuals with dementia, Dovetale Press implemented several modifications in their adaptations. These changes included simplifying the language to enhance comprehension, shortening the text to reduce cognitive burden, increasing the space on each page to improve readability, and incorporating visual aids to support understanding. The adapted books featured memory aids in the form of short summaries throughout the text, helping readers maintain a clear grasp of the story's progress. Additionally, participants received an unpublished book of haikus accompanied by illustrations created by Professor Julia Lockheart. This unique collection of short, evocative poems aimed to provide a different reading experience, allowing participants to engage with various fiction. Finally, participants received a paper reading diary to track the frequency and duration of reading sessions over the 4-week reading period.

4.7.4 Procedure

4.7.4.1 *Recruitment and Consent*

Prospective participants were contacted through the Join Dementia Research (JDR) platform via email and telephone. They received an invitation to join the study, a study poster, and a participant information sheet. Interested individuals attended informational telephone calls to discuss the study in detail and ask questions. Participants then completed an online consent form, with additional phone consultations available for further clarification.

4.7.4.2 Screening

After gaining informed consent, participants completed an online eligibility questionnaire. The questionnaire had several criteria, including an age limit of 65 and above and a requirement for English fluency. Other criteria required normal vision and hearing due to the study's reading and video call elements. Participants were also screened for major neurological or psychiatric conditions, medication effects, and substance abuse history. Exclusion criteria included reading or writing disorders, living in a care facility, and high scores on the Depression, Anxiety, and Stress Scale (DASS-21). Specifically, scores that led to exclusion were 14 or higher for depression, 10 or higher for anxiety, and 19 or higher for stress. Those with diagnosed sleep disorders were also excluded.

4.7.4.3 Enrolment

Eligible participants attended a 45-minute Zoom video call to administer the Montreal Cognitive Assessment (MoCA) and explain the study's procedures. Following this, participants received study materials to their home addresses by post. The study commenced once participants had received their materials, which included:

- Participant information sheet
- Camntech Pro-Diary actigraph with charging cable
- Actigraphy usage and maintenance guide
- Consensus Sleep Diary
- Reading Diary
- Reading Materials (Four dementia-friendly books from Dovetale Press, one poetry book and a Haiku Book)
- Frequently Asked Questions document (to address protocol-related questions)
- Study design schematic
- Appointment tracking sheet with questionnaire deadlines and assessment timelines
- Thank-you note

4.7.4.4 Baseline Measures

At the beginning of the study, participants completed a questionnaire online using Qualtrics (Insert version) to capture baseline measures of sleep quality, mood, and wellbeing. The questionnaire included a subjective sleep quality questionnaire (PSQI), a perceived subjective cognitive decline questionnaire (the Cognitive Change Index) to stratify groups into HOA and SCD groups, and a questionnaire assessing wellbeing (PERMA-profiler). Participants were then instructed to complete their daily sleep diary (Consensus Sleep Diary) over the next 8-weeks and abstain from reading fiction before bedtime for two weeks. To ensure the correct interpretation of each item on the CSD, item-specific instructions were provided to participants within the diary. All items were to be completed in the morning within one hour of getting out of bed, as stated in the instructions.

Participants were told to wear their actigraphs from the beginning of the study and to remain wearing them for the 8-week duration. The impact of wrist placement appears minimal regarding data accuracy (Driller et al., 2017). However, older adults typically have lower activity levels than younger populations (M. G. Davis & Fox, 2007). For devices using threshold-based scoring algorithms, these lower activity levels may distort accuracy (Fanning et al., 2022). We instructed individuals to wear the actigraphy devices on their dominant wrist to optimise data accuracy for our older participant demographic. The dominant wrist tends to be more active, potentially mitigating inaccuracies from threshold-based scoring algorithms in a lower-activity population.

Participants wore the actigraphy devices for at least 14 days before and after the reading period, following recommendations for adequate wear time (Van Someren, 2007; Grandner et al., 2012; Landry et al., 2015). While seven days were previously deemed sufficient to capture daily sleep variability, more recent evidence indicates 14 days better captures week-to-week variability (Grandner et al., 2012; Landry et al., 2015). Over the full 8-week study duration, participants were instructed to wear the devices continuously, except when in contact with water, as the Pro-Diary is not waterproof. To ensure proper usage and maintenance, participants received detailed instructions emphasising dominant wrist placement for optimal data accuracy. This guide covered essential points like charging and positioning. The raw actigraphy data was downloaded and analysed using MotionWare software version 1.3.17 (CamNTEch, 2021).

4.7.4.5 Week 2

In week 2, participants were instructed to begin the reading period. For the 4-week reading period, participants were instructed to read fiction for at least 10 minutes every night before going to sleep. As this is a novel study with no established guidelines for optimal reading durations in this context, the 10-minute daily interval was chosen to balance the goals of encouraging consistent participation and minimising the burden on participants. While participants were allowed to read longer if desired, the 10 minutes was the minimum daily reading time.

To maintain engagement and accommodate individual preferences, participants were free to choose any fiction book for the study, rather than being limited to the provided reading material. However, in line with traditional sleep hygiene guidelines that discourage non-sleep activities in bed (Wickwire et al., 2009), participants were advised to engage in their reading activity outside of bed, immediately before sleep. This precaution was taken to mitigate the risk of developing counterproductive associations with the sleep environment, as the effects of reading on sleep and mood are not yet well understood.

Participants were required to maintain a daily reading diary to document their reading habits. The diary captured details such as the frequency and duration of reading sessions, fluctuations in relaxation levels before and after reading using a 5-item Likert scale from -2 (not relaxed at all) to 2 (very relaxed), and the level of interest in the chosen reading material in a similar fashion -2 (not interested at all) to 2 (very interested). In addition to the reading diary, participants received an online questionnaire that included the PSQI to measure sleep quality, the DASS-21 to evaluate mood, and the PERMA-profiler to assess overall wellbeing.

4.7.4.6 Week 4

In week 4, participants were asked to complete an online questionnaire that included PSQI, DASS-21, and the PERMA profiler. Participants were asked to continue completing their reading and sleep diaries.

4.7.4.7 Week 6

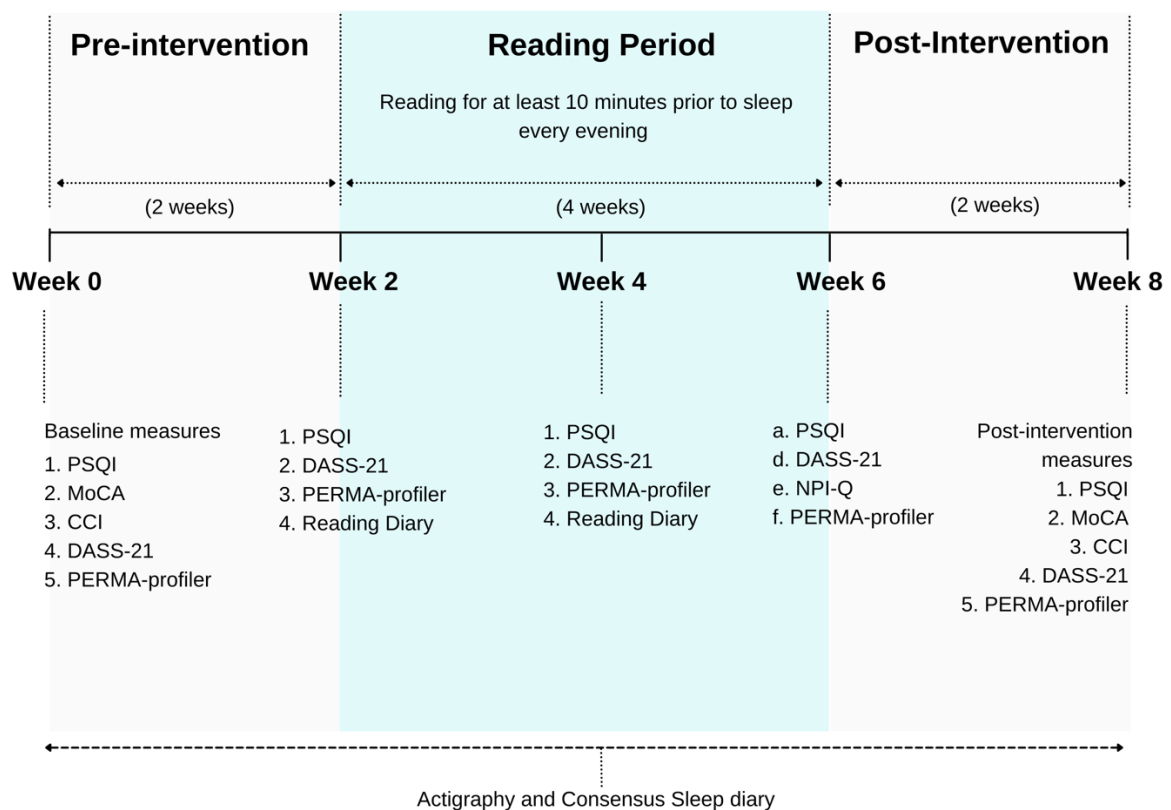
At the end of the 4-week reading period (week 6 of the study), participants were prompted to complete a questionnaire similar to the one administered at week 4. However, this questionnaire included another measure called the Story World Absorption Scale (SWAS; Kuijpers et al., 2014). The SWAS is a tool designed to assess various aspects of the reading experience, providing insight into the participants' level of engagement with the narrative. The SWAS measures four key dimensions of story world absorption: narrative transportation, mental imagery, focused attention, and emotional engagement. Narrative transportation refers to the extent to which readers feel immersed in the story world as if they have been transported into the narrative. Mental imagery assesses the vividness and detail of the reader's mental pictures of the story's settings, characters, and events. Focused attention evaluates the degree to which readers can concentrate on the story and block out external distractions. Finally, emotional engagement assesses the reader's emotional connection to the characters and their experiences.

When answering the SWAS questions, participants were instructed to reflect on the most captivating book they had read during the study. This approach aimed to capture the maximum extent to which participants had become absorbed in a narrative of their choice. After completing the week six questionnaire, including the SWAS, participants were directed to stop their nightly reading sessions and their daily reading diary entries.

4.7.4.8 Week 8

At the end of the study, participants were asked to complete a final questionnaire, which incorporated measures such as the PSQI, CCI, DASS-21, and PERMA-profiler. Subsequently, participants were invited to complete a final MoCA and were given the opportunity to ask questions about the study. All study materials were then posted back to the research team using prepaid postage. Finally, participants were then formally debriefed and thanked for their valuable contributions to the research.

Figure 27: A Schematic overview of the Study Procedure



4.7.5 Analysis

To examine the changes in variables regarding sleep, wellbeing, and mood in relation to reading activity across the study, variables are aggregated into three distinct periods: pre-intervention (baseline to week 2), intervention (weeks 3-6), and post-intervention (weeks 7-8), giving rise to 3 average scores for each variable. A series of analyses are performed to examine the effect of the reading intervention on sleep, wellbeing, mood and reading activity variables.

4.7.5.1 Sleep

A series of 3x2 mixed factorial ANOVA was conducted to assess the effects of the within-subjects factor of the study phase (three levels: pre-intervention, intervention, and post-intervention) and between-subjects factor of group (HOA vs. SCD) on sleep variables. This

included examining global PSQI score, CSD sleep quality, actigraphically derived sleep quality, objective Total Sleep Time (TST), objective Sleep Onset Latency (SOL), objective Sleep Efficiency (SE) and objective Sleep Fragmentation (SF). Assumption checks for all sleep-related dependent variables were conducted using Levene's test for homogeneity of variances and tests for sphericity, which are presented in the results section. Where violations of the assumptions occur, strategies for addressing and managing the violations are discussed within each corresponding section.

4.7.5.2 Actigraphic Sleep Parameter Calculations

To determine objective sleep quality based on the multiple sleep parameters measured by the actigraph, a composite measure was created based on the methods of Landry et al. (2015). This included averaging the z-scores of Total Sleep Time (TST), Sleep Efficiency (SE) and Sleep Fragmentation Index (SFI). The SFI was multiplied by -1 before averaging as a high SFI score represents more sleep fragmentation, indicating poor-quality sleep. A high SE, on the other hand, is indicative of good-quality sleep. Therefore, the transformation of the SFI by multiplying by -1 results in a composite score where higher scores represent better sleep quality.

Determining TST requires establishing a 'sleep window', a period in which an individual is likely to be asleep based on their typical sleep pattern. Ideally, a light sensor would be used to determine 'lights off (bedtime)' and 'lights on (wake time)', clearly defining the sleep window. In the absence of a light sensor to determine 'lights off' and 'lights on' to indicate bedtime and wake time, the Consensus Sleep Diary (CSD) was used. This included using the time self-recorded for sleep onset, minus the Sleep Onset Latency (SOL), to determine 'lights out' or bedtime. To determine 'lights on,' the time recorded for waking up was used. The decision was based on prior research suggesting that actigraphy may not be as accurate in determining SOL, as individuals might be motionless yet awake, resulting in a false indication of sleep in the actigraphic record (Fekedulegn et al., 2020).

Following the protocol used by (Van Den Berg et al., 2008), Sleep Start was determined using the first immobile period of at least 10 minutes after bedtime, or 'lights off', with no more than one 30-second epoch of movement within that period. The midpoint of this was

classified as Sleep Start. Similarly, Sleep End was determined by identifying the final period of at least 10 minutes of immobility before waking up, with no more than one 30-second epoch of movement. The last epoch of this period was classified as Sleep End.

TST was calculated as the period between Sleep Start and Sleep End minus bouts of wakefulness as identified by MotionWare. SOL was determined by subtracting the time between Sleep Start and when an effort to sleep was made (from the CSD). SE was calculated by dividing the TST by the Time In Bed (TIB) and multiplying by 100. TIB is determined by calculating the elapsed time between self-recorded bedtime and Got Up time, which MotionWare automatically calculates. See Table 44 for the summary of the sleep parameter calculation.

Table 44: Actigraphy Parameter Measurements

Sleep Parameter	Description of Measurement
Bedtime (lights off)	The time indicated for bedtime in the CSD sleep diary is subtracted from the time noted for attempting to sleep.
Sleep Start	Sleep start is measured by the midpoint of an Immobile period 10 minutes after bedtime with no more than one 30-second epoch of activity. (Landry et al., 2015)
Sleep End	Final 10 mins of immobility (before waking up), with no more than one 30-second epoch of activity. The last epoch of this period is calculated as Sleep End.
Got Up	MotionWare automatically calculates the threshold of activity count.
TST	The total time spent in sleep according to the epoch-by-epoch wake/sleep categorisation by MotionWare.
Sleep Onset Latency (SOL)	Calculated sleep start time subtracted from the bedtime recorded in the CSD sleep diary.
Sleep Efficiency	(Actual sleep time expressed as a percentage of time in bed) = $(TST - WASO) / (\text{time in bed}) \times 100$

Sleep Fragmentation	Calculated as the sum of 'Mobile Time (%)' and 'Immobile Bouts ≤ 1 min (%)', this metric serves as an indicator of sleep period fragmentation and, consequently, a proxy for sleep quality. Here, 'Mobile Time (%)' refers to the duration of mobility during the presumed sleep period, expressed as a percentage of the total assumed sleep time.
Quality Composite	Average of Z-scores of (TST + SE + (SFI x-1))

4.7.5.3 Objective Versus Subjective Measures of Sleep

A series of Pearson's r correlation analyses assessed the relationship between objective and subjective sleep quality measures. Specifically, we examined the correlations between actigraphy sleep quality and PSQI scores, as well as between actigraphy sleep quality and CSD sleep quality. For all correlation analyses, the assumption of normality and linearity were checked for and reported. If these assumptions were violated, non-parametric alternatives such as Spearman's Rho were used and reported where applicable.

4.7.6 Wellbeing

To determine whether wellbeing changed throughout the study in relation to the reading period, a series of 3x2 factorial mixed ANOVAs were conducted. This analysis included a between-subjects factor of group and a within-subjects factor of the study phase. The PERMA-Profilers subscales of Positive Emotion, Engagement, Relationships, Meaning, Achievement, Loneliness, and Negative Emotion, along with overall wellbeing (PERMA), were used as dependent variables in this analysis.

4.7.7 Wellbeing and Sleep

Next, to determine whether changes in wellbeing across the study phase were correlated with changes (Δ) to sleep quality, a series of Pearson's r correlation analyses were conducted on

Δ PERMA versus Δ actigraphy sleep quality, Δ PERMA and Δ global PSQI scores, and Δ PERMA and Δ CSD sleep quality.

4.7.8 Mood

To assess the impact of the reading intervention on mood disturbances, as measured by the DASS-21, a series of 3x2 factorial ANOVAs were conducted on the subscale scores for depression, anxiety, and stress. Additionally, overall mood disturbance was evaluated by combining these subscale scores.

4.7.9 Reading

To determine whether time spent reading was related to sleep quality, Pearson's r correlation analyses were conducted between time spent reading and three measures of sleep quality: actigraphy sleep quality, CSD sleep quality, and the PSQI global score. Next, to determine whether narrative engagement was related to sleep quality, subscales of the SWAS, including Attention, Emotional Engagement, Mental Imagery and Transportation, were correlated with PSQI global scores, CSD sleep quality and actigraphy sleep quality.

4.7.10 Covariates

Given the exploratory nature of this research, I have chosen not to control for common covariates such as age, sex, and years of education. Controlling for these variables could mask important nuances, as demonstrated by (Shapiro et al., 2021) in health research. Treating these factors as confounding variables risks assuming uniform effects across levels, potentially obscuring critical interactions for future interventions (VanderWeele & Knol, 2014). Moreover, the small sample size raises concerns about overfitting and reduced statistical power when introducing multiple covariates (Hawkins, 2004). As one of the first studies in this specific context, the aim is to provide a foundational understanding of the raw, uncontrolled effects of the intervention. While acknowledging the limitations, this approach allows for a more general exploration of the data, potentially revealing important patterns that might otherwise be obscured. Future research can build upon these findings by investigating

how these highlighted covariates might moderate or mediate the observed effects, improving targeted investigations.

4.7.11 Participants Analysis

Of the 26 participants who completed the study, 16 adhered to the prescribed 4-week reading protocol within the set timeframe (i.e. the start of week 3 to the end of week 6). Of the 10 who did not adhere to the set reading protocol, a subgroup of 6 participants read continuously over the study's full 8-week duration, citing a preference to continue reading fiction rather than abstaining for two weeks before and after the intervention period. Additionally, four participants deviated from the designated 4-week reading protocol: one extended the reading to 5 weeks, and three others read for 6 weeks. The underlying reasons for these deviations are unclear.

However, a detailed review of participant compliance revealed that all participants who completed the study adhered to the core requirement of reading fiction for at least 10 minutes before sleep during the designated 4-week reading phase and that all participants did not read fiction before sleep outside of this timeframe. To confirm this, specific questions were asked at the beginning of the study, which explored participants' perceptions regarding the cessation of bedtime reading during the final 2 weeks of the study. Additionally, at the end of week 8, participants were asked about the activities that replaced bedtime reading during the last 2 weeks of the study. Furthermore, email reminders were sent to participants, instructing them to refrain from reading before bed during the specified 2-week periods at the beginning and end of the study. In response to questions about their feelings regarding not reading in the last 2 weeks and the activities that replaced evening reading, all participants confirmed that they had read before bedtime during the intervention phase. Outside this phase, participants reported completely abstaining from reading fiction or only reading during the daytime.

Thus, a 3-step analysis approach was employed to account for protocol deviations. First, a preliminary analysis was conducted to determine if there were any differences between the participants who completed the protocol properly (full protocol group) and those who deviated from it (nighttime reader group). A series of 3x2 mixed repeated measures ANOVAs were conducted. These analyses focused on sleep quality (measured by actigraphic sleep

quality, sleep diary, and PSQI), wellbeing (mean PERMA score), and mood (mean DASS-21 score). The within-subject factor was the study phase (pre, intervention, and post), and the between-subject factor was the protocol group (full protocol versus bedtime reader protocol).

No significant differences between full and part-protocol compliant participants were found across any of the study variables, suggesting that reading before bed, rather than during the daytime, may reflect any changes in study variables found in subsequent analyses. Second, based on the findings from the preliminary analysis, a full sample analysis was conducted using data from all participants, examining the impact of nighttime reading on study variables, irrespective of daytime reading outside of the dedicated reading period. Third, to ensure the robustness of the findings, an analysis was performed using only the data from participants who strictly followed the protocol. Results of this analysis are provided in the appendix and are discussed in connection with the results from the full sample.

4.7.12 Results

Table 45: Descriptive Statistics for Objective and Subjective Sleep Quality and Objective Sleep Variables

Variable	Group (n=26) HOA (n=10) SCD (n=16)	Study Phase		
		Pre-intervention Mean (SD)	Intervention Mean (SD)	Post-Intervention Mean (SD)
Global PSQI Score	HOA	5.65 (1.70)	3.75 (.95)	3.80 (1.03)
	SCD	7.22 (2.83)	4.59 (1.20)	4.56 (1.79)
Consensus Sleep Diary Sleep Quality	HOA	3.60 (.45)	3.85 (.47)	3.53 (.42)
	SCD	3.33 (.73)	3.52 (.68)	3.35 (.64)
Actigraphy Composite Quality Score	HOA	.46 (2.16)	.50 (1.97)	.12 (1.93)
	SCD	-.20 (2.08)	-.30 (1.87)	-.02 (1.35)
Objective Total Sleep Time (seconds)	HOA	25803.22 (2341.14)	26701.05 (1992.24)	25182.75 (1922.29)
	SCD	26196.19 (3380.87)	26734.95 (2649.10)	25804.13 (2911.56)
Sleep Latency (seconds)	HOA	850.87 (765.89)	780.33 (470.52)	838.99 (362.55)
	SCD	793.93 (649.51)	731.95 (502.79)	668.55 (493.21)
Sleep Efficiency (%)	HOA	88.55 (3.81)	88.50 (3.64)	88.47 (2.04)
	SCD	87.83 (4.32)	87.98 (3.73)	88.75 (3.71)
Sleep Fragmentation (SFI index)	HOA	22.33 (5.83)	22.83 (6.85)	24.75 (6.87)
	SCD	28.77 (9.30)	28.26 (8.48)	27.47 (10.83)

Table 46: Descriptive Statistics for Wellbeing Variables (PERMA-Profiler)

Variable	Group (n=26) HOA (n=10) SCD (n=16)	Study Phase		
		Pre- intervention Mean (SD)	Intervention Mean (SD)	Post- Intervention Mean (SD)
Global Wellbeing (PERMA)	HOA	7.88 (1.17)	7.63 (1.76)	8.14 (1.20)
	SCD	8.09 (1.10)	8.36 (1.02)	8.33 (1.20)
Positive Emotion	HOA	7.70 (1.30)	7.63 (1.76)	7.50 (1.84)
	SCD	7.85 (.87)	8.36 (1.02)	8.25 (1.13)
Engagement	HOA	7.53 (1.18)	7.82 (1.43)	7.83 (1.71)
	SCD	7.76 (1.04)	7.98 (1.07)	8.19 (.95)
Relationships	HOA	7.98 (1.87)	8.40 (1.95)	7.83 (1.71)
	SCD	8.52 (1.54)	8.33 (1.60)	8.19 (.95)
Meaning	HOA	7.70 (1.55)	8.02 (2.06)	8.03 (2.15)
	SCD	8.35 (1.70)	8.46 (1.78)	8.38 (1.76)
Achievement	HOA	8.25(.85)	8.37 (.95)	8.08 (1.47)
	SCD	7.34 (1.33)	8.09 (1.26)	8.08 (1.47)
Loneliness	HOA	1.90 (2.73)	2.55 (3.49)	2.20 (3.22)
	SCD	3.19 (2.55)	1.78 (1.78)	1.81 (2.43)
Negative Emotion	HOA	2.88 (1.11)	2.80 (.93)	2.63 (1.16)
	SCD	3.94 (1.90)	2.94 (1.68)	2.71 (2.08)

Table 47: Descriptive Statistics for Mood Variables (DASS-21 Item)

Variable	Group (n=26) HOA (n=10) SCD (n=16)	Study Phase		
		Pre-intervention Mean (SD)	Intervention Mean (SD)	Post-Intervention Mean (SD)
Global Mood (DAS)	HOA	2.90 (2.69)	2.85 (2.46)	2.60 (2.46)
	SCD	4.94 (3.08)	3.91 (3.46)	3.25 (2.82)
Depression	HOA	.75 (1.21)	.80 (1.84)	1.00 (.56)
	SCD	.97 (1.27)	.50 (1.03)	.56 (1.09)
Anxiety	HOA	.90 (.94)	.75 (.63)	1.00 (1.33)
	SCD	1.63 (1.30)	1.13 (1.10)	1.50 (1.41)
Stress	HOA	1.35 (1.33)	1.40 (2.34)	.60 (.70)
	SCD	2.41 (1.42)	2.34 (1.96)	1.19 (1.42)

Table 48: Descriptive Statistics for Reading Variables

Variable	Group (n=26) HOA (n=10) SCD (n=16)	Study Phase
		Intervention Mean (SD)
Mean time spent reading per week (minutes)	HOA	35.68 (23.62)
	SCD	31.49 (11.32)
SWAS (M, SD)	HOA	4.93 (.36)
	SCD	4.86 (.85)
Attention	HOA	5.68 (.45)
	SCD	5.48 (.82)
Transportation	HOA	2.76 (.76)
	SCD	3.07 (1.39)
Emotional Engagement	HOA	5.36 (.61)
	SCD	4.92 (1.28)

4.7.12.1 Baseline Differences Between Groups

Before conducting the 3x2 factorial ANOVAs, a series of independent samples t-tests were conducted to determine whether there were any baseline differences between the groups (HOA and SCD). This step was taken to ensure that any observed effects in the ANOVA were not due to pre-existing differences. When the assumption of normality was violated, as assessed by the Shapiro-Wilk test, a Mann-Whitney U test was performed. When the assumption of equality of variances was violated, as assessed by Levene's test, a Welch's t-test was used to handle unequal variances.

Results showed no differences for most variables at baseline between the HOA and SCD groups. However, there were exceptions. For self-reported achievement, Welch's t-test indicated a significant difference ($t(22.66) = 2.48, p = .02, d = .92$) with HOAs (Median = 8.33, IQR = .67) reporting higher achievement than the SCD group (Median = 7.00, IQR = 2.17). For self-reported negative emotion, Welch's t-test indicated a significant difference ($t(23.33) = -2.22, p = .04$) with the SCD group (Median = 3.50, IQR = 3.08) reporting higher levels of negative emotions compared to the HOA group (Median = 2.50, IQR = 2.00). These baseline differences will be considered when discussing the main effects of study phase and group, as well as the interactions between these factors for the relevant variables.

Table 49: Assumption Checks for Independent Samples T-Test conducted on Baseline Variables

Domain	Variable	t-test (Mann-Whitney)	Normality (Shapiro-Wilk) W (p-value)		Equality of variances (Levene's)
			HOA	SCD	
Sleep	PSQI	t(24)=-1.98, p=.06	.95 (0.62)	.92 (.14)	F(1,24)=2.76, p=.11
	CSD	t(23)=1.09, p=.29	.88 (.12)	.94 (.43)	F(1,23)=.64, p=.43
	Actigraphy	T(24)=1.20, p=.24	.95(.70)	.91 (.14)	F(1,24)=.21, p=.65
Wellbeing	PERMA	U=90.50, p=.60	.82 (.03)	.93 (.24)	F(1,24)=.02, p=.88
	Positive Emotion	T(24)=.57, p=.58	.91 (.29)	.96 (.65)	F(1,24)=.04, p=.84
	Engagement	T(24)=.67, p=.51	.93 (.46)	.91 (.10)	F(1,24)=.08, p=.78
	Relationships	U=77, p=.89	.86 (.09)	.88 (.04)	F(1,24)=2.06, p=.16
	Meaning	U=56.50, p=.22	.88 (.13)	.82 (<.001)	F(1,24)=<.001, p=.98
	Achievement	T(22.66)=2.48, p=.02, d=.92*	.95 (.66)	.97 (.91)	F(1,24)=6.39, p=.02*
	Negative Emotion	T(-2.22)=23.33, p=.04*	.94 (.51)	.94 (.36)	F(1,24)=4.84, p=.04*
	Loneliness	U=61.50, p=.32	.65, (<.001)	.80 (<.001)	F(1,24)=<.001, p=.99
Mood	DASS	T(24)=-1.51, p=.14	.75 (.06)	.91 (.11)	F(1,24)=.15, p=.70
	Depression	(U=64.50, p=.38)	.59 (<.001)	.76 (<.001)	F(1,24)=.95, p=.34

	Anxiety	T(24)=-1.57, p=.13)	.89 (.15)	.91 (.10)	F(1,24)=2.41, p=.13
	Stress	(U=52.00, p=.14)	.71 (<.001)	.92 (.16)	F(1,24)=.13, p=.72

4.7.13 Main Effects

For all mixed 3x2 ANOVAs examining the within factor of study phase (pre-intervention, intervention and post-intervention) against the between factor of group (HOA and SCD), assumption checks of tests of equality of variances using the Levene's Test and test of sphericity using Mauchly's test of sphericity were performed and are reported in table 50. Where sphericity has been violated, a Greenhouse-Geisser correction has been applied. For violations of equality of variances, these are discussed in the following results section.

Table 50: Assumption Statistics for Main Effects of 3x2 factorial ANOVAs

Domain	Variable	Levene's Test for Equality of Variances df (1,22)			Mauchly's test of Sphericity df (2)
		Pre	Intervention	Post	
Sleep Quality	Actigraphic Sleep Quality	F<.001, p=1.00	F=.03, p=.87	F=3.38, p=.08	W=.75, p=.05* (ϵ = .80)
	Sleep Diary Quality	F=1.06, p=.32	F=.03, p=.86	F=1.87, p=.18	W=.95, p=.58
	Global PSQI quality	F=8.31, p<.001**	F=.42, p=.52	F=10.61, p<.001**	W=.85, p=.16
Sleep Parameters	TST	F=.92, p=.35	F=.45, p=.51	F=.58, p=.45	W=.87, p=.26
	SOL	F<.001, p=.96	F=.04, p=.85	F=.06, p=.80	W=.63, p=.01* (ϵ = .73)
	SE	F=.49, p=.49	F<.001, p=.98	F=3.22, p=.09	W=.53, p<.001* (ϵ = .68)
	SF	F=2.12, p=.016	F=.38, p=.55	F=4.71, p=.04*	W=.69, p=.02* (ϵ = .76)
Wellbeing	PERMA mean	F<.001, p=.99	F=1.74, p=.20	F=.14, p=.71	W=.97, p=.73
	Positive Emotion	F=1.05, p=.32	F=.174, p=.20	F=.61, p=.44	W=.96, p=.61
	Engagement	F<.001, p=.99	F<.001, p=.98	F=.62, p=.44	W=.84, p=.13
	Relationships	F=.06, p=.81	F=.18, p=.67	F=.62, p=.44	W=.76, p=.04* (ϵ = .81)
	Meaning	F=.03, p=.85	F=.01, p=.90	F=.11, p=.75	W=.82, p=.10
	Achievement	F=1.91, p=.18	F=.89, p=.35	F=1.13, p=.30	W=.55, p<.001**

					($\varepsilon = .69$)
	Negative Emotion	F=2.65, p=.12	F=2.40, p=.13	F=2.52, p=.13	W=.55, p<.001** ($\varepsilon = .69$)
	Loneliness	F<.001, p=.92	F=.393, p=.06	F=1.12, p=.30	W=.58, p<.001** ($\varepsilon = .70$)
Mood	DASS	F=.13, p=.73	F=1.18, p=.29	F=.18, p=.68	W=.67, p=.01* ($\varepsilon = .67$)
	Depression	F=.18, p=.67	F=.65, p=.43	F=2.79, p=.11	W=.96, p=.63
	Anxiety	F=1.21, p=.28	F=3.37, p=.08	F=.15, p=.71	W=.83, p=.12
	Stress	F=.20, p=.66	F=.02, p=.89	F=1.93, p=.18	W=.89, p=.25

Table 51: Secondary Analysis Main Effects, Between-Subject Differences, and Interaction Statistics

*Main effects for full sample using 2 (Group; HOA and SCD) x 3 (Time point; baseline, intervention, post) factorial ANOVA

Domain	Variable	Main Effects	Between Subject differences	Interaction
Sleep Quality	Actigraphic Sleep Quality	F(1.60, 35.10)=.06, p=.90, $\eta p^2<.001$	F(1,22)=.50, p=.48, $\eta p^2=.02$	F(1.60, 35.10)=1.30, p=.28, $\eta p^2=.06$
	Sleep Diary Quality	F(2,44)=4.90, p=.01, $\eta p^2=.18$	F(1,22)=2.67, p=.12, $\eta p^2=.11$	F(2,44)=1.98, p=.15, $\eta p^2=.08$
	Global PSQI quality	F(2,48)=24.79, p<.001, $\eta p^2=.51$	F(1,24)=3.26, p=.08, $\eta p^2=.12$	F(2,48)=.72, p=.49, $\eta p^2=.03$
Sleep Parameters	TST	F(2,42)=7.69, p<.001, $\eta p^2=.27$	F(1,21)=.06, p=.82, $\eta p^2<.001$	F(2,42)=.58, p=.57, $\eta p^2=.03$

	SOL	F(1.46, 30.69)=.47, p=.57, η^2 =.02	F(1,21)=.25, p=.62, η^2 =.01	F(1.46,30.69)=.19, p=.76, η^2 <.001
	SE	F(1.36, 29.97)=.44, p=.57, η^2 =.02	F(1,22)=.05, p=.83, η^2 <.001	F(1.36, 29.97)=.59, p=.50, η^2 =.03
	SF	F(1.52, 32.02)=.07, p=.89, η^2 <.001	F(1,21)=2.32, p=.14, η^2 =.10	F(1.52, 32.02)=3.92, p=.04, η^2=.16
Wellbeing	PERMA mean	F(2, 48)=3.02, p=.06, η^2 =.11	F(1,24)=.54, p=.47, η^2 =.02	F(2,48)=3.53, p=.04, η^2=.13
	Positive Emotion	F(2,48)=1.84, p=.17, η^2 =.07	F(1,24)=1.18, p=.29, η^2 =.05	F(2,48)=4.28, p=.02, η^2=.15
	Engagement	F(2,48)=2.77, p=.07, η^2 =.10	F(1,24)=.30, p=.59, η^2 =.01	F(2,48)=.19, p=.83, η^2 <.001
	Relationships	F(1.62,38.82)=1.67, p=.21, η^2 =.07	F(1,24)=.21, p=.65, η^2 <.001	F(1.62,38.82)=1.21, p=.30 η^2 =.05
	Meaning	F(2,48)=1.19, p=.31, η^2 =.05	F(1,24)=.45, p=.51, η^2 =.02	F(2,48)=.5, p=.53, η^2 =.02
	Achievement	F(1.37,32.99)=6.52, p<.001, η^2=.21	F(1,24)=1.30, p=.27, η^2 =.05	F(1.37, 32.99)=2.47, p=.12, η^2 =.09
	Negative Emotion	F(1.38,33.17)=3.30, p=.07, η^2 =.12	F(1,24)=.45, p=.57, η^2 =.02	F(1.38,33.17)=1.69, p=.20, η^2 =.07
	Loneliness	F(1.41, 33.77)=.60, p=.50, η^2 =.02	F(1,24)<.001, p=.96, η^2 <.001	F(1.41, 33.77)=2.36, p=.12, η^2 =.09
Mood	DASS	F(1.51,36.21)=2.90, p=.08, η^2 =.11	F(1,24)=1.35, p=.26, η^2 =.05	F(1.51, 36.21)=1.49, p=.24, η^2 =.06
	Depression	F(2,48)=.61, p=.55, η^2 =.02	F(1,24)=.12, p=.73, η^2 <.001	F(2,48)=1.64, p=.20, η^2 =.06
	Anxiety	F(2,48)=1.05, p=.36, η^2 =.04	F(1,24)=2.01, p=.17, η^2 =.08	F(2,48)=.24, p=.78, η^2 =.01

	Stress	F(2, 48)=7.33, p<.001, η^2=.23	F(1,24)=2.77, p=.11, η^2 =.10	F(2,48)=.34, p=.71, η^2 =.01

Table 52: Post-Hoc Tests for Secondary Main Analysis using Bonferroni Correction

*Time periods: Pre = baseline (first 2 weeks), Intervention = 4-week reading intervention period, Post = 2 weeks following intervention completion. ‘Pre-Intervention’ compares baseline to intervention, ‘Pre-Post’ compares baseline to follow-up, ‘Intervention-Post’ compares intervention period to follow-up.

Domain	Variable	Pre-Intervention	Pre-Post	Intervention-Post
Sleep Quality	Actigraphic Sleep Quality	-	-	-
	Sleep Diary Quality	t(24)=2.73, p=.03, d=.38	t(24)=<.001, p=1.00, d<.001	t(24)=-2.69, p=.03, d=.37
	Global PSQI quality	t(24)=-6.11, p<.001, d=1.26	t(24)=-6.08, p<.001, d=1.25	t(24)=.03, p=1.00, d<.001
Sleep Parameters	TST	-	-	-
	SOL	-	-	-
	SE	-	-	-
	SF	-	-	-
Wellbeing	PERMA mean	-	-	-
	Positive Emotion	-	-	-
	Engagement	-	-	-
	Relationships	-	-	-
	Meaning	-	-	-
	Achievement	t(24)=2.90, p=.02, d=.35	t(24)=3.31, p<.001, d=.40	t(24)=.41, p=1.00, d=.05

	Negative Emotion	-	-	-
	Loneliness	-	-	-
Mood	DASS			
	Depression			
	Anxiety	$t(24)=-.02, p=.98, d<.001$	$t(24)=-3.33, p<.001, -.64$	$t(24)=-3.31, p<.001, d= -.64$
	Stress			

4.7.13.1 Sleep Quality

4.7.13.1.1 Objective Sleep Quality (Actigraphy)

In terms of objective sleep quality, there was no main effect of study phase on actigraphic quality composite score $F(1.60, 35.10) = 1.60, p = 0.90, \eta p^2 < .001$, nor was there a main effect of group, $F(1,22) = .50, p = .48, \eta p^2 = .02$, or interaction between study phase and group, $F(1.60, 35.10) = 1.30, p = .28, \eta p^2 = .06$, suggesting that objective sleep quality did not significantly change throughout the study for all participants.

4.7.13.1.2 Subjective Sleep Quality (CSD and PSQI)

CSD

However, there was a significant main effect of study phase on subjective sleep quality in terms of the Consensus Sleep Diary (CSD), $F(2,44) = 4.90, p = .01, \eta p^2 = .18$. There was no main effect of group on CSD ratings $F(1,22) = 2.67, p = .12, \eta p^2 = .11$, nor an interaction between study phase and group, $F(2,44) = 1.98, p = .15, \eta p^2 = .08$. Post-hoc analysis using a Bonferroni Correction revealed that subjective ratings of sleep quality increased significantly by .21 units ($SE=.08$) from baseline to reading period $t(22) = 2.73, p = .03, d = .38$, but then dropped significantly from the reading period to the end of the study by .21 units ($SE = .08$), $t(22) = 2.69, p = .03, d = -.37$.

PSQI

Similarly, in terms of PSQI subjective sleep quality ratings, there was a main effect of study phase, $F(2,48)=24.79$, $p<.001$, $\eta p^2 = .51$, but no main effect of group, $F(1,24) = 3.26$, $p = .08$, $\eta p^2 = .12$, nor a significant interaction between group and study phase, $F(2,48) = .72$, $p = .49$, $\eta p^2=.03$. Post-hoc tests revealed that PSQI scores dropped significantly from baseline to the reading period by 2.26 points ($SE = .37$), $t(24) = -6.11$, $p < .001$, $d = -1.26$. Higher PSQI scores indicate poorer sleep, which suggests that subjective sleep quality improved over this period. Similarly, subjective sleep ratings were significantly lower at the end of the study compared to baseline by 2.25 points ($SE=.37$), $t(24) = 6.08$, $p < .001$, $d = 1.25$. There was no significant difference from the reading period to the end of the study in terms of PSQI-rated subjective sleep quality $t(24) = -.03$, $p = 1.00$, $d < .001$.

4.7.13.1.3 Sleep Quality Summary

Overall, these results suggest that while there were no significant differences in objective sleep quality, subjective assessments revealed that participants perceived their sleep to have improved during the reading period. However, the CSD showed a subsequent drop in sleep quality, whereas the PSQI did not reveal any significant drop in subjective sleep quality toward the end of the study.

4.7.13.2 Objective Sleep Parameters

4.7.13.2.1 Total Sleep Time (TST)

In terms of objective sleep parameters as measured by actigraphy, there was a significant main effect of study phase on total sleep time (TST), measured in seconds, $F(2,42) = 7.69$, $p < .001$, $\eta p^2 = .27$. There was no significant main effect of group, $F(1,21) = .06$, $p = .82$, $\eta p^2 < .001$, nor a significant interaction between study phase and group, $F(2,42) = .58$, $p = .57$, $\eta p^2 = .03$. Post-hoc analyses revealed that TST increased from baseline to the reading period by an average of 790.40 seconds ($SE = 309.41$), $t(21)=2.55$, $p = .04$, $d = .29$. Additionally, TST

dropped significantly following the reading period, comparing the reading period to the end of the study by an average of -1192.65 seconds ($SE = 309.41$), $t(21) = -3.85$, $p < .001$, $d = .44$. However, the difference between baseline and the end of the study in terms of TST was not significantly different $t(21) = -402.25$, $p = .60$, $d = .15$. Overall, this suggests that for all participants TST increased during the reading period and subsequently dropped, though the difference between TST at the end of the study and the start was not significant.

4.7.13.2.2 Sleep Onset Latency (SOL)

In terms of SOL, measured in seconds, there was no main effect of study phase, $F(1.46, 30.69) = .47$, $p = .57$, $\eta p^2 = .02$, nor was there a main effect of group, $F(1,21) = .25$, $p = .62$, $\eta p^2 = .01$, nor was there a significant interaction between study phase and group, $F(1.46, 30.69) = .19$, $p = .76$, $\eta p^2 < .001$.

4.7.13.2.3 Sleep Efficiency (SE)

In terms of SE (%), there was no main effect of study phase, $F(1.36, 29.97) = .44$, $p = .57$, $\eta p^2 = .02$, nor was there a main effect of group, $F(1,22) = .05$, $p = .83$, $\eta p^2 < .001$, nor was there an interaction between study phase and group, $F(1.36, 29.97) = .59$, $p = .50$, $\eta p^2 = .03$.

4.7.13.2.4 Sleep Fragmentation (SF)

In terms of SF, there was no main effect of study phase, $F(1.52, 32.02) = .07$, $p = .89$, $\eta p^2 < .001$, nor was there a main effect of group, $F(1,21) = 2.32$, $p = .14$, $\eta p^2 = .10$. However, there was a significant interaction between study phase and group, $F(1.52, 32.02) = 3.92$, $p = .04$, $\eta p^2 = .16$. Despite this significant interaction, post-hoc comparisons using Tukey's HSD corrections did not reveal any significant differences between specific comparisons.

The lack of significant post hoc findings can likely be attributed to several factors, including high variability within groups (as indicated by high standard deviations), multiple comparisons (15), and a small sample size ($n = 23$). Descriptive plots indicate distinct patterns between the groups: for the SCD group, SF decreased by an average of 0.89 units

from baseline to the reading period and continued to drop by 1.30 units from the reading period to the end of the study. For the HOA group, SF increased by an average of 0.50 units ($SE = 3.63$) from baseline to the reading period, then increased by 1.92 units ($SE = 1.32$) from the reading period to the end of the study. These trends suggest that the SCD group experienced a reduction in SF across the study phases, whereas the HOA group showed an increase in SF. However, these differences were not statistically significant in the post-hoc tests.

4.7.13.2.5 Objective Sleep Parameters Summary

Overall, these results suggest that only TST and SF changed significantly across the study period, whereas SOL and SE did not. For all participants, TST increased significantly during the reading period and then dropped significantly following the reading period. However, differences between baseline and the end of the study were not significantly different. For SF, the results suggest that the HOA and SCD groups responded differently; the SCD group showed decreases across the reading phase and the end of the study, whereas the HOA group showed increased SF during the reading period and towards the end of the study. However, these comparisons were not significant in the post-hoc tests.

4.7.13.3 Wellbeing

In terms of overall subjective wellbeing, as captured by the PERMA-profiler and averaging ratings relating to PERMA (positive emotion, engagement, relationships, meaning and achievement), there was no main effect of study phase, $F(2, 48) = 3.02, p = .06, \eta p^2 = .11$. There was also no main effect of group, $F(1,24) = .54, p = .47, \eta p^2 = .02$. However, there was a significant interaction between study phase and group on overall subjective wellbeing, $F(2,48) = 4.28, p = .02, \eta p^2 = .15$. Post-hoc comparisons using Tukey's HSD, did not reveal any significant comparisons, likely for similar reasons as reported with TST. Examining descriptive plots revealed that for those in the SCD group, overall ratings of wellbeing increased from baseline to the reading period by an average of .28 units ($SE = .14$) and then dropped slightly by .03 units ($SE = .14$), whereas for the HOA group, ratings of wellbeing dropped during the reading period from baseline by an average of -.24 units ($SE = .53$) but

then rose to levels higher than baseline by an average of .51 units ($SE = .18$). Overall, this suggests that subjective ratings of wellbeing rose for those in the SCD group during the reading period, but dropped for those in the HOA group, though the comparisons were not significant.

Positive Emotion

In terms of subjective ratings of positive emotion, there was no main effect of study phase, $F(2,48) = 1.84, p = .17, \eta p^2 = .07$, nor was there a main effect of group, $F(1,24) = 1.18, p = .29, \eta p^2 = .05$. However, there was a significant interaction between study phase and group $F(2,48) = 4.28, p = .02, \eta p^2 = .15$. Post hoc analyses using a Tukey's HSD correction, revealed that for the SCD group, subjective perception of positive emotions increased from baseline to the reading period by an average of .51 units ($SE = .14$), $t(24) = 3.55, p = .01, d = .40$. No other comparisons were significant.

Engagement

There was no main effect of study phase on subjective perceptions of engagement, $F(2,48) = 2.77, p = .07, \eta p^2 = .10$, nor a main effect of group $F(1,24) = .30, p = .59, \eta p^2 = .01$, nor a significant interaction between study phase and group, $F(2,48) = .19, p = .83, \eta p^2 < .001$.

Relationships

There was no significant main effect of study phase on perceived evaluations of relationships $F(1.62,38.82) = 1.67, p = .21, \eta p^2 = .07$, nor was there a significant main effect of group $F(1,24) = .21, p = .65, \eta p^2 < .001$, nor was there an interaction between study phase and group, $F(1.62,38.82) = 1.21, p = .30, \eta p^2 = .05$.

Meaning

In terms of perceived meaning, there was no significant main effect of study phase, $F(2,48) = 1.19, p = .31, \eta p^2 = .05$, nor was there a main effect of group, $F(1,24) = .45, p = .51, \eta p^2 = .02$, nor was there a significant interaction between study phase and group, $F(2,48) = .5, p = .53, \eta p^2 = .02$.

Achievement

In terms of perceived achievement, there was a significant main effect of study phase $F(1.37,32.99) = 6.52, p < .001, \eta p^2 = .21$, though there was no main effect of group, $F(1,24) = 1.30, p = .27, \eta p^2 = .05$, nor was there an interaction between study phase and group, $F(1.37, 32.99) = 2.47, p = .12, \eta p^2 = .09$. Post-hoc analyses using a Bonferroni Correction revealed that participants sense of achievement increased from baseline to the reading period significantly by an average of .43 units ($SE = .15$), $t(24) = 2.90, p = .02, d = .35$. Additionally, there was a significant increase in participants sense of achievement from comparing the start of the study to the end of the study with a mean increase of .49 units ($SE = .15$), $t(24) = 3.31, p < .001, d = .40$. There was no significant difference in sense of achievement from the reading period to the end of the study $t(24) = -.06, p = 1.00, d = -.05$. Overall, these results suggest that all participants' sense of achievement increased from baseline to the reading period and that this was higher at the end of the study compared to baseline.

Negative Emotion

In terms of perceived negative emotion there was no main effect of study phase, $F(1.38,33.17) = 3.30, p = .07, \eta p^2 = .12$, nor was there a significant main effect of group, $F(1,24) = .45, p = .57, \eta p^2 = .02$, nor was there a significant interaction between study phase and group, $F(1.38,33.17) = 1.69, p = .20, \eta p^2 = .07$.

Loneliness

There was no main effect of study phase on perceived loneliness, $F(1.41, 33.77) = .60, p = .50, \eta p^2 = .02$, nor was there a main effect of group, $F(1,24) < .001, p = .96, \eta p^2 < .001$ nor was that an interaction between study phase and group, $F(1.41, 33.77) = 2.36, p = .12, \eta p^2 = .09$.

Wellbeing summary

A significant interaction suggested that those in the SCD group perceived that their sense of wellbeing improved during the intervention, though diminished post-intervention. In contrast, overall wellbeing decreased during the reading for the HOA group, subsequently improving post-intervention. However, these comparisons were not significant. Perceived sense of positive emotion increased during the intervention for the SCD group only. Additionally, for all participants, the perceived sense of achievement improved during the intervention and remained higher than at baseline. This suggests that the SCD showed greater benefits compared to the HOA group in terms of improvements in wellbeing during the study. However, all participant's sense of achievement increased during the reading period and remained higher than at baseline.

4.7.13.4 Mood Disturbances

Global Mood Disturbances (DASS)

In terms of mood disturbances as measured by the DASS-21, there was no main effect of the study phase on overall mood disturbances (which combined symptoms of depression, anxiety, and stress), $F(1.51, 36.21) = 2.90, p = .08, \eta p^2 = .11$, nor was there a main effect of group, $F(1, 24) = 1.35, p = .26, \eta p^2 = .05$, nor was there a significant interaction between study phase and group, $F(1.51, 36.21) = 1.49, p = .24, \eta p^2 = .06$.

Depression

In terms of symptoms of depression there was no significant main effective study phase, $F(2, 48) = .61, p = .55, \eta p^2 = .02$, nor was there a significant main effect of group, $F(1, 24) = .12, p = .73, \eta p^2 < .001$, nor was there an interaction between study phase and group, $F(2, 48) = 1.64, p = .20, \eta p^2 = .06$.

Anxiety

For self-reported anxiety symptoms, there was no main effect of study phase, $F(2,48) = 1.05$, $p = .36$, $\eta p^2 = .04$, nor was there a significant main effect of group, $F(1,24) = 2.01$, $p = .17$, $\eta p^2 = .08$ nor was an interaction between study phase and group, $F(2,48) = .24$, $p = .78$, $\eta p^2 = .01$.

Stress

In terms of self-reported stress symptoms there was a significant main effect of study phase, $F(2, 48) = 7.33$, $p < .001$, $\eta p^2 = .23$. However, there was not a significant main effect of group $F(1,24) = 2.77$, $p = .11$, $\eta p^2 = .10$, nor was there a significant interaction between study phase and group, $F(2,48) = .34$, $p = .71$, $\eta p^2 = .01$. Post hoc comparisons using a Bonferroni correction revealed that perceived stress symptoms were significantly lower at the end of the study compared to baseline with a mean difference of $-.98$ units ($SE = .30$), $t(24) = -3.33$, $p < .001$, $d = -.64$. Additionally, perceived stress symptoms dropped at the end of the study compared to the reading with an average of $-.98$ units ($SE = .30$), $t(24) = -3.31$, $p < .001$, $d = -.64$. However there was no significant difference between baseline and the intervention $t(24) = .02$, $p = 1.00$, $d = <.001$.

Mood disturbances Summary

Overall, these results suggest that global ratings of mood disturbances did not significantly change across the study periods. Similarly, symptoms of depression and anxiety did not significantly change for all participants. However, symptoms of stress were significantly lower at the end of the study compared to baseline, with a notable decrease from the intervention period to the end.

4.7.13.5 Correlations for change variables

Next, to determine whether changes in sleep quality are related to changes in mood disturbances and wellbeing during the reading period, a series of pairwise correlations were performed, examining changes from baseline to the end of the reading period. Assumption checks were conducted for each pairwise comparison; when the assumption of normality was

violated, as assessed by the Shapiro-Wilk test, Spearman's rho was used instead of Pearson's r . The results of these correlations are reported in the table below.

Table 53: Correlation Statistics between Changes in Sleep Quality from Baseline to the Intervention

Domain	Variable 2	df (25)		Normality (p-value)
		Pearson's r (Spearman's Rho)	P Value	
Actigraphy (Intervention)	PSQI	.15	.50	.98 (.90)
	CSD	-.34	.10	.94 (.21)
PSQI	SCD	-.05	.79	.96 (.44)

Table 54: Correlation Statistics between Changes in Sleep Quality and Wellbeing Measures from Baseline to the Intervention

Domain	Variable 2	df (25)		Normality (p-value)
		Pearson's r (Spearman's Rho)	P Value	
Actigraphy (Intervention)	PERMA	-.02	.94	.92 (.06)
	Positive Emotion	-.07	.74	.96 (.40)
	Engagement	-.11	.60	.95 (.32)
	Relationships	-.16	.44	.99 (.99)
	Meaning	-.31	.14	.96 (.49)
	Achievement	-.35	.09	.94 (.20)
	Negative Emotion	<.001	1.00	.97 (.60)
	Loneliness	(.38)	.06	.88 (<.001)
Sleep Diary	PERMA	-.34	.09	.94 (.10)
	Positive Emotion	-.17	.42	.96 (.40)
	Engagement	-.31	.11	.96 (.45)
	Relationships	(-.23)	.26	.91 (.03)
	Meaning	-.13	.52	.97 (.52)
	Achievement	(-.10)	.63	.81 (<.001)
	Negative Emotion	(.36)	.07	.83 (<.001)

	Loneliness	(-.06)	.76	.90 (.01)
PSQI	PERMA	<.001	.97	.89 (<.001)
	Positive Emotion	-.22	.27	.95 (.30)
	Engagement	.09	.66	.98 (.82)
	Relationships	-.14	.50	.96 (.34)
	Meaning	-.11	.60	.97 (.52)
	Achievement	(.05)	.81	.81 (<.001)
	Negative Emotion	-.37	.06	.86 (<.001)
	Loneliness	<.001	.98	.87 (<.001)

Table 55: Correlation Statistics between Changes in Sleep Quality and Mood Disturbances Measures from Baseline to the Intervention

Domain	Variable 2	df (25)		Normality (p-value)
		Pearson's r (Spearman's Rho)	P Value	
Actigraphy (Intervention)	DAS	(.31)	.13	.88 (<.001)
	Depression	(.28)	.19	.89 (<.001)
	Anxiety	(.14)	.52	.87 (<.001)
	Stress	.26	.23	.93 (.08)
Sleep Diary	DAS	(-.19)	.34	.87 (<.001)
	Depression	(-.33)	.10	.91 (.03)
	Anxiety	(-.21)	.30	.90 (.01)
	Stress	-.13	.52	.97 (.69)
PSQI	DAS	.11	.61	.88 (<.001)
	Depression	-.34	.08	.84 (<.001)
	Anxiety	-.02	.93	.90 (.01)
	Stress	.36	.07	.97 (.69)

Table 56: Correlation Statistics between Changes in Sleep Quality from Baseline to the End of the Intervention Phase and Measures of Narrative Engagement Taken at the End of the Reading Period

Domain	Variable 2	df (25)		Normality (p-value)
		Pearson's r (Spearman's Rho)	P Value	
Actigraphy (Intervention)	Attention	-.15	.49	.94 (.21)
	Transportation	-.39	.07	.95 (.25)
	Emotional Engagement	(-.16)	.46	.73 (<.001)
	Mental Imagery	-.32	.13	.92 (.08)
	SWAS mean	-.08	.70	.95(.37)
Sleep Diary	Attention	.10	.62	.95 (.21)
	Transportation	.30	.15	0.95 (.24)
	Emotional Engagement	(.24)	.25	.78 (<.001)
	Mental Imagery	.13	.54	.93 (.08)
	SWAS mean	.25	.22	.94 (.12)
PSQI	Attention	-.07	.73	.98 (.88)
	Transportation	0.10	.62	.98 (.86)
	Emotional Engagement	(<.001)	.99	.78 (<.001)
	Mental Imagery	-.11	.59	.96 (.46)
	SWAS mean	-.23	.27	.98 (.86)

The results from the series of correlation analyses indicate that changes in subjective sleep quality were not significantly correlated with changes in objective sleep quality, nor were changes in measures of subjective sleep quality correlated with one another (i.e. CSD vs PSQI). Moreover, changes in measures of sleep quality were not correlated with any

wellbeing variables or mood variables. Similarly, aspects of story engagement were not correlated to any changes in sleep variables.

4.7.14 Discussion

This novel study investigated the effects of a 4-week fiction reading intervention on sleep quality, wellbeing, and mood in healthy older adults (HOA) and those with subjective cognitive decline (SCD). By employing objective and subjective measures of sleep, alongside assessments of wellbeing and mood using a pre-post-test design over 8 weeks, we sought to provide a comprehensive understanding of the potential benefits of bedtime reading for these populations. As the first of its kind, our findings provide new insights into the relationship between fiction reading, sleep, and psychological wellbeing in older adults, contributing to the growing body of research on non-pharmacological interventions for sleep improvement in ageing populations with and without cognitive decline.

4.7.14.1 Sleep Quality: Subjective Improvements and Objective Discrepancies

Our first hypothesis, that objective and subjective sleep quality would improve during the reading period, was partially supported. One of the most striking findings of this study was the significant improvement in subjective sleep quality across all participants during the reading intervention. Both the Consensus Sleep Diary (CSD; Carney et al., 2012) and the Pittsburgh Sleep Quality Index (PSQI; Buysse et al., 1989) showed significant improvements, with small to large effect sizes (Cohen's $d = 0.38$ for CSD and Cohen's $d = -1.26$ for PSQI; Cohen, 2009). Interestingly, the CSD data revealed a decline in sleep quality after the reading period ended, suggesting that the positive effects may diminish without continued engagement. Whilst there is limited research on reading fiction and sleep quality, these findings align with audiobook fiction consumption and sleep quality. For instance, a study investigated the use of audiobooks on sleep quality and vital signs in 56 intensive care patients and found, using a pre-post-test design, that audiobook listening significantly improved subjective sleep quality (Mermer & Arslan, 2024).

These significant subjective improvements were not reflected in objective sleep measures derived from actigraphy, as there was no significant change in objective sleep across the study for all participants. This discrepancy between subjective and objective sleep measures is not uncommon in sleep research (Landry et al., 2015; DiNapoli et al., 2017) and raises important implications regarding the nature of sleep quality and its measurement. While

objective measures like actigraphy and polysomnography provide valuable data on sleep architecture, continuity, and quantity, they may not fully capture the experiential aspects of sleep that contribute to an individual's perception of sleep quality (O'Donnell et al., 2009; D. B. Kay et al., 2015). On the other hand, subjective measures reflect the individual's lived experience of sleep, including factors such as perceived restfulness, satisfaction with sleep, and daytime consequences of sleep (Harvey et al., 2008; O'Donnell et al., 2009). Both sleep measures offer unique and complementary insights reflected in recommendations to combine both types in sleep research.

The discrepancy observed in our study aligns with the argument by Krystal and Edinger (2008) that subjective sleep quality should be considered a distinct and important construct in sleep research and clinical practice. This perspective is supported by a growing body of evidence demonstrating that subjective sleep quality is a critical factor in overall health and wellbeing, often independent of objective sleep measures (Gould et al., 2018). In older adults specifically, subjective sleep quality has been linked to several key areas of functioning and wellbeing, including mood, cognitive performance, and health-related quality of life. For instance, in 167 community-dwelling older adults, Gould et al. (2018) found that subjective sleep quality was more strongly associated with anxiety and depression symptoms than objective measures of sleep. Moreover, Maglione et al. (2012) found that in older adults, greater depressive symptoms were associated with more subjective sleep disturbance. Additionally, Nebes et al. (2009) demonstrated that subjective sleep quality, as measured by the PSQI, was associated with better performance on cognitive tasks in older adults. Moreover, subjective sleep complaints significantly predicted cognitive decline in middle-aged and older adults over a period of 3 years (Jelicic et al., 2002). These findings collectively highlight that even in the absence of objective sleep improvements, enhanced subjective sleep quality may have significant benefits for older adults across multiple domains of health and wellbeing.

4.7.14.2 Potential Mechanisms Underlying Subjective Sleep Improvements in Response to Fiction Reading

The improvement in subjective sleep quality observed in this study may be attributed to several interrelated psychological mechanisms, each potentially contributing to a beneficial

pre-sleep state. However, due to the limited research specifically addressing fiction reading and sleep quality, the proposed mechanisms are derived from a synthesis of related studies in related fields. While these proposed explanations offer plausible interpretations of our findings, they require further investigation within the context of fiction reading and sleep quality in older adults. The following sections explore these potential mechanisms, drawing connections between existing research and our findings.

4.7.14.3 Cognitive Distraction and Narrative Transportation

One potential mechanism for the improvement observed in subjective sleep quality in relation to reading fiction is the role of reading as a cognitive distraction and regulation strategy. Reading fiction requires active engagement with the text, as readers must process and interpret words on the page, construct mental images and simulations of fictional worlds, and follow the narrative structure (Wilson, 2002; Mar et al., 2009, 2011; Nijhof & Willems, 2015). The cognitive engagement required may serve as a distraction from real-life concerns, stressors and worries that could otherwise interfere with sleep onset and maintenance, key aspects of sleep quality (Molen et al., 2013; Libman et al., 2016).

The concept of narrative transportation offers further insight as to how narratives may aid in distraction. Narrative transportation refers to the phenomenon where readers become deeply absorbed in a story, experiencing a sense of being immersed in the narrative world (Green & Brock, 2000; Kuijpers, 2020). This state of absorption is characterised by a high level of mental imagery, emotional involvement, and a temporary loss of access to real-world information (Green & Brock, 2000; Kuijpers, 2020; Isberner et al., 2019). Immersion in narratives and in fictional worlds and disengagement from real-world information supports the framework that fictional reading may distract from real-life stressors and for reading to be a worry-incompatible behaviour. This hypothesis was supported by research by (Molen et al., 2013), who found that reading fictional books prior to bedtime was associated with reduced cognitive arousal in adults with insomnia.

This aligns with the cognitive model of insomnia proposed by Harvey (2002), which suggests that excessively negatively toned cognitive activity such as rumination, worry, and pre-sleep arousal are key factors in maintaining insomnia, resulting in greater difficulty falling asleep

and maintaining sleep. While this model was developed for insomnia, it offers insights into sleep quality enhancement in healthy sleepers as well. Research has shown that in healthy sleepers, worry, rumination, and pre-sleep arousal have been associated with poor sleep quality. For example, in university students, shorter sleep duration was associated with higher levels of worry than in longer sleepers (Kelly, 2002), and longer sleep latency and lower sleep efficiency in healthy adults (Åkerstedt et al., 2007). Additionally, in healthy young adults, higher levels of worry were associated with greater cognitive activity at night and greater subjective sleep disturbances than those with lower worry (Omvik et al., 2007).

Research has shown that rumination and worry are linked to increased mental alertness before sleep, which negatively impacts sleep quality. Yeh et al. (2015) identified that pre-sleep arousal acts as a mediator in this relationship, meaning that rumination and worry increase pre-sleep arousal, leading to poorer sleep quality. This is consistent with other research exploring pre-sleep arousal and media consumption before bed. For example, Tu et al. (2023) found that restricting smartphone use while in bed improves sleep quality for young adults and decreases pre-sleep arousal, with pre-sleep cognitive arousal mediating the relationship between limiting smartphone use and sleep quality. A meta-analysis exploring the extent to which sleep is causally related to mental health found that interventions that improved subjective sleep quality led to a medium effect on rumination (Scott et al., 2021). Molen et al. (2013) found that for adults with insomnia, reading was associated with reduced pre-sleep arousal, with somatic components of arousal decreasing at follow-up. Taken together, by engaging with a narrative requiring cognitive participation, readers may potentially reduce pre-sleep arousal and worry, thus improving sleep quality.

4.7.14.4 Establishment of a Consistent Pre-sleep Routine

Another potential mechanism is the establishment of a consistent pre-sleep routine. Participants were asked to read consistently nightly for 4-weeks. Research has shown that in 96 community-dwelling older adults, stability in daily routines predicted shorter sleep latency, higher sleep efficiency and improved sleep quality according to subjective sleep measures as measured by the PSQI (Zisberg et al., 2010). Whilst this study focused on daily routines, reading could contribute to sleep hygiene practices, as suggested by Hale et al. (2011). Reading may also act as a constructive time filler, potentially reducing sleep onset

anxiety for some individuals. This aspect of reading could tie into its possible roles in cognitive distraction and emotional regulation, but the specific relationships between these factors are yet to be empirically addressed. Taken together, reading before bed may facilitate beneficial effects in relation to subjective sleep quality: engaging the mind, possibly regulating emotions, establishing a routine, filling time constructively, and potentially inducing physical relaxation. These factors may work together to lower pre-sleep arousal and anxiety, potentially enhancing the subjective perception of sleep quality.

4.7.14.5 Wellbeing and Mood

Additionally, regarding our second and third hypotheses, which predicted improvements in wellbeing and reductions in symptoms of depression, anxiety, and stress, our results showed mixed support. We observed differential effects of the reading intervention on wellbeing between the HOA and SCD groups. While post-hoc comparisons were not statistically significant, the patterns suggested that the SCD group experienced greater improvements in positive emotion and overall wellbeing during the reading period than the HOA group, as reflected by a significant interaction. This finding, although tentative, supports our fifth hypothesis that the SCD group would show greater overall benefits from the reading intervention.

The cognitive stimulation hypothesis could explain these potential benefits for the SCD group (Lachman et al., 2010). This theory suggests that engaging in cognitively stimulating activities can help maintain or even improve cognitive function in older adults. Reading fiction, which involves complex cognitive processes such as theory of mind, perspective-taking, and imagination (Mar & Oatley, 2008), may provide valuable cognitive stimulation for individuals with SCD, potentially contributing to improved wellbeing. This aligns with research by Wilson et al. (2013), who found that more frequent cognitive activity, including reading, was associated with reduced cognitive decline in older adults. Similarly, Stern (2012) proposed the concept of cognitive reserve, suggesting that engaging in intellectually stimulating activities throughout life can help maintain cognitive function in the face of age-related brain changes or pathology. Moreover, we observed a reduction in stress levels for all participants by the end of the study. While potentially attributable to study completion, these results may also be related to the reading intervention. The stress-reducing effects of reading

have also been demonstrated physiologically, with Baikie and Wilhelm (2005) showing that expressive writing can lead to improvements in both physical and psychological health.

The lack of other significant mood changes suggests that the effects of reading on overall mood might be subtle or require more sensitive measures, particularly those that capture pre-sleep mood states. Global measures of mood disturbances may not reflect mood states immediately prior to sleep. For instance, Ong et al. (2017) found that pre-sleep positive affect was associated with better sleep quality suggesting that the mood-enhancing effects of reading might be most relevant in the immediate pre-sleep period. Vandekerckhove et al. (2011) found that negative emotions at pre-sleep were associated with objectively higher sleep fragmentation, increased WASO, and reduced percentage of REM sleep, suggesting that the emotional content of pre-sleep activities could impact sleep quality. Reading, especially positive or emotionally neutral content, might help regulate emotions before sleep, though this hypothesis requires further testing in our specific context.

4.7.14.6 Narrative Engagement and Sleep Quality

Contrary to our hypothesis that deeper transportation would be positively associated with changes in sleep quality, we found no significant correlations between measures of narrative engagement and changes in sleep quality from baseline to the end of the reading period. Research suggests that individuals differ in their propensity to become transported into story worlds. For example, Weibel et al. (2010) found that personality factors such as openness to experiences, neuroticism, and extraversion are positively associated with immersive tendencies in media consumption among 220 adults. Moreover, Kuijpers et al. (2019) found that trait measures of openness to experience predict concentration and attentional flexibility, important in narrative absorption. Thus, while personality differences across the sample may account for this null finding, the particular use of the SWAS questionnaire to assess narrative absorption in this study may have also contributed. Given the novel nature of this study and the lack of precedent with older adults, we prioritised reducing participant burden to maximise retention and adherence to the protocol. Consequently, the SWAS was administered as a single measure at the end of the study, asking participants to reflect on a book they felt most absorbed in during the intervention. However, this single measure may not accurately reflect maximal narrative engagement throughout the study period, as research has shown

that psychological transportation can vary according to different narratives consumed. Gnambs et al. (2014) found that transportation varied depending on experimentally altered narratives, with the structure of the narrative influencing the degree of transportation experienced by students. In our study, the type of book chosen may have affected transportation levels across the intervention period. Therefore, the lack of correlation between narrative engagement and changes in sleep quality may be due to methodological limitations rather than a true null effect.

4.7.14.7 Limitations

Thus, this study is not without limitations. Several factors that could have influenced the results were not captured in the current study design. One limitation is the lack of pre-post reading variables. With the exception of sleep data and reading frequency, most variables were collected at 2-week intervals and based on global evaluations of wellbeing and mood. This approach may have missed important short-term effects of reading on mood and physiology. Research examining the effects of Non-pharmacological interventions such as music therapy has demonstrated that collecting physiological data such as heart rate and heart rate variability (Iwanaga et al., 2005; Mojtabavi et al., 2020), as well as subjective evaluations of mood (Magee & Davidson, 2002), immediately before and after exposure can provide insights into the acute effects of the activity. Similarly, studies on the effects of mindfulness meditation have shown that measuring HR and HRV can help determine the extent of psychological relaxation associated with the practice (Brown et al., 2021; Shearer et al., 2016). The absence of these measures in the current study limits our understanding of how pre-post effects, such as arousal and relaxation, may be associated with reading and any subsequent changes to sleep quality.

Wearable devices like HR and HRV could be particularly beneficial in collecting objective measures. This would provide more detailed and continuous data and reduce participant burden, an important consideration given the protocol deviations observed in some participants. This approach aligns with the need to balance comprehensive data collection with participant adherence in longitudinal studies, as demonstrated in research on physical activity interventions (Brickwood et al., 2021). Additionally, more frequent, brief assessments of mood and wellbeing could capture fluctuations that fortnightly global evaluations might

miss. This could be achieved through short daily questionnaires or ecological momentary assessment techniques, which have been successfully employed in studies on stress and wellbeing (Wrzus & Neubauer, 2023), providing an understanding of the immediate effects of reading on psychological states.

Another limitation is the absence of data on the emotional content of the books participants read. Research on the effects of expressive writing has shown that the emotional content of the writing can influence the writer's emotional state and wellbeing (Pennebaker & Chung, 2007). As such, it is unclear how the emotional content of the reading material consumed by participants interacted with sleep, wellbeing and mood in this study. Similarly, it would be valuable to investigate how the emotional content of the reading material interacts with the reader's pre-existing emotional state. This information could help clarify whether the emotional content of the book or the reader's pre-reading mood influences sleep quality and duration.

Moreover, the study also had a relatively small sample size, which may limit the generalisability of the findings. Future research should aim to recruit a larger, more diverse sample to increase the statistical power and determine how potentially confounding factors such as baseline cognition, gender, and age affect reading-related outcomes. Additionally, participants' preferences towards fiction and their pre-existing reading habits were not assessed in this study. Research on the effects of music on emotions has shown that individual preferences and familiarity with the music can influence the emotional response (Liljeström et al., 2013). Similarly, these factors may influence the impact of reading on sleep, as individuals who regularly read fiction may respond differently to the intervention than those who do not. Future studies should consider collecting data on participants' reading preferences and habits to control for these potential confounding variables. Lastly, the SWAS was not administered as regularly as would be optimal. A study found that audiobooks can have positive enduring impacts on older adult wellbeing, however this depends on the level of engagement and absorption with its content (Poerio & Totterdell, 2020). Thus, more frequent assessments of sleep quality and duration throughout the study period could provide more detailed insights as to how narrative engagement might influence subjective sleep quality and wellbeing over time.

Our findings contribute to the growing literature on non-pharmacological interventions for sleep improvement in older adults. The significant enhancement in subjective sleep quality suggests that reading may benefit older adults with and without subjective cognitive decline. The discrepancy between subjective and objective sleep measures in our study aligns with previous research, showing that these measures often capture different aspects of sleep quality, even in healthy sleepers (Unruh et al., 2008). While objective measures provide information about sleep physiology, subjective measures reflect the individual's lived sleep experience, including factors such as perceived restfulness and satisfaction with sleep. Our results indicate that engaging in pre-sleep behaviour like reading might enhance the subjective experience of sleep, even if it doesn't immediately alter objective sleep parameters. This improvement in perceived sleep quality could be due to factors such as reduced pre-sleep anxiety, enhanced relaxation, or a more positive association with the bedtime routine. However, future research should aim to examine these factors empirically. Given the positive effects observed with older adults with and without SCD, the following study aims to replicate the protocol with adults living with Vascular Dementia.

4.8 Vascular Dementia and Fiction Reading Feasibility Study

4.8.1 Method

4.8.1.1 Participants

This study aimed to replicate the reading intervention protocol with 15 individuals diagnosed with Vascular Dementia (VaD) within the past five years to compare against the Healthy Older Adults (HOA) and Subjective Cognitive Decline (SCD) groups from the previous study. However, due to time constraints in candidature and recruitment challenges, only 3 participants (2 females and 1 male) were recruited for the full 8-week protocol. The mean age of the participants was 72.46 (SD=4.98). Participants were self-referred as having a diagnosis of VaD and were conveniently recruited using the Join Dementia Research platform, following the same protocol as the HOA group. An additional recruitment criterion was the inclusion of a knowledgeable "study partner" for each participant. Study partners were required to be familiar with the primary participant's daily affairs and willing to assist with completing forms and diaries and remind the participant of study appointments (e.g., completing questionnaires on time) if needed.

4.8.2 Design, Materials, and Procedure

The study followed the same materials and procedures as the prior fiction study, including the timing of activities. The only additional measure incorporated was the Neuropsychiatric Inventory-Questionnaire (NPI-Q; Cummings, 1997), which was completed every two weeks from the study's start to its conclusion, amounting to five time points. The NPI-Q is designed to evaluate neuropsychiatric symptoms and identify potential psychopathology in individuals with dementia or other neurological conditions. It assesses both the presence (yes/no) and the severity (1 for mild, 2 for moderate, 3 for severe) of a range of symptoms, including delusions, hallucinations, agitation or aggression, depression or dysphoria, anxiety, elation or euphoria, apathy or indifference, disinhibition, irritability or emotional lability, aberrant motor behaviour, sleep and nighttime behaviour disorders, and appetite and eating disorders.

Participants in this study could complete the NPI-Q themselves or have their study partner do so.

4.8.3 Presentation of Findings

Due to the limited sample size resulting from recruitment challenges, this study will employ a feasibility approach to present its findings and will feature descriptive statistics to outline changes across various study phases, specifically focusing on sleep, wellbeing, mood, and neuropsychiatric domains. In contrast to the previous study, this study will not present subdomains relating to wellbeing and mood (e.g. positive emotion, engagement, relationship, meaning and achievement) but will present global scores due to the small sample size. Subdomain presentations are listed in the appendix for supplementary information. The aim is to qualitatively compare the trends among the available participants rather than conducting statistical tests for significance. Additionally the aim of this study is to explore whether the protocol conducted in prior studies is suitable for individuals living with VCI. This approach allows for an exploratory examination of patterns that may offer insights for future research despite the smaller than intended sample size.

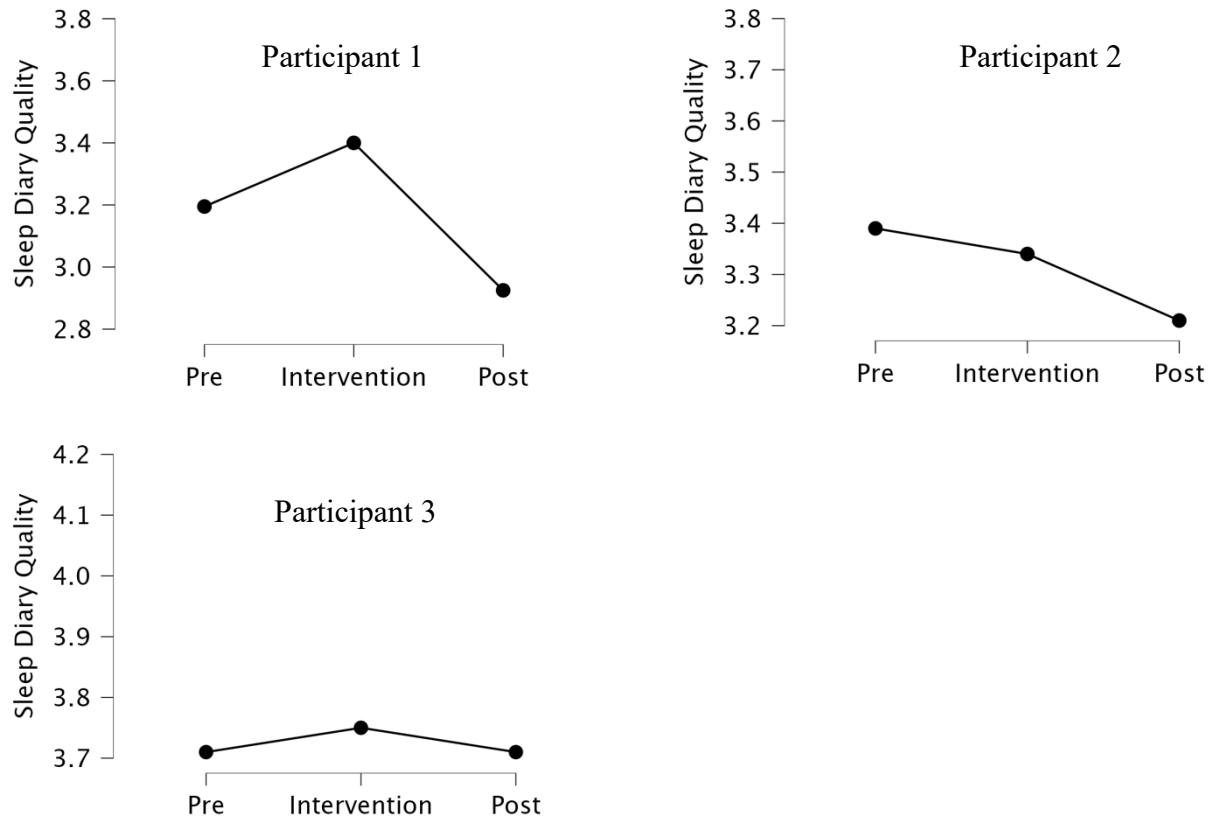
4.8.4 Results

Table 57: Sleep quality (CSD, Actigraphy and PSQI) across an 8-week Study Period

Sleep Quality	Participant	Week (M(SD))							
		Baseline	2	3	4	5	6	7	8
Sleep Diary	1	3.07 (.71)	3.64 (.30)	3.57 (.40)	3.93 (.30)	3.36 (.51)	3.57 (.20)	3.07 (.91)	3.29(.61)
	2	3.5 (.55)	3.29 (.76)	2.43 (.79)	3.43 (1.51)	4.00 (.63)	3.50 (.55)	3.29 (1.50)	3.14 (1.35)
	3	3.57 (.98)	3.86 (1.21)	3.86 (.69)	3.71 (.49)	3.71 (1.11)	3.71 (.49)	3.71 (.76)	3.71 (.49)
Actigraphy	1	-1.55 (.03)	-2.81 (-1.14)	0.48 (.35)	1.61 (1.15)	1.30 (.68)	-1.72 (-.20)	.02 (-.19)	1.17 (1.06)
	2	-1.40 (-1.01)	.37 (.43)	-2.34 (-1.13)	-2.30 (-.58)	-2.81 (-1.15)	-1.51 (-.88)	-2.38 (-.89)	-1.48 (-.14)
	3	-1.55 (-.03)	-2.81 (-1.14)	.48 (.35)	1.61 (1.15)	1.30 (.68)	-1.72 (-.20)	.02 (-.19)	1.17 (1.06)
PSQI	1	9	9		8		10		9
	2	7	7		7		7		6
	3	4	5		5		5		5

4.8.4.1 Sleep Diary Quality

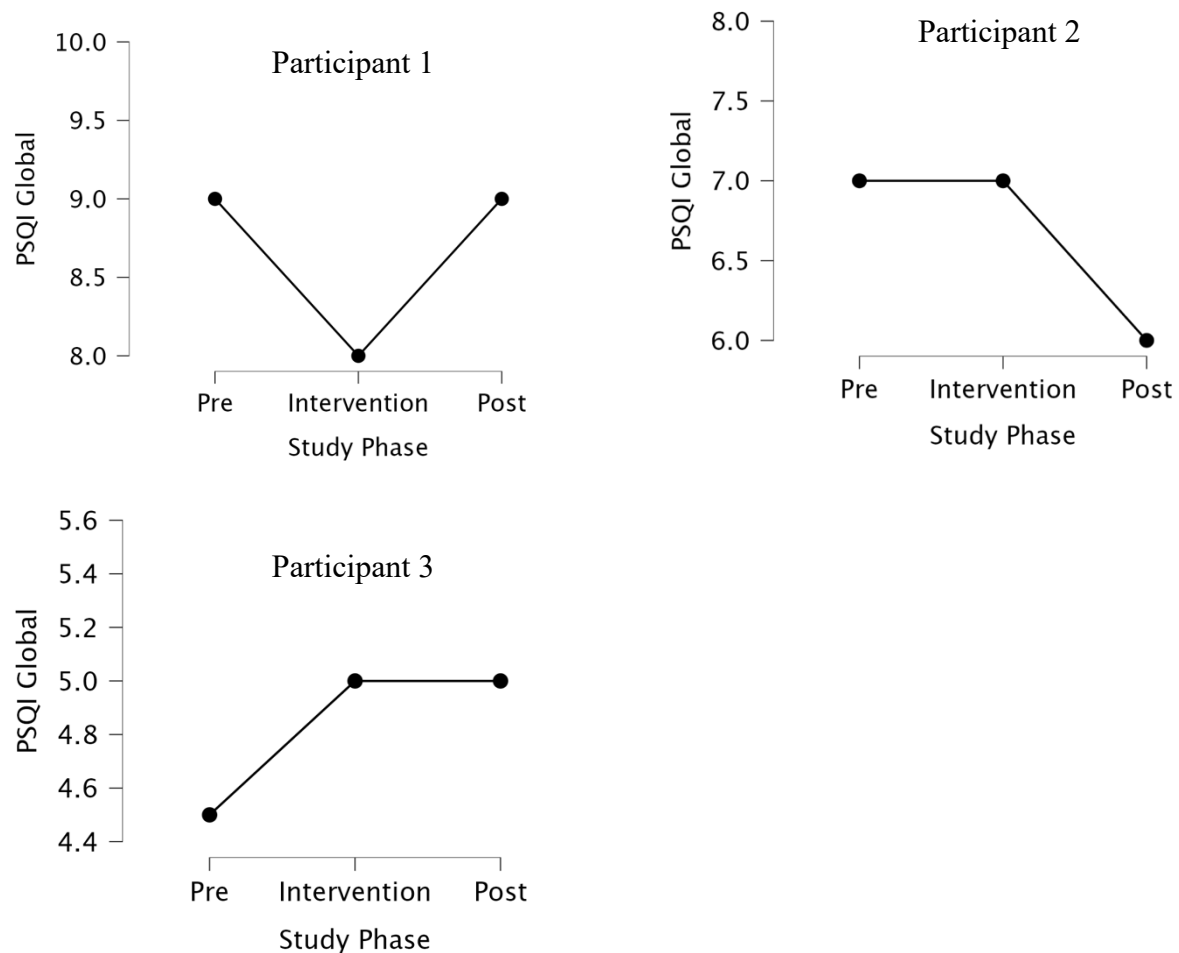
Figure 28: CSD sleep diary quality across 3 study phases



The subjective interpretations of sleep quality by the 3 participants gave rise to mixed results. Importantly, these self-reported assessments were made independently, without assistance from study partners, and therefore reflect each participant's perception of their sleep quality. Participant 1 reported a temporary improvement in sleep quality during the intervention, followed by a decline that fell below initial levels in the post-intervention period. This suggests a short-lived benefit eventually leading to poorer perceived sleep quality. Participant 2 observed a gradual worsening in their sleep quality over the course of the intervention, with a mean decline of 0.2 points, hinting that the reading activity may have been counterproductive for them. Meanwhile, Participant 3 reported slightly improved sleep quality during the reading phase, which reverted to pre-intervention levels afterwards. The findings suggest that fiction reading may have a variable and potentially transient impact on subjective sleep quality.

4.8.4.2 PSQI Sleep Quality

Figure 29: PSQI Sleep Quality

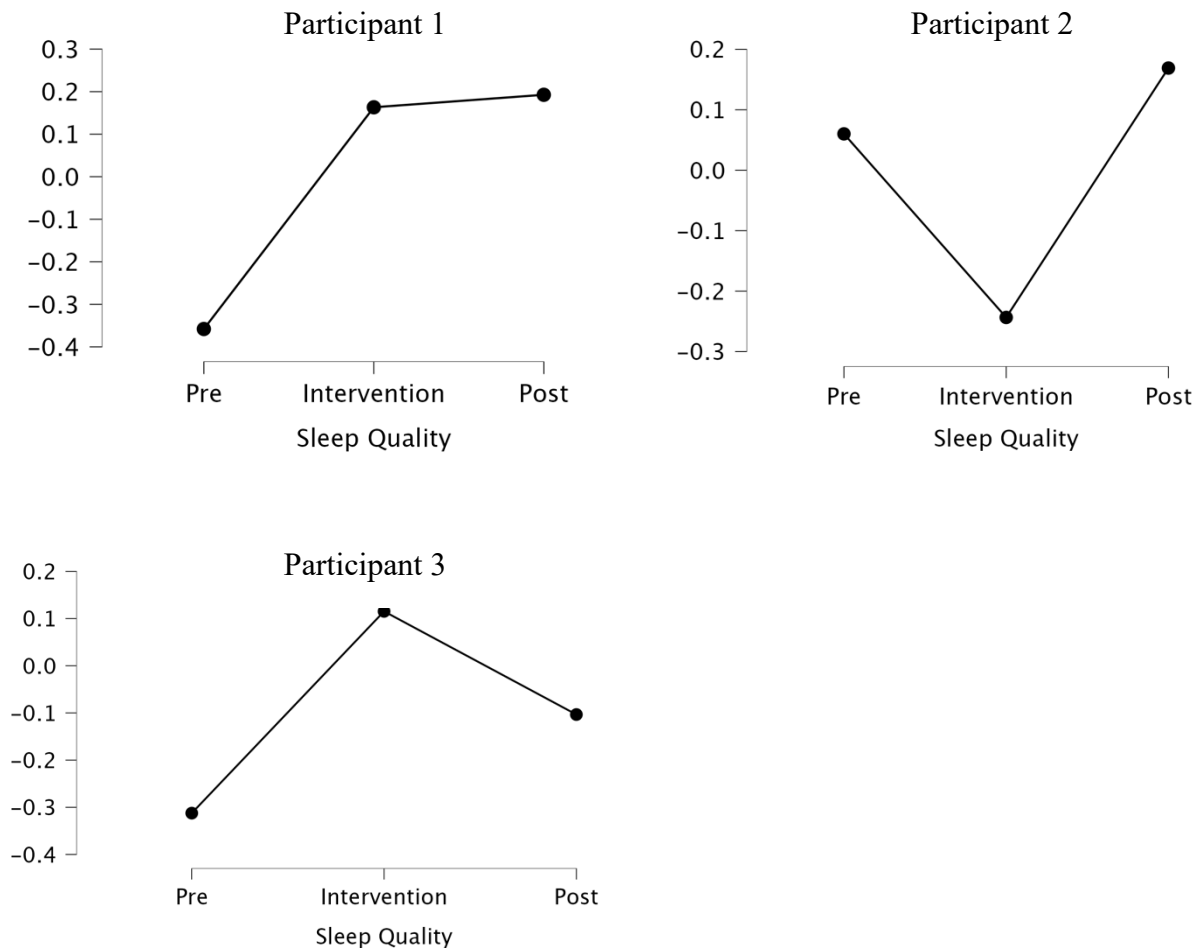


The results show interesting variations in comparing the subjective measures from the daily sleep diaries and the monthly PSQI assessments. The PSQI, which assesses perceptions of sleep quality over the past month, showed that Participant 1 experienced an improvement during the intervention, aligning with their sleep diary. However, the sleep benefits in both measures reverted to pre-intervention levels in the post-intervention phase. Participant 2's PSQI scores remained stable during the intervention but improved post-intervention, suggesting that stopping reading was associated with perceived sleep benefits. This contrasts with their sleep diary, where a gradual decline in sleep quality was observed during the intervention. Participant 3 reported worsening sleep during the intervention on the PSQI, consistent with their sleep diary, and no change post-intervention.

Given that PSQI is a retrospective measure covering a month-long period, its validity may be influenced by factors like recency bias and current emotional state. These factors could particularly impact participants with dementia, affecting their ability to accurately recall past sleep quality. On the other hand, the daily sleep diaries are immediate assessments and may offer a more accurate snapshot of daily sleep quality. The discrepancies between the two measures for Participant 2 highlight the complexities in self-perceived sleep quality and suggest that various factors, including the act of reading itself, the cessation of reading, or other external variables, could influence these subjective assessments.

4.8.4.3 Actigraphy Sleep Quality

Figure 30: Actigraphic Sleep Quality (Composite Z-Score)



Objective sleep quality z-scores were computed based on Sleep Efficiency (SE), Total Sleep Time (TST), and sleep fragmentation multiplied by -1 relative to each participant's mean scores. Participant 1 showed a substantial improvement in objective sleep quality during the intervention, and this trend continued, albeit slightly, into the post-intervention phase. This suggests that the reading intervention had a lasting positive impact on their objective sleep quality. Participant 2's objective sleep quality deteriorated during the reading period. Then it reverted to baseline levels after the intervention, indicating that reading could be associated with diminished objective sleep quality for this individual. For Participant 3, there was an

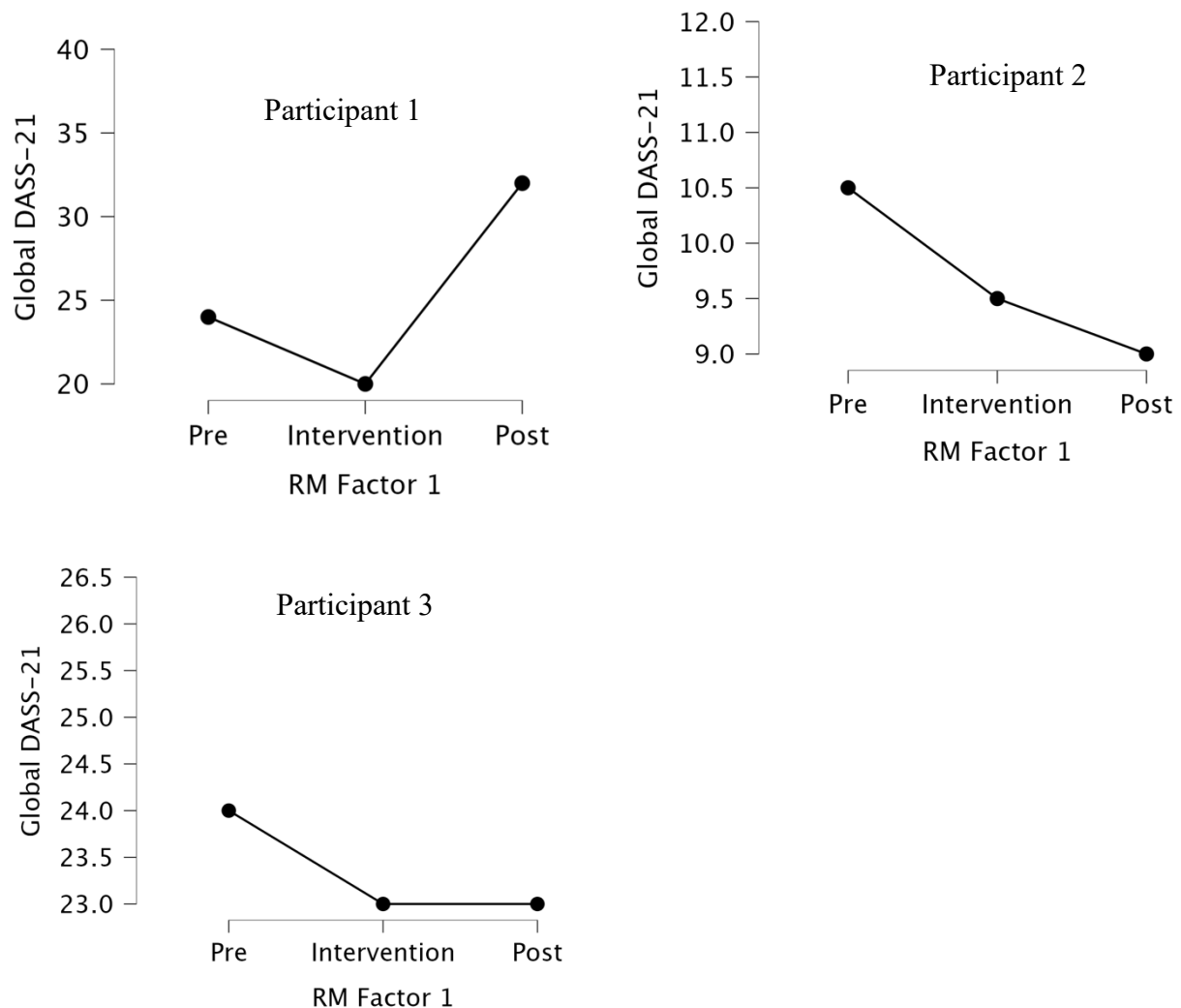
improvement in objective sleep quality during the intervention. Although there was a decline post-intervention, the objective metrics remained above the baseline, implying some sustained benefit.

4.8.4.4 Sleep Quality Summary

Comparing these objective findings with the subjective assessments from the sleep diaries and PSQI scores provides a complicated picture. While Participant 1's objective and subjective measures during the intervention were in agreement, they differed post-intervention, where the objective measures showed a slight improvement, but the subjective assessment indicated a decline. Participant 2's post-intervention improvement in PSQI scores corroborates the return to baseline levels in objective sleep quality, suggesting that ceasing to read may have beneficial effects. Finally, Participant 3's subjective and objective sleep metrics indicated improvement during the intervention, although the objective data suggested a more positive change than was subjectively perceived.

4.8.4.5 Global Mood Disturbances DASS-21

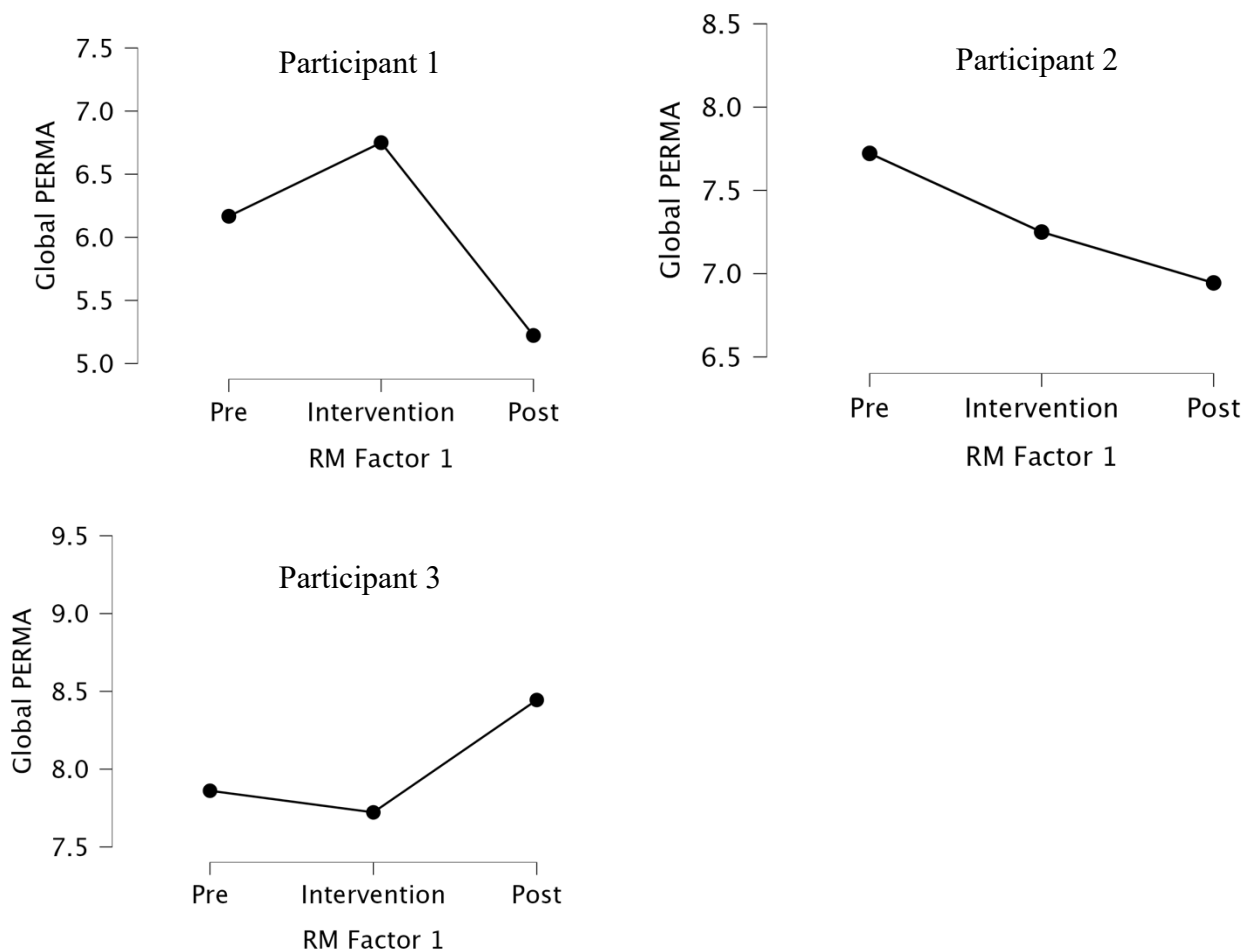
Figure 31: Global Mood Disturbances (DASS-21)



In terms of the combined DASS-21 Global score for depression, anxiety, and stress, all participants showed reduced psychiatric symptoms during the reading phase, suggesting a mood-improving effect. Post-reading results varied: Participant 1 showed increased symptoms exceeding pre-reading levels, indicating the potential removal of a reading benefit. Participant 2 showed further improvements, implying sustained benefits, while Participant 3 maintained the improved levels associated with reading. These findings suggest that reading may generally benefit mood, but discontinuing it is associated with varied outcomes, possibly due to the loss of potentially positive impact that reading may have.

4.8.4.6 Wellbeing (PERMA-Profiler)

Figure 32: Global Wellbeing (PERMA-Profiler)



Interestingly, whilst Participant 1 showed an overall improvement in global wellbeing, Participants 2 and 3 showed slight drops during the reading period. Participants 1 and 2's wellbeing dropped post-reading, whilst that of Participant 3's wellbeing increased at the end of the study. Overall, in terms of global wellbeing, this presents a mixed picture, with some showing improvements and others showing small drops during the reading period.

4.8.4.7 Neuropsychiatric Symptoms

Regarding neuropsychiatric symptoms (NPS), results are presented at baseline, at the end of the reading period, and the end of the study. Notably, participant 3 did not report any NPS over the eight weeks.

Figure 33: Neuropsychiatric Symptoms- Participant 1

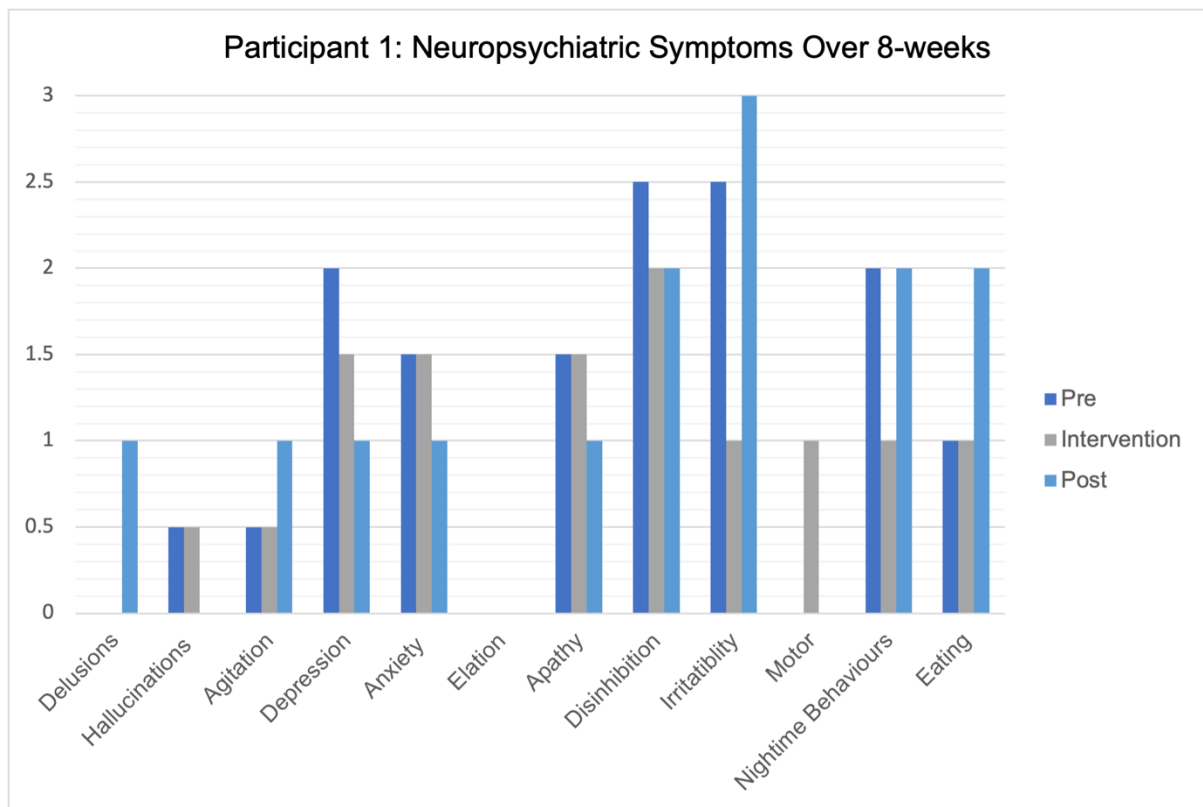
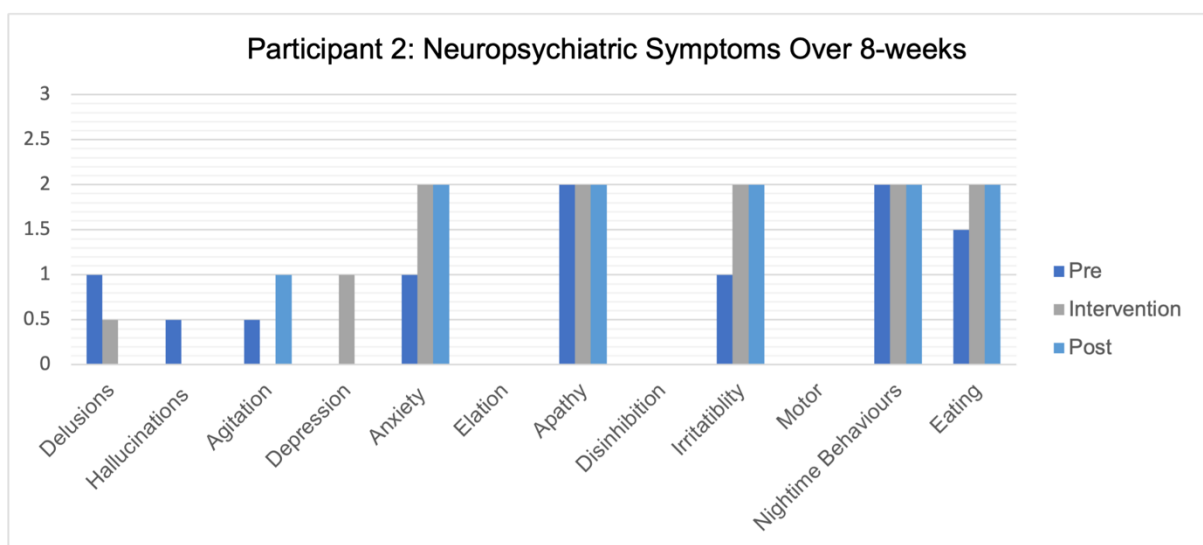


Figure 34: Neuropsychiatric Symptoms- Participant 2

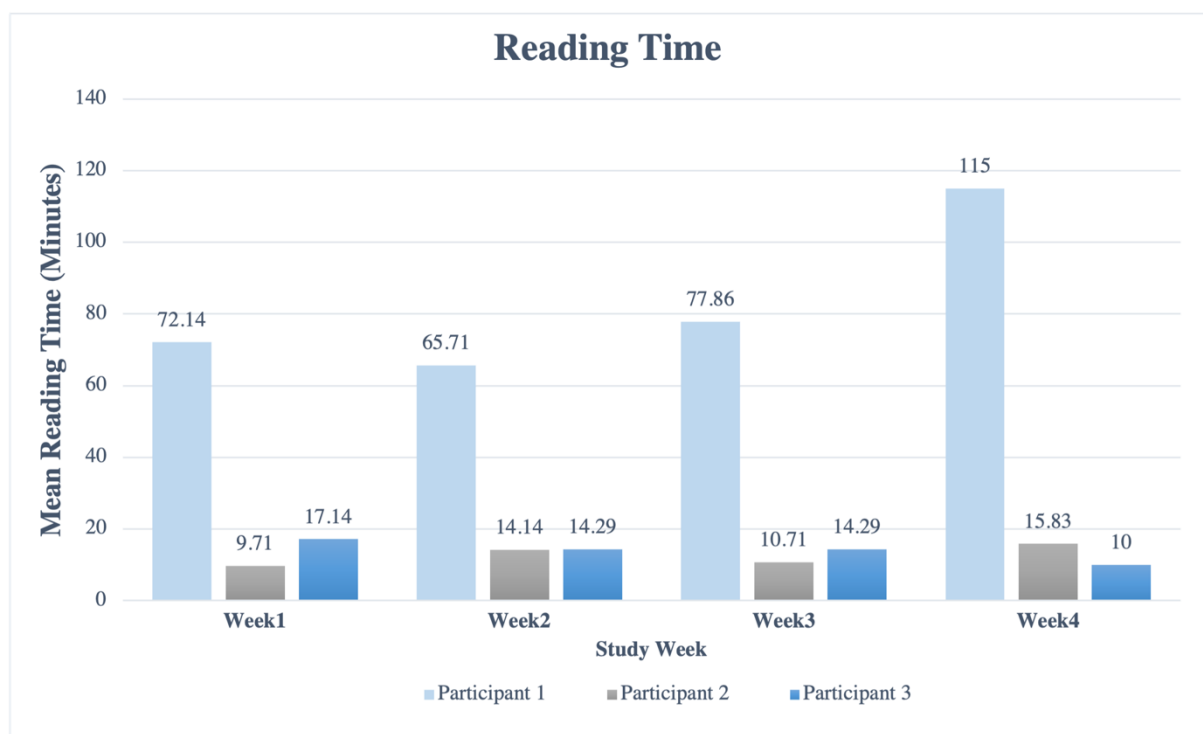


For Participant 1, interestingly, all NPS showed either the same level or a reduction at the reading intervention compared to baseline, except motor behaviours, which were present during the reading period only. At the end of the study, some NPS were higher than in previous study phases, such as irritability, agitation and delusions. Overall, this suggests that for participant 1, NPS appear to reduce during the reading period.

For Participant 2, some NPS reduced during the reading period, including delusions and hallucinations, though many increased during the reading period. Overall, this suggests that for Participant 2, some NPS increased during the reading period.

4.8.4.8 Reading time (Minutes)

Figure 35: Mean Reading Time (Minutes) Across 4-week Reading Period



The pattern of mean reading time (minutes) suggests that participant 1 read more than the other 2 minutes. Participant 1 shows a greater overall improvement pattern across variables than Participants 2 and 3.

4.8.5 Discussion

The present study aimed to explore the potential impact of a fiction reading intervention on sleep quality, mood, wellbeing, and neuropsychiatric symptoms in three individuals diagnosed with Vascular Dementia (VaD). Despite the small sample size, the study provides valuable insights into the practicality of implementing such an intervention in this population.

As measured by subjective (sleep diaries and PSQI) and objective (actigraphy) methods, sleep quality showed mixed results across participants. Participant 1 demonstrated a temporary improvement in subjective sleep quality during the intervention, which was corroborated by the objective measures. However, the post-intervention phase showed a decline in subjective sleep quality, while objective measures showed an improvement. Participant 2's results were more inconsistent, with subjective measures indicating a gradual decline in sleep quality during the intervention. In contrast, objective measures showed a deterioration followed by a return to baseline post-intervention. Interestingly, the PSQI scores remained stable during the intervention but improved post-intervention. These findings suggest that the cessation of reading might have been associated with perceived sleep benefits for this participant. Participant 3 reported slightly improved subjective sleep quality during the reading phase, which reverted to pre-intervention levels afterwards. Objective measures, however, showed an improvement during the intervention that persisted, albeit to a lesser degree, post-intervention. This implies some level of sustained benefit from the reading intervention.

In terms of mood, as measured by the DASS-21, all participants showed reduced psychiatric symptoms during the reading phase, suggesting a mood-improving effect. However, post-reading results varied, with Participant 1 showing an increase in symptoms, Participant 2 showing further improvements, and Participant 3 maintaining the improved levels. These findings suggest that while reading may generally benefit mood, discontinuing it is associated with varied outcomes, possibly due to losing the potentially positive impact of reading.

Global wellbeing, assessed by the PERMA-Profiler, presented a mixed picture. Participant 1 improved overall, while Participants 2 and 3 showed slight drops during the reading period. Post-reading, wellbeing dropped for Participants 1 and 2 but increased for Participant 3.

These varied results underscore the need for further research to better understand the relationship between reading and wellbeing in individuals with VaD. Neuropsychiatric symptoms (NPS) also showed varied patterns. Participant 1 experienced a reduction in most NPS during the reading period, with the exception of motor behaviours. Some NPS increased post-intervention, suggesting a potential benefit of reading that was lost upon cessation. Participant 2 saw a reduction in some NPS (delusions and hallucinations) during the reading period, while others increased. Participant 3 reported no NPS throughout the study. Interestingly, Participant 1, who showed the highest mean reading time, demonstrated a greater pattern of improvement across variables compared to Participants 2 and 3. This observation raises the question of whether the amount of reading time might influence the magnitude of the intervention's effects.

While the study does present some interesting patterns in terms of sleep quality, mood, wellbeing, and neuropsychiatric symptoms, these findings should be interpreted with caution due to the limited sample size and the inherent limitations of a case study approach. The mixed results across participants and domains emphasise the heterogeneity of responses to the intervention and the need for larger, more controlled studies to draw definitive conclusions about the effectiveness of fiction reading in this population. However, the most notable strength of this case study lies in its demonstration that participants with VaD could complete the 8-week reading intervention. All three participants followed the protocol perfectly, completing all required forms and assessments. This finding suggests that with the support of a study partner, individuals with VaD can engage in a structured reading intervention, highlighting the feasibility of this study design.

In conclusion, this study demonstrates the feasibility of implementing a fiction reading intervention for individuals with VaD, highlighting the benefit of enrolling study partners to support study adherence and completion. While the findings related to sleep quality, mood, wellbeing, and neuropsychiatric symptoms are interesting, they should be considered preliminary and interpreted with caution due to the limitations of the study. Future research should build upon this feasibility study by conducting larger controlled trials to assess the effect of fiction reading interventions in this population.

Chapter 5. Addressing the Challenges of Online Research Recruitment and Participation Among Older Adults: Insights and Recommendations Based on Reflections from Studies in This Thesis

5.1 Abstract

Older adults' participation in research is crucial for understanding age-related changes and developing interventions. However, recruiting and retaining older adults in online studies poses challenges. This study aimed to identify factors contributing to low recruitment and retention rates in previous online studies and provide recommendations to address these issues. A mixed-methods approach was employed, analysing quantitative data from two online studies involving older adults and adults with Vascular Dementia (VaD). Qualitative feedback from participants was also collected. Recruitment efforts and dropout rates were examined, and factors contributing to dropout and refusal were identified. Study completion rates were low (1.08% for the emotional memory study, 7.01% for the fiction reading study with healthy older adults, and 4.48% for the VaD group). Substantial effort was required for recruitment and retention (1478 emails and 46.61 hours of telephone/video calls for 42 participants). Challenges included technological barriers, protocol adherence issues, environmental factors, communication and trust concerns, data quality problems, and cognitive capacity variations. The identified challenges highlight the need for tailored strategies to improve recruitment and retention of older adults in online research. Recommendations include multi-modal communication, user-friendly technology, flexible data collection methods, and ongoing support. This study provides valuable insights into the challenges of conducting online research with older adults and offers practical solutions for future researchers.

5.2 Introduction

The global population is undergoing a significant demographic shift, with an increasing number of individuals reaching older adulthood (J. Li et al., 2019). This demographic change highlights an increasing need to include older adults in research as older adults represent a population with an increased risk of developing neurodegenerative conditions such as dementia, making their inclusion in research vital for understanding and addressing these age-related health concerns and drawing inferences between age-related and pathological changes (Jacelon, 2007; McNeil et al., 2016; Burks et al., 2021). This information is essential for developing interventions for early detection, preventative measures, treatments, and improved quality of life (Jacelon, 2007). However, the success of such studies heavily depends on participant retention, which can be influenced by various factors related to study design, data collection methods, and the consideration and accommodation of participants' specific needs (Forsat et al., 2020).

Accounting for the individual needs of older adults is crucial to retaining participants, as research indicates that refusal rates tend to be higher among older adults than younger participants. For example, it's been found that approximately 20-30% of older adults decline to participate in clinical trials, a stark contrast to the reported 5-10% refusal rate among younger demographics (Thompson et al., 1994). Moreover, research indicates that many older adults may not meet the eligibility criteria despite their willingness to participate due to the high prevalence of health conditions. For example, one study found that among every 9-12 older adults approached, only one will meet the eligibility criteria and enrol in the study (D. E. Williams et al., 1988). Even when older adults agree to participate and meet the eligibility requirements, dropout rates are high. This is supported by a study by Ridda et al. (2010) that reported a 50% failure rate in retaining older adults in research studies. These findings highlight the need to identify and address the contributing factors influencing participant recruitment and retention of older adults. In doing so, we can enhance the effectiveness of the recruitment process and, in turn, improve the efficacy and outcomes of future research involving this demographic (Forsat et al., 2020).

Older adults face several challenges that can lead to reduced engagement in research studies, and these factors can be viewed from both the researcher's and the participant's perspectives.

Research has highlighted several barriers to participation for older adults, which can be categorised into five main areas: medical, cognitive, commitment, access to research sites, and gatekeepers (Forsat et al., 2020; Hawranik & Pangman, 2002; Knechel, 2013; Mody et al., 2008; Ridda et al., 2010).

5.2.1 Medical

Firstly, health-related issues, including a higher prevalence of health conditions and multimorbidity, can make it challenging for older adults to commit to study protocols or endure lengthy research procedures. For example, according to the National Council on Aging (2022), nearly 95% of older adults in the U.S. aged 60 and over have at least one chronic condition (e.g. diabetes, arthritis and heart disease), and nearly 80% have two or more. Moreover, prevalence rates for fair or poor health increase with advancing age, doubling and tripling between 55-64 and 85 years and over, respectively (Schoenborn et al., 2022). These are important considerations when designing and involving older adults in research as this may, in part, account for higher attrition rates as some studies have noted that frequent hospitalisations, fatigue, pain, shortness of breath, and visual and auditory impairments all affect an individual's ability to participate in research (Forsat et al., 2020; Hawranik & Pangman, 2002; Mody et al., 2008; Ridda et al., 2010). For example, around a fifth (18%) encountered poor retention rates due to participants not feeling in sufficient health to complete the study. Additionally, transportation and mobility issues can pose significant barriers, especially for those residing in remote areas or with limited access to transportation options (Schlenk et al., 2009).

5.2.2 Cognition

Cognitive decline, often associated with ageing, can significantly impact older adults' ability to comprehend study protocols or engage effectively with research procedures, potentially leading to dropout (Arvanitakis et al., 2019). Forsat et al. (2020) found that in a review of 50 clinical trials, 12% experienced dropouts due to participants not understanding the study, while seven studies faced recruitment failure because participants perceived the study material as overly complicated or lengthy. The complexity of research documentation can

contribute to this issue. Lacey et al. (2017) highlighted that lengthy consent forms and participant information sheets, often laden with technical jargon and lacking visual accessibility (e.g., small font size, poor contrast), can affect comprehension. However, another critical factor is undetected cognitive decline often accompanying advancing age (Federman et al., 2023). This issue is particularly significant when considering very older adults, who are often underrepresented in research and more likely to experience undetected cognitive decline (Federman et al., 2023). Cognitive slowing can impact their ability to understand and engage with research, potentially leading to dropout (R. Davis & Bekker, 2022).

5.2.3 Commitment

Another factor that has been identified with regard to older adult retention in studies related to commitment factors such as time constraints. Older adults may have various commitments and responsibilities, such as caring for family members, attending medical appointments, or engaging in social activities, which can limit their availability for research participation. Additionally, the duration and frequency of study sessions can be a deterrent, as older adults may experience fatigue or discomfort during lengthy or intensive research procedures. This can contribute to their decision to drop out of a study prematurely. Furthermore, older adults may be more sensitive to certain research procedures, such as invasive tests, discomforting stimuli, or strenuous physical activities. Their reluctance or inability to tolerate such procedures may also lead to dropout. In dementia research, a lack of time to commit to a project has been identified as a common barrier to participation (Tsai et al., 2009).

5.2.4 Gatekeepers

Gatekeeping refers to the process of control over access to someone or something (Barnes et al., 2005; Kars et al., 2016). With regard to older adults in the context of research, this can include care providers such as medical staff or caregivers who provide access to research participation (Kars et al., 2016; L. Kay, 2019). Research has shown that gatekeepers play important mediator roles in older adult research and in older adult's decision to participate in research (Ridda et al., 2010). Scourfield (2012) reported that with regard to recruiting

individuals in care homes, residents became “hard to reach” due to defensive attitudes adopted by gatekeepers who may block access to participants who are not cognitively impaired. Moreover, Bailey et al. (2012) suggest that older adults may participate in more research if gatekeepers do not block them. From a researcher’s perspective, involving gatekeepers in the research process can increase time investment as the study process takes longer for consenting, explaining procedures, and accommodating the needs of both the study participant and their study partner (Knechel, 2013)

5.2.5 Access to Research Sites

Geographical constraints, transportation issues, and limited access to research sites represent significant barriers to older adults’ participation in research (Cherubini et al., 2010; Buttgereit et al., 2021; Rigatti et al., 2022). The ability to reach research locations is crucial for participation, and studies have shown that older adults with poorer overall functioning are less likely to have the means of transportation necessary to access research teams and sites (Rigatti et al., 2022). This challenge is further exacerbated for individuals with limited mobility, who face additional obstacles in using public transportation to reach study locations (Dahan-Oliel et al., 2010). Rigatti et al. (2022) found a correlation between proximity to research sites and willingness to participate in studies. Their research revealed that older adults who could drive and lived closer to research facilities were more inclined to engage in research studies, highlighting the importance of considering geographical accessibility in study design and recruitment strategies. These findings suggest that studies may inadvertently exclude older adults with mobility issues or those living in remote areas, leading to a less representative sample. Due to transportation barriers, individuals from rural or underserved communities may be underrepresented in studies (Rigatti et al., 2022). Participants may drop out of long-term studies due to the ongoing burden of travel (Buttgereit et al., 2021).

5.2.6 Online Research

Online research offers advantages such as increased accessibility, cost-effectiveness, convenience, large sample sizes, anonymity, and reduced social desirability bias (Lane et al., 2015). However, conducting research online introduces new challenges, including

technological literacy, limited access to resources such as computer equipment, concerns about online safety and distrust, and visual issues related to predetermined font sizes on certain websites (Provencher et al., 2014; Lane et al., 2015). Despite the potential benefits, research on online data collection focusing on older adults remains sparse (Lane et al., 2015). The recruitment issues faced in Chapters 3 and 4 of this thesis highlight the need to understand the challenges associated with online research and the recruitment and retention of older adults. This study aims to explore these challenges, focusing on improving participant retention, achieving a more representative sample, and facilitating meaningful participation by drawing from the researcher's experience in recruiting older adults for a memory study and fiction reading study.

5.3 Aim and Objectives

Online research offers advantages such as increased accessibility, cost-effectiveness, convenience, large sample sizes, anonymity, and reduced social desirability bias (Lane et al., 2015). However, conducting research online introduces new challenges, including technological literacy, limited access to resources such as computer equipment, concerns about online safety and distrust, and visual issues related to predetermined font sizes on certain websites (Provencher et al., 2014; Lane et al., 2015). Despite the potential benefits, research on online data collection focusing on older adults remains sparse (Lane et al., 2015). Given the recruitment issues faced in Chapter 3 and Chapter 4 in conducting online research with older adults, it is important to understand the specific challenges associated with online research and the recruitment and retention of older adults. Thus, this study aims to explore the challenges associated with online recruitment for older adults, focusing on improving participant retention, achieving a more representative sample, and facilitating meaningful participation. Drawing from the researchers' experience recruiting older adults for a memory study, this investigation seeks to provide practical recommendations for future research practices, aiming to enhance inclusivity and the validity of findings in older adult studies. By addressing these challenges and capitalising on the potential benefits of online research, this study endeavours to develop a more comprehensive understanding of older adults and promote their active engagement in research endeavours.

This chapter aims to explore and address the challenges faced during the recruitment process of older adults and adults living with Vascular Dementia for prior studies in this thesis. This study seeks to identify the reasons behind low response and high dropout rates, identify specific issues, and propose evidence-based strategies to enhance participation and completion rates in future studies. The objectives of this study are to:

1. Investigate factors contributing to low response and high dropout rates among older adults and individuals with Vascular Dementia in online studies conducted in this thesis.
2. Identify potential sources of confusion or deterrents associated with study instructions, procedures, and protocols.
3. Use the literature review on the challenges and barriers typically associated with recruiting older adults and those with dementia to identify potential flaws or constraints in the study designs of previous chapters.
4. Propose recommendations for adapting online study protocols to better accommodate the needs and capabilities of older adults and individuals with dementia, enhancing participation and completion rates in future studies.

5.4 Method

5.4.1 Design and Analysis

The methodology will include an integrated analysis of two studies in a single chapter using a mixed methods approach. Quantitative data from the older adult emotional memory study and the 8-week fiction reading study for older adults and adults living with Vascular Dementia. These include correspondences stored via the official Swansea University system and tracked records of participant information stored using a personal, password-protected, and encrypted database using Notion. Based on these records, a total of 763 individual and personalised study invitations were sent across both studies. All correspondences were sent via the official Swansea University email system using the Outlook platform. Email records and interactions noted using the Notion database will be used to determine outcome measures. Furthermore, older adult participants who consented to participate in the emotional memory and fiction reading studies were subsequently approached to provide qualitative feedback. This feedback focused on multiple aspects of the studies, including the clarity of the information sheets and instructions, study design, the level of assistance they received, and their overall experience. Participants were informed that their insights would contribute to the current chapter. They were assured that their feedback would be used anonymously, safeguarding their privacy and confidentiality.

5.4.2 Ethical approval, Data management and Security

Ethical approval for both studies was obtained from Swansea University's Psychology Departmental Ethics Committee. All correspondences to participants during recruitment were tracked and managed using Notion (Version 2.3.0), an encrypted data-management tool. To ensure data privacy and security, the Notion database was password-protected and encrypted, reflecting good practice and commitment to the ethical handling of participant data.

5.4.3 Participants

The participants for this study were comprised of three distinct groups, each participating in one of two separate studies. The first study, an older adult emotional memory study, was comprised of one group: healthy older adults. The second study, an 8-week fiction reading study, comprised of two groups: healthy older adults and adults living with Vascular Dementia and their study partners. All participants did not receive any incentive to take part, and all were recruited using convenience sampling through the Join Dementia Research platform. Moreover, all participants have been assigned participant identifiers to ensure anonymity. Participants from the older adult emotional memory study are labelled 'EM' followed by a participant number (e.g. 'EMP1'). Participants from the older adult fiction reading study are labelled 'FR' followed by a participant number (e.g. 'FRP1'), and those from the VaD fiction reading study are labelled 'VaDFR' followed by a participant number (e.g. 'VaDFRP1').

Participants for the emotional memory study ($n = 27$) who agreed to take part and who were screened were aged between 65 and 81 years ($M = 70.89$, $SD = 4.85$), comprising a balanced gender distribution of 14 females and 13 males. Participants in this chapter include those who did not complete the study but who consented to participate.

Participants from the fiction reading study consisted of healthy older adults (HOAs; $n = 35$) who agreed to take part and went through screening were aged between 65-83 years ($M = 72.17$, $SD = 5.26$), comprising 26 females and 9 males. With regard to individuals diagnosed with VaD and their designated study partners. Participants were 2 females and 1 male (mean age = 72.46, $SD = 4.98$). The study partners were cognitively healthy themselves had a familiar understanding of the daily life of the primary participant with VaD. They were also in regular contact and expressed a willingness to support the primary participant throughout the 8-week study.

5.4.3.1 Inclusion/Exclusion Criteria

For inclusion/exclusion criteria, Table 58 outlines criteria relating to the older adults emotional memory study, whilst Table 59 outlines criteria relating to the fiction reading study and provides criteria for both HOAs and those with VCI.

Table 58: Inclusion/Exclusion Criteria for Older Adult Emotional Memory Study

Inclusion	Exclusion
Aged 65 and over.	Are living with a diagnosed psychiatric condition.
Had access to a computer or laptop.	Had a history of cognitive impairment (e.g. Mild cognitive impairment, dementia)
Possessed normal or corrected-to-normal vision and hearing.	Had a diagnosed reading or writing disorder (e.g. dyslexia).
Were fluent English speakers.	Had a diagnosed sleep disorder (e.g. insomnia, sleep apnoea, etc).
Were community-dwelling individuals.	Scored more moderate or above for depression (≥ 14), anxiety (≥ 10) and stress (≥ 19) as evaluated by the Depression, Anxiety and Stress Scale- 21 item (DASS-21) form (Lovibond & Lovibond, 2011).
Must abstain from drinking caffeine after 1pm for 7 days	Took more than 30 minutes to fall asleep on more than 1 night a week and had a sleep efficiency of < 70 as evaluated by the Pittsburgh Sleep Quality Index (PSQI; (Buysse et al., 1989).
Must abstain from drinking alcohol for 7 days	

Table 59: Inclusion/Exclusion Criteria for Fiction Reading Study

	HOA	VCI	VCI Study Partner
Inclusion	• Individuals aged 65 or older • Capacity to provide informed consent. • Possession of normal, or corrected-to-normal, auditory and visual capacities. • Proficiency in the English language • Access to a computer equipped with a video camera (for video call purposes) • Residing within the community	• Individuals diagnosed with VCI, VaD or vaMCI within the past five years • Ability to provide informed consent • English proficiency (as the study material and questionnaires/tests are available only in English) • Normal or corrected-to-normal auditory and visual capacities. • Access to a computer equipped with a video camera (for video calls) • Residing within the community	• Individuals aged 65 or older • Capacity to provide informed consent • Possession of normal, or corrected-to-normal, auditory and visual abilities • Proficiency in the English language • Access to a computer equipped with a video camera (for video call purposes) • Residing within the community • Willingness to assist the primary participant throughout the 8-week study • Comprehensive knowledge about the primary participant's daily activities and maintains regular visits.
Exclusion	• Neurological, psychiatric or medical conditions that may affect cognition and mood • History of cognitive impairment • Reading or writing impairment • A diagnosed sleep disorder (e.g. insomnia, sleep apnea, etc.) • DASS-21 (cut-off scores for severity will be considered as moderate or above (i.e. depression ≥ 14, Anxiety ≥ 10, Stress ≥ 19).	• No other significant contributory cause of cognitive impairment (e.g. no other clinically significant neurological, psychiatric, or medical condition, no significant psychoactive drugs, no history of substance or alcohol dependency) • Reading or writing impairment not attributable to cognitive impairment (e.g. dyslexia)	• No other significant contributory cause of cognitive impairment (e.g. no other clinically significant neurological, psychiatric, or medical condition, no significant psychoactive drugs, no history of substance or alcohol dependency) • Reading or writing impairment not attributable to cognitive impairment (e.g. dyslexia)

5.4.4 Procedure

To first examine the effectiveness and efficacy of the recruitment process along with the general procedure of each study, the following outcome measures will include:

1. Invitation rate: The number of invitations sent to potential participants.
2. Response rate: The proportion of potential participants who showed initial interest.
3. Consent rate: The proportion of those who demonstrated interest and consented to participate in the study.
4. Screening rate: The proportion of those who completed screening and were eligible for the study.
5. Post-screening failure rate: The proportion of people who provided consent but were not eligible for the study post-screening.
6. Enrolment rate: The proportion of people who completed screening, were eligible for the study and enrolled.
7. Post-enrolment dropout rate: The proportion of participants who enrolled in the study but did not complete the study.
8. Completion rate: The proportion of participants who finished the study after enrolment.
9. Comprehension rate: The proportion of participants who completed the study successfully without any errors in protocol adherence.

To provide a more comprehensive understanding of the recruitment process, the methodology will also incorporate personal anecdotes and participant feedback, subject to their consent. These first-hand accounts will serve as case studies to highlight practical issues that participants encountered during the recruitment process, adding a richer dimension to the analysis.

5.5 Results

Table 60: Number of People for Outcome Measures for Each Study/Cohort

Outcome Measure	Study/Cohort			Combined Total
	EM healthy older adults	8-week older adult	8-week VaD	
Invitation rate: No of invites sent	368	328	67	763
Response rate- showed interest	145	27 + 40	26	171
Consent rate (provided consent to start study)	34	49	6	89
Screening rate	27	35	6	68
Post-screening failure rate	8	0	0	8
Enrolment rate	10	31	5	46
Post-enrolment dropout rate	4	5	2	11
Completion rate	6	26	3	35
Comprehension rate	4	23	3	27

5.5.1 Study 1: Emotional Memory Study with Healthy Older Adults

5.5.1.1 Quantitative results

The quantitative outcomes of the emotional memory study with healthy older adults revealed key findings. A total of 368 individual and personalised invitations were sent via email. 145

individuals were interested in either knowing more about the study or taking part. Of all individuals contacted for the study, 34 (9.23%) signed the consent form. Only 7 individuals were lost to follow-up at this stage, despite attempts to re-establish contact, as 27 invitees completed the screening forms. Subsequently, 8 were excluded due to not meeting the eligibility criteria. This means that of those who had provided consent 23.53% of participants were not eligible for the study. A further 9 were lost to follow-up without providing a reason, meaning that 10 participants were formally enrolled in the study. This equates to a 2.7% enrolment rate from the entire contacted group. From those who initially expressed interest, the enrolment rate was 6.89%.

Following enrolment, four participants opted to withdraw from the study. Two individuals cited the complexity and frustration in sending voice notes as their reason for withdrawal. Another participant withdrew due to a personal decision not to abstain from consuming alcohol during a family visit. The final withdrawal was due to the participant's distress over their perceived decline in memory performance, which they attributed to the study's focus on memory metrics. Consequently, 6 participants completed the full 7-day study period. However, the data from two participants will be excluded from the full analysis due to incomplete submission of story recordings and deviation from the stipulated submission times. The study design required the completion of sessions strictly 12 hours apart. As these participants missed these windows, their data cannot be included in the analysis. Thus, the final dataset consists of complete data from 4 participants. As such, compared to the initial number of individuals contacted for the study, the success rate of study completion stands at 1.08%.

5.5.2 Study 2: 8-week Fiction reading study with Older Adults and Adults living with VaD and their Study Partners

5.5.2.1 Older adults

The quantitative outcomes of the 8-week study with healthy older adults reveal that 328 personalised invitations were sent via email. A response expressing interest in either knowing more about the study or participating was received from 67 individuals. Of all individuals

contacted for the study, 49 (14.94%) signed the consent form. A total of 35 invitees completed the screening forms, with no one failing the post-screening stage. This indicates that all individuals screened were eligible for the study, thus leading to a 100% eligibility rate at this stage. A total of 31 participants were formally enrolled in the study, representing a 9.45% enrolment rate of all contacted participants. From those who initially expressed interest, the enrolment rate was 46.27%. After enrolment, five participants chose to withdraw from the study for various reasons. Consequently, 26 participants completed the full 8-week study period. However, upon a comprehensive review of all submitted data, three participants' data was excluded due to incomplete submissions or other non-adherence to study protocols. Thus, the final dataset includes complete data from 23 participants. Therefore, compared to the initial number of individuals contacted for the study, the success rate of study completion stands at 7.01%.

5.5.2.2 *Vascular Dementia and Study Partners*

The quantitative outcomes of the 8-week study with individuals diagnosed with Vascular Dementia (VaD) produced intriguing results. A total of 67 telephone calls and personalised invitations were sent out after pre-screening, and 26 individuals expressed interest in learning more or participating in the study. Of all individuals contacted, 6 (8.96%) signed the consent form. Reasons for not proceeding with the study included a lack of interest in the study's subject matter, unwillingness or unavailability to commit to the role of a study partner, a study partner not having the time to commit to the project, concerns over capacity and decision-making ability, time constraints, disinterest in reading and from the point of view of the researcher, there were instances where potential participants did not proceed with the study despite expressing interest on multiple occasions during follow-up calls and emails

All the six invitees who provided consent completed the screening forms, and none failed the post-screening stage. This study observed that all individuals who provided consent and proceeded through the screening process met the eligibility criteria, demonstrating a 100% eligibility rate. This notably high rate can be attributed to a comprehensive pre-screening process employed during recruitment. For instance, potential participants were contacted via telephone, and the eligibility criteria were thoroughly and verbally reviewed before they were

invited to sign the consent form. This strategic approach ensured a more efficient screening process, resulting in and explaining a highly eligible group of consented participants.

A total of 5 individuals were formally enrolled in the study, resulting in a 7.46% enrolment rate of all pre-screened participants. From those who initially expressed interest, the enrolment rate was 19.23%. Following enrolment, two participants chose to withdraw from the study. One of the primary reasons for withdrawal was the discomfort experienced by a participant with VaD due to the demands of maintaining daily sleep diaries and completing forms, even with the assistance of a study partner. This participant, an enthusiastic reader, found the requirement to abstain from reading fiction for two weeks before the study period particularly distressing, even though non-fiction reading was permitted. The study partner reported that the distress was notably exacerbated by this restriction. The second withdrawal was due to the deteriorating condition of a participant with VaD. As reported by the study partner, the participant's dementia had progressed to a point where comprehension of the study instructions and completion of the required forms were no longer feasible. As a result, continuing with the study became unviable for this participant. Consequently, three participants completed the full 8-week study period. This translates to a completion rate of 60% among enrolled participants. Compared to the initial number of pre-screened individuals, the success rate of study completion is 4.48%.

5.5.3 Researcher Engagement

Next, an analysis of participant interactions throughout the study process is presented to quantify the resource allocation and researcher engagement required for participant recruitment and retention. This includes a detailed breakdown of communication frequency, duration, and nature of contacts with participants who initially consented to the studies. These data provide an understanding of the time and effort invested in participant recruitment and retention despite the low study completion rates observed.

5.5.4 Correspondences for those enrolled in the study

Emotional memory older adult:

Table 61: Number of Correspondences with Participants in the Emotional Memory Study Involving Older Adults

Participant Identifier	Number of emails	Minutes in calls
EMP1	19	0
EMP2	14	0
EMP3	18	0
EMP4	21	135
EMP5	12	0
EMP6	24	42
EMP7	21	15
EMP8	11	0
EMP9	14	0
EMP10	5	0
Total	154	192
Mean	17.11	19.2

8-week fiction Older Adult

Table 62: Number of Correspondences with Participants in the 8-Week Fiction Reading Study Involving Older Adults

Participant name	Number of emails	Minutes in calls
FRP1	29	90
FRP2	22	90
FRP3	8	90
FRP4	36	90
FRP5	8	90
FRP6	12	90
FRP7	17	90
FRP8	32	90

FRP9	32	135
FRP10	18	90
FRP11	11	90
FRP12	19	90
FRP13	16	90
FRP14	17	90
FRP15	19	120
FRP16	25	90
FRP17	21	90
FRP18	24	90
FRP19	23	90
FRP20	27	100
FRP21	23	90
FRP22	47	90
FRP23	19	90
FRP24	37	90
FRP25	28	70
FRP26	15	90
FRP27	29	110
FRP28	14	90
Total	628	2605
Mean (SD)	22.43	93.06

Note. All participants were scheduled for 3 30-minute calls across the study period: one to discuss the study before enrolment, one to conduct the first MoCA and explain study protocols and the final MoCA and debriefing.

Table 63: Combined Total Engagement (once showed interest)

Study	Emotional Memory Study (HOA)	8-week Fiction study (HOA)	Total
Emails	154	628	782
Calls (mins)	192	2605	2797

Table 64: Combined Total Recruitment effort (including invitations)

Study	Emotional Memory Study (HOA)	8-week Fiction study (HOA)	Total
Emails	522	956	1478
Calls (mins)	192	2605	2797 (46.61)

5.5.5 Methodological Challenges

After reviewing researcher notes in conjunction with contracting participants for feedback on methodology, 6 factors were identified as having contributed to low recruitment and retention success rates and poor participant success in completing the studies. These included technological challenges, protocol adherence and scheduling issues, environmental and personal factors, communication and trust issues, data quality and integrity concerns, cognitive capacity, and study comprehension.

5.5.6 Technological Challenges

Technological challenges emerged as a significant barrier to effective study implementation and participant retention. Communication via email proved problematic, with important study-related messages occasionally being filtered into participants' junk mail folders. This led to missed instructions and appointments, which was particularly detrimental for time-sensitive protocols such as the emotional memory study. We noted that these emails were being delivered to junk inboxes as emails were being relayed through Qualtrics and, therefore, were not recognised as a prior sender of the recipient. Given the low enrolment rates, the importance of maintaining consistent communication and retaining participants throughout the research process became evident. Moreover, using Qualtrics, an online platform for delivering customised surveys, presented another technological issue. Several participants reported unfamiliarity with this platform, describing it as "confusing." While we

lack specific data on the comprehensibility of the emotional memory study task, this feedback highlights the potential impact of using unfamiliar software on participant engagement and data quality.

Challenges in completing sleep diaries were observed, but interestingly, these difficulties were specific to participants in the emotional memory task who were provided with a digital paper diary. In contrast, participants in the fiction task, who were given a traditional paper diary, did not show similar difficulties in diary completion. Participants using the digital format often struggled with various aspects of the task, including remembering to complete the diary regularly and accurately inputting the required information. Some participants reported forgetfulness in accessing and filling out the digital diary, while others expressed confusion about the specific information required or how to send the completed diary. While digital tools offer advantages in data collection and analysis, they may present unexpected barriers for some older participants.

Finally, using voice recording to send story task recordings proved difficult for enrolled participants. The emotional memory study protocol initially included researcher presence via Zoom throughout all story tasks. However, due to time constraints, this approach was modified. Participants were instead asked to independently record their story sessions and send the recordings to the researcher using WhatsApp or any mobile application capable of recording and sending voice notes via email. Three participants encountered significant difficulties completing and submitting their recordings despite providing instructional videos outlining this process. These challenges compromised data quality and led to increased participant frustration, as evidenced by email communications, ultimately contributing to higher dropout rates.

5.5.7 Protocol Adherence and Scheduling

The complex nature of the emotional memory study design, involving multiple testing points and specific timing requirements, presented significant challenges in participant adherence and scheduling difficulties emerged as a primary concern. The requirement for multiple testing points created logistical challenges for many participants, who often had to balance study commitments with personal obligations and health-related appointments. The need for

participants to complete tasks at a specific time, particularly for the emotional memory study, which required participants to complete testing precisely 12 hours apart, meant that deviations from scheduled times could compromise data quality and integrity. The need for frequent reminders of study appointments became apparent, placing an unexpected burden on the research team. To reduce participant and researcher burden, Qualtrics links containing specific story task sessions were emailed to participants using timed links so they could be sent at specific times. Shortly before prompting participants that a story task was due, an email was also sent. However, despite these prompts, some participants still struggled to complete links on time, resulting in participant dismissal. This raises important questions about resource allocation and the sustainability of such intensive participant management in larger-scale studies.

A particularly problematic issue arose with timed links used in the study protocol. Some participants encountered difficulties accessing or completing study components within the designated time windows. This led to missed data points but also caused frustration among participants, potentially contributing to attrition rates. While necessary for certain aspects of the study design, the rigid nature of these timed elements proved to be a significant barrier for some participants.

5.5.8 Environmental and Personal Factors

The online nature of our studies revealed several environmental and personal factors that significantly impacted participant engagement and data quality. Caring responsibilities emerged as a significant source of distraction for some participants. Several individuals reported difficulties fully engaging with study tasks due to concurrent caregiving duties, whether for spouses, grandchildren, or other family members. This dual responsibility led to interrupted sessions or divided attention during critical study moments within study tasks such as story recall, potentially affecting the reliability of collected data. Controlling for participants' attention and ensuring a consistent testing environment proved challenging in the remote setting. In one notable instance, a participant completed a recall task while in a public park, raising concerns about environmental distractions and the standardisation of testing conditions across participants. Such variability in testing environments could introduce uncontrolled variables into the study, potentially confounding results.

A personal factor that emerged was participants' anxiety about task performance. Some individuals expressed excessive worry about performing "perfectly" on study tasks, which in one particular case almost led to participant dropout. These concerns may have influenced their natural responses or increased stress levels during participation. This perfectionism could skew data or lead to participant burnout, especially in longitudinal study designs. Moreover, the fear of poor performance extended beyond the study itself, with some participants expressing anxiety about what their performance might indicate about their cognitive health. For example, participant EMP8 shared, "Probably what is really holding me back is the fear that I will not be able to sufficiently recall the stories, and that will give me a complex about having dementia!!" This particular participant chose not to enrol in the study. This comment reveals a deeper concern among older participants, where study performance becomes intertwined with fears about cognitive decline.

5.5.9 Communication and Trust Issues with Researchers

Our recruitment efforts revealed challenges related to communication and trust, highlighting the importance of transparent and reliable interactions with potential participants, particularly in the context of online research with older adults. Prospective participants showed wariness towards telephone recruitment. Several individuals expressed concerns about the potential for scams, potentially reflecting a broader societal issue of increased vigilance against fraud targeting older adults. This wariness created a barrier to initial engagement, potentially leading to the loss of eligible and interested participants before they could be fully informed about the study. The online nature of the research further exacerbated trust issues, with participants expressing a need for verifiable online researcher identification. The absence of face-to-face interaction seemed to heighten concerns about the study's legitimacy and the researchers' credentials. This highlights the importance of developing methods for establishing researcher credibility in online settings, such as official university web pages or digital credentials that participants can easily verify.

Perhaps most concerning was the feedback from some potential participants who cited previous negative experiences with research participation as a reason for their unwillingness to enrol in our study. These individuals reported participating in prior studies where they

were promised follow-up information about the results and how their time had been used but never received such feedback. This breach of trust affected our recruitment efforts and pointed to a broader issue in the research community regarding the responsible conduct of research and participant engagement.

5.5.10 Data Quality and Integrity Concerns

While necessary and beneficial in many ways, the transition to remote research methodologies has introduced significant challenges in maintaining data quality and integrity. These concerns are particularly salient in older adult studies, where controlling for environmental factors and ensuring protocol adherence become more complex without direct researcher supervision. One of the primary challenges encountered was ensuring consistent testing environments across participants. Unlike controlled laboratory settings, remote participation allows for various environmental conditions that could potentially influence study outcomes. Factors such as background noise, interruptions from family members, or even the physical comfort of the participant's chosen location could introduce uncontrolled variables into the data. This variability in testing conditions raises questions about the comparability of data across participants and the overall reliability of the findings. Maintaining strict protocol adherence without direct researcher supervision was another significant concern. A striking example of this issue emerged when it was confirmed that one participant had written down previous stories and recalled them by reading from a script during the memory task. This behaviour, while understandable given the participant's likely desire to perform well, fundamentally undermines the validity of the data collected. It also raises broader questions about the extent to which other participants might have engaged in similar behaviours without the research team's knowledge.

5.5.11 Cognitive Capacity and Study Comprehension

Our study encountered challenges related to participants' cognitive capacity and ability to comprehend and retain study-related information. These issues raise important questions about the assumptions we make when designing studies for healthy older adults and the potential for undiagnosed cognitive impairment to impact research outcomes. Several

instances highlighted significant difficulties among some participants in managing basic study-related information. For example, some individuals struggled to accurately record the researcher's email address despite being provided multiple times, which posed problems when contacting participants during the study process. Others forgot scheduled study dates, needing repeated reminders and rescheduling efforts. Perhaps most concerning was the observation that some participants, even after being reminded of the study's purpose at various time points, could not retain this information, suggesting potential issues with memory or overall study comprehension.

5.6 Discussion

Older adults represent a population at risk of cognitive decline. Their participation in research is essential for developing effective interventions to maintain cognitive health, understanding age-related changes in cognition, improving quality of life for ageing populations, and informing public health policies and healthcare practices (D. E. Williams et al., 1988; McHenry et al., 2015; Buttgereit et al., 2021). Research has shown that compared to younger adults, older adults have unique needs when participating in research studies (Buttgereit et al., 2021). Addressing these needs is crucial to enhance recruitment and retention of participants. The benefits of online research include the potential to include more participants who might otherwise be constrained by geographical or health-related factors preventing in-person participation (Lane et al., 2015). However, factors contributing to low recruitment and retention rates in older adult online research are poorly understood (Lane et al., 2015). This study aimed to examine factors that may have contributed to low recruitment and retention rates in previous studies in this thesis and to provide future recommendations to alleviate the impact of these factors, potentially supporting the unique needs of older adults in online research contexts. This study quantitatively examined the recruitment effort of two separate studies, analysed rates of drop-out along various phases of the study journey, calculated the percentage of individuals completing the study compared to the number contacted, and examined potential factors contributing to drop-out and reasons for refusal using participant feedback and researcher reflections.

This study found that for the emotional memory study fiction reading study for healthy older adults and those with VaD, the success rate of study completion compared to the number of individuals contacted for the study was 1.08%, 7.01%, 4.48%, respectively. Whilst we did not review our recruitment materials within this study, we did aim to adhere to prior recommendations of using limited scientific language, large font size and large spacing between text. There was a large difference between the emotional memory study and the fiction reading study in terms of the people who completed the study compared to those who showed initial interest (EM older adults: 6.89%, FR older adults: 46.27%, FR VaD group: 19.23%), even though the fiction reading study was substantially longer (8-weeks) than the emotional memory study (7-days). However, after reviewing the researcher's effort,

substantially more emails and calls were made to participants for the 8-week study, suggesting that reduced contact with the researcher may be attributed to this discrepancy.

The effort made by a single researcher to recruit a total of 42 participants across was substantial and amounted to a total of 1478 emails and 46.61 hours of telephone and video calls, highlighting the effort required to recruit older adults into research. This information is useful for future researchers in replications or conducting online research with older adults to determine the resources required to allocate prior to recruitment efforts. Several challenges have been identified in this study, including challenges relating to technology, protocol adherence and scheduling, environmental and personal factors, communication and trust issues with researchers, data quality and integrity concerns, cognitive capacity and study comprehension. As a result, several recommendations will be made to enhance participant recruitment and retention for older adults in online studies.

5.6.1 Technological challenges

Challenges identified with communication included email issues, unfamiliarity with online survey platforms, difficulties with digitised versions of paper resources (i.e., sleep diaries), and problems with voice recording tasks. These obstacles lead to missed instructions, confusion, data quality issues, and increased participant frustration, ultimately contributing to higher dropout rates. Firstly, given issues with unrecognised emails used through Qualtrics, it is important to have multiple methods of contacting participants. This approach aligns with research by Buckley et al. (2023), who found that a multi-modal recruitment strategy significantly improved participation rates in older adults. Researchers should use a combination of phone calls, emails, and texts, and even send printed study materials and appointment reminders to home addresses, where possible. However, participant preferences for contact methods should be observed, as Forsat et al. (2020) noted that tailoring communication methods to individual preferences can enhance engagement and retention. For those opting for email communication, implementing a notification system for email correspondence may help to address the uncertainty of whether participants have received and read email communications, reducing the risk of missed instructions or confusion due to unread study information.

To ensure that surveys and study tasks are user-friendly, conducting usability tests with a small group of older adults can help identify and address confusing elements. This approach is supported by research showing that involving older adults in identifying issues not anticipated by researchers promotes more inclusivity in research (Fudge et al., 2007; Seale et al., 2002). For example, Fudge et al. (2007) found that co-designing digital health interventions with older adults led to improved usability and acceptance. Where possible, offering a choice between paper and digital tools may serve to reduce confusion with study design and protocol. This flexibility is supported by Medlock et al. (2015), who found that older adults have diverse preferences for health information delivery methods. Providing options may improve compliance and engagement. However, providing training and support is necessary for those opting for digital tools.

In cases where digital tools cannot be avoided, such as recording story recalls for memory studies, and where these tasks can only be completed once at a specific time, there is little room for error. With hindsight, as the emotional memory study protocol was already complicated with several steps in the process, study appointments, and tasks within each session, asking older adults to complete this independently contributed to sampling failure. Given the heterogeneity of the older adult population, where cognitive impairment may be a factor, supporting participants via video call would ensure that participants are guided through the research process, thereby enhancing the validity of the results. This approach is supported by research from Sixsmith (2021), who found that personalised support and guidance can significantly improve older adults' engagement with digital technologies in research contexts.

5.6.2 Protocol Adherence and Scheduling

The emotional memory study design presented significant challenges due to its complex nature, involving multiple testing points and specific timing requirements. These challenges led to difficulties in participant adherence and scheduling, compromised data quality, and increased participant frustration. Timed links and the need for precise task completion times proved particularly problematic, contributing to missed data points and potential attrition. To overcome these issues, simplifying the study design in conjunction with research presence may reduce participant burden and improve retention. For example, with regard to the

emotional memory study, as mentioned, having a researcher present via video call would mitigate the need for participants to find and access specific timed links to read instructional material. It would allow the participant to ask questions at all stages of the task. Moreover, implementing a flexible approach to participant scheduling and accommodating prior engagements is important in retaining participants. Of course, many studies are limited by researcher time, and it is essential to balance this, but offering a personalised schedule in conjunction with improved communication and support is important in retaining older adults. For example, in a systematic review of studies that reviewed strategies for improving participant retention in older adult research (Provencher et al., 2014), seven studies reported that being flexible about the time and place of the interview improved participant retention rates (Schmidt et al., 2000; Ewart et al., 2001; Sharkey, 2002; Bandinelli et al., 2006; Marcantonio et al., 2008; Peel & Wilson, 2008; Crawford Shearer et al., 2010).

5.6.3 Communication and Trust Issues with Researchers

The main issues identified with regard to communication and trust issues with researchers include wariness towards telephone recruitment due to concerns about scams, trust issues related to the online nature of the research, and negative past experiences with research participation. Several strategies can be adopted to address these challenges and improve future studies. Firstly, as suggested previously, a multi-method recruitment approach, as supported by Buckley et al. (2023), could help to reach prospective participants through methods they trust and feel comfortable with. In their review, McHenry et al. (2015) report that many research studies have reported that trust-building relies heavily on face-to-face interactions and that it is the most effective way to recruit older adults. In the context of online research, offering a video call could improve participant knowledge about the researcher, putting a face to a name. This would also help participants confirm the researcher's identity through an online presence. Enhanced credibility verification methods would also enable participants to confirm the identity of researcher calls and emails. These could include ensuring that the researcher has an online presence of a reputable source, such as an official university page with information about the researcher, using office university email addresses or providing digital certificates to establish researcher authenticity. Additionally, implementing a policy of complete transparency regarding the research process, data usage, and dissemination of results is important. Of course, this should form part of the

research process anyway. However, this would be particularly pertinent for researcher follow-up. If participants want a follow-up to know where their research time and effort has been used, then ensuring that participants receive this is important. In the interest of sending user-friendly materials, it could be beneficial as part of the research plan to incorporate participant-friendly follow-up documents explaining methods, results and outcomes in an accessible, jargon-free way, as outlined by McHenry et al. (2015).

5.6.4 Data Quality and Integrity Concerns

The challenges surrounding data quality and integrity concerns related to ensuring consistent testing environments and maintaining strict protocol adherence without direct researcher supervision. Although some research has found no difference between unsupervised web-based assessments and cognitive tests administered through videoconferencing in older adults (Belleville et al., 2023), we found that in multiple instances, unsupervised web assessments relating to story recall resulted in incomplete data submissions potentially due to distracting environments. Firstly, providing clear guidelines for creating a consistent testing environment at home, including recommendations for lighting, noise levels, and potential distractions, could help standardise testing conditions. Moreover, virtual supervision through video conferencing for critical data collection sessions could allow researchers to monitor the testing environment and ensure protocol adherence. Developing comprehensive training materials that clearly explain the importance of following study procedures precisely as instructed, emphasising the impact of deviations on data integrity, could enhance protocol adherence. The training materials should be tailored to the needs and preferences of older adults, using clear language, visual aids, and examples to illustrate key concepts (McHenry et al., 2015). Moreover, incorporating very brief questionnaires after each session where participants report on their adherence to protocols and any environmental factors that may have affected their performance could provide valuable context for data interpretation. These questionnaires should be concise and easy to understand to reduce participant burden.

5.6.5 Cognition

Our study revealed challenges related to participants' cognitive capacity and ability to comprehend and retain study-related information. Some participants struggled with basic tasks such as recording the researcher's email address, remembering scheduled dates, and retaining information about the study's purpose. These observations raise important questions about the potential impact of undetected cognitive decline on research outcomes with older adults. Several strategies can be implemented to address these issues and improve future studies. Providing clear, concise instructions and repeating them at various stages of the study may help participants with memory difficulties to better retain important study information. As suggested by EMP4, incorporating reassuring language such as "just do your best" may help reduce performance anxiety and potentially improve engagement. Additionally, incorporating memory aids such as written summaries, visual cues, or digital reminders can help participants retain important study information.

5.6.6 Conclusion

This study has provided valuable insights into the challenges of recruiting and retaining older adults in online research, with implications for future study designs and methodologies. The low completion rates observed (1.08% for the emotional memory study, 7.01% for the fiction reading study with healthy older adults, and 4.48% for the VaD group) highlight the significant challenges in this area of research. The substantial effort required for recruitment and retention, as evidenced by the 1478 emails and 46.61 hours of telephone and video calls for 42 participants, provides important information for resource allocation in future studies. This insight can help researchers and institutions better prepare for the demands of conducting online research with older adults.

The identified challenges, including technological barriers, protocol adherence issues, environmental factors, communication and trust concerns, data quality problems, and cognitive capacity variations, provide an overview of the obstacles faced in online research with older adults. The recommendations, such as implementing multi-modal communication strategies, enhancing user-friendly technology, offering flexible data collection methods, and providing ongoing support, offer practical solutions for future researchers. These strategies may improve recruitment rates, enhance participant retention, and produce more robust and representative research outcomes. This work not only benefits the scientific community but

also has the potential to improve the representation of older adults in research, ultimately contributing to better health outcomes and policies for this growing demographic.

Chapter 6. General Discussion

6.1 Overview

This thesis aimed to investigate the relationship between sleep and cognitive function, particularly memory, in the context of cognitive impairment and dementia, specifically focusing on Vascular Cognitive Impairment (VCI). Despite the growing recognition of VCI as a prevalent form of cognitive impairment (Erkinjuntti & Rockwood, 2001; Bowler, 2005; Van Der Flier et al., 2018), research on the role of sleep in cognitive function within this population has been limited compared to the extensive literature on Alzheimer's Disease (AD). The relationship between sleep disturbances and cognitive decline in AD has been well documented, with studies suggesting a bidirectional relationship. For example, sleep issues have been shown to increase the risk of AD development, exacerbate cognitive symptoms, and accelerate neurodegeneration (Shi et al., 2018; Ibrahim et al., 2024). Conversely, AD progression contributes to an increased prevalence of sleep disturbances (Bubu et al., 2017; Shi et al., 2018). Given that mixed dementia, which refers to shared pathology between AD and VaD, a subtype of VCI, shares pathological features with AD (Van Der Flier et al., 2018), it is plausible that sleep issues may similarly contribute to accelerated cognitive decline in VCI. However, this relationship remains largely unexplored in the context of VCI specifically. Existing research has primarily focused on the increased risk of developing VCI due to various sleep disorders and disturbances, including sleep apnoea, sleep fragmentation, and extreme sleep durations (Chang et al., 2013; Shi et al., 2018; Culebras & Anwar, 2018).

Moreover, given the evolving nosology of VCI, which now encompasses a spectrum of cognitive impairments associated with cerebrovascular disease, researchers have suggested that the prevalence of VCI may be underestimated due to evolving nosology and therefore, with the inclusion of CVD, VCI may be the most prevalent form of dementia (Bowler, 2002; Van Der Flier et al., 2018), as such understanding the impact of sleep disturbances on cognitive function in VCI is of critical importance. This thesis aimed to address this gap by examining the relationship between sleep and cognitive function in VCI, identifying sleep-related cognitive vulnerabilities, and exploring potential non-pharmacological interventions to enhance sleep quality in older adults with and without cognitive impairment. The primary aim of this thesis was to serve as an essential first step in building foundational knowledge in

this understudied area. By investigating these relationships, this work aspires to provide a foundation to inform future research that could better inform diagnostic criteria for VCI, enhance our understanding of sleep-related mechanisms in cognitive decline, and explore the potential of sleep interventions aiming to ameliorate negative consequences of poor sleep. Ultimately, this thesis may contribute to developing strategies to slow sleep-related cognitive decline in VCI patients, highlighting the importance of sleep in the broader context of vascular cognitive health.

The studies presented in this thesis employed a range of methodologies and populations across four chapters and nine studies to provide new insights into the role of sleep disturbances in cognitive functioning. Firstly, using an extensive database, this thesis examined the effect of sleep issues on cognitive domains across a spectrum of cognitive impairment ranging from healthy older adults to adults with VaD. Before this work, these effects were unknown. Secondly, this thesis developed a narrative-based task to assess declarative and emotional memory to expand on the previous study's findings and build on the limitations of commonly used tasks assessing sleep-dependent emotional memory processing. Moreover, this thesis developed an automatic counting tool to rapidly and accurately count story recalls, aiming to enhance the useability of narrative tools in memory research. Additionally, this thesis aimed to explore the feasibility and effectiveness of a non-pharmacological bibliotherapy intervention to improve sleep quality in older adults and individuals with VCI. Finally, this thesis examined specific issues associated with the recruitment and retention of older adults in online and remote research, given some recruitment issues experienced in prior studies due to adapting methodology in response to the COVID-19 pandemic and subsequent restriction of conducting in-person research.

With regards to experimental studies in this thesis, an additional aim was to examine sleep, cognition and interventions across a spectrum of cognitive impairment ranging from healthy ageing to Vascular Dementia (VaD) to reflect the objective of most dementia research, to ultimately slow cognitive decline and enable people to live as well as possible for as long as possible. By examining earlier stages of cognitive impairment, such as Mild Cognitive Impairment (MCI) and Subjective Cognitive Decline (SCD), this thesis aimed to provide a broader understanding of the effect of sleep issues on cognition and to examine the efficacy of sleep-related intervention in these populations, in addition to those with VaD. This research provides a foundation for future studies that could inform diagnostic criteria for VCI, enhance

understanding of sleep-related mechanisms in cognitive decline, and explore targeted sleep interventions to mitigate cognitive decline. Ultimately, this work highlights sleep as a modifiable risk factor in vascular cognitive health, potentially contributing to strategies for slowing sleep-related cognitive decline in VCI patients.

6.2 Chapter 2: The Effect of Sleep Disturbances on Cognitive Performance in Vascular Cognitive Impairment: Findings from the National Alzheimer's Coordinating Center Uniform Dataset.

Chapter 2 examined the impact of sleep issues, including sleep disorders and markers of sleep disturbances such as nighttime awakenings, waking too early and taking excessive naps, on cognitive performance in individuals with VCI, primarily individuals with Vascular Dementia (VaD), using the National Alzheimer's Coordinating Center Uniform Data Set (NACC-UDS). This study considered the heterogeneity in cognitive presentation observed in VCI by examining a range of cognitive domains to identify specific domains affected by sleep disturbances. The results supported the hypothesis that individuals with sleep disturbances would show poorer performance across several cognitive domains than those without sleep issues, with effects observed in memory, executive function, language, and orientation. Notably, individuals with VaD were disproportionately affected by sleep disturbances compared to healthy older adults and those with Mild Cognitive Impairment (MCI). The effect sizes provided a clearer understanding of the magnitude of the impact of sleep disturbances on specific cognitive domains, with orientation showing the largest effect ($d = 0.69$), followed by global cognitive function ($d = 0.68$), executive function ($d = 0.31$), and memory ($d = 0.22$).

These findings align with and extend previous research demonstrating the negative impact of sleep disturbances on cognitive function in AD and other types of dementia (Bubu et al., 2017; Shi et al., 2018) by specifically focusing on VaD, an understudied population in the context of sleep and cognition. The observed effects of sleep disturbances on executive function and orientation in VaD are particularly noteworthy, as these cognitive domains are important predictors for subsequent decline and daily functioning (Boyle & Cahn-Weiner, 2004; Razani et al., 2009). These findings are supported by proposed mechanisms underlying the relationship between sleep and cognitive function in VCI. The well-established role of sleep in memory consolidation, synaptic plasticity, and clearance of neurotoxic waste

products (Mander et al., 2013a; Xie et al., 2013; Rasch & Born, 2013; Mander et al., 2015, 2017) suggests that sleep disturbances may exacerbate cognitive decline in VaD through multiple pathways. For example, the disruption of slow-wave sleep, which is critical for memory consolidation and synaptic downscaling (Born & Wilhelm, 2012), may impair the ability to consolidate memories effectively during sleep in VaD. Sleep fragmentation and intermittent hypoxia associated with sleep disorders like obstructive sleep apnoea may also contribute to oxidative stress, inflammation, and endothelial dysfunction (Lavie, 2007; A. S. P. Lim et al., 2014; Culebras & Anwar, 2018; Van Der Flier et al., 2018) compromising cerebrovascular health and cognitive function in VaD, though future work would need to explore this empirically.

The implications of these findings are significant for diagnostic accuracy and identifying sleep-related cognitive vulnerabilities in VaD. Given that memory impairments are used in diagnostic criteria to discriminate early cases of cognitive impairment between VCI and AD, with non-amnesic multidomain impairment predicting VCI and amnesic MCI predicting AD (Brooks & Loewenstein, 2010; Van Der Flier et al., 2018), the observed impact of sleep disturbances on memory function in VaD suggest that sleep disturbances may complicate the diagnostic process by exacerbating memory impairments in VaD, potentially leading to misclassification of cognitive subtypes or overestimating disease severity. Consequently, these findings, in conjunction with the well-established role of sleep in memory consolidation (Diekelmann & Born, 2010; Born & Wilhelm, 2012; Rasch & Born, 2013), highlighted the need for a more focused examination of sleep-dependent memory processes in VCI, which informed the development of an emotional memory task in Chapter 3.

6.3 Chapter 3: Sleep-Dependent Emotional Memory Consolidation: Development of a Narrative Task, Preliminary Findings in Young and Older Adults, and Implications for Future Research for Individuals with Vascular Cognitive Impairment

Chapter 3 consisted of five studies focused on developing and validating a new narrative memory task designed to assess sleep-dependent memory consolidation in young and older adults with and without cognitive impairment. The decision to use narrative tasks was based on prior literature suggesting that emotional memories are preferentially consolidated across sleep compared to neutral information (Lipinska et al., 2019) and effective consolidation of

emotional memories has implications for daytime mood and wellbeing (S. E. Williams et al., 2022), suggesting that the examination of both declarative and emotional memory may be of benefit for those with VCI and sleep issues. Additionally, narrative tasks resemble memory structures used in everyday life more closely than word-list tasks (León, 2016) and are suitable for assessing emotional memory using free-recall paradigms, which are more sensitive to sleep-dependent memory effects (Lipinska et al., 2019).

The development process of the narrative task involved a series of pilot studies (Study 1 and Study 2) to refine the stories and ensure their matching for memorability, difficulty, and emotional valence, considering the methodological considerations highlighted in previous meta-analyses (Lipinska et al., 2019). Study 3 tested the narrative task in 24 young adults using a within-participant crossover design to examine the effect of sleep versus wakefulness on performance. While the expected preferential consolidation of emotional narratives over neutral narratives during sleep was not observed, the results revealed a general sleep benefit for memory performance across all story types. This aligns with research demonstrating sleep's role in declarative memory consolidation (Diekelmann & Born, 2010; Rasch & Born, 2013) and indicates the task's sensitivity to sleep-related memory effects.

The absence of an emotional enhancement effect in young adults may be due to the relatively weaker negative valence of the stories compared to positive ones, as rated by the young adult sample. This aligns with research showing age-related biases in emotional memory processing: younger adults typically exhibit better sleep-dependent memory for negative stimuli, while older adults show improved retention of positive information (B. J. Jones et al., 2016; Huan et al., 2020). The weaker negative valence may have failed to reach the threshold necessary for preferential consolidation during sleep in young adults. However, given older adults' positivity bias, these narratives may be particularly suited for examining sleep-dependent emotional memory in older populations with and without dementia, a focus of Study 5.

However, it was found that during the scoring process of the narrative tasks in Study 3, the stories took a long time to score and required high cognitive effort to ensure greater accuracy. As such, prior to Study 5, Study 4 addressed the time-consuming and error-prone nature of manual scoring found in the prior study by developing and validating an automatic scoring tool using Python. Study 4 found that the tool was more accurate, and estimations of scoring time improvement suggested it was approximately twenty times faster than manual counting.

This technological advancement represents a significant methodological contribution to sleep and memory research, enabling researchers to analyse large datasets quickly and reliably, thus enhancing the feasibility and scalability of narrative-based memory research.

Study 5 aimed to extend the findings from the young adult study to healthy older adults and individuals with VCI. However, significant methodological challenges arising from COVID-19 disruptions and recruitment difficulties resulted in a limited sample size ($n = 5$). While the case studies using older adults offer interesting patterns, the small sample size precludes any definitive conclusions about the effects of sleep on emotional memory consolidation in these populations. This study highlighted the need for adapted methodologies and support strategies when conducting research with older adults and individuals with cognitive impairment, particularly in online research, which are examined and addressed in Chapter 5.

Although the results from this chapter provide novel and significant advancements in methodology for examining sleep-dependent memory consolidation and offer novel findings regarding sleep-dependent memory consolidation for narratives in young adults, the lack of participants with VaD prevented the examination of sleep-dependent mechanisms in this population. However, this chapter serves as a foundation for exploring sleep-dependent mechanisms in individuals with VaD, and the methodology developed is ready to be employed in future research. Moreover, given that many people with dementia experience sleep disturbances and that sleep has been shown to impact quality of life and wellbeing negatively (Shi et al., 2018; Burks et al., 2021), the next chapter then sought to focus on examining whether a new non-pharmacological bibliotherapy intervention would be associated with improved sleep quality in older adults with and without VCI.

6.4 Chapter 4: The Effect of Bedtime Fiction Reading on Sleep, Wellbeing, and Mood in Healthy Older Adults and Individuals with Subjective Cognitive Decline.

While numerous non-pharmacological interventions have been shown to improve sleep quality in people living with dementia, many require input from research or, clinical teams or external providers, such as delivering cognitive interventions or facilitating weekly programmes (Dyer et al., 2018; Blackman et al., 2021). Given the high prevalence of sleep issues in dementia (Bubu et al., 2017), there is a need for non-pharmacological interventions that can be implemented independently as not everyone has access to interventional

programmes as constraints such as constrained by health conditions, mobility issues, or location can restrict access (Cvitkovich & Wister, 2001; Schlenk et al., 2009). Chapter 4 addressed this gap in the literature by investigating whether independent fiction reading before bedtime would be associated with improved sleep quality, wellbeing, and mood in HOAs individuals with subjective cognitive decline (SCD) and those with VCI. This study is the first to specifically examine the effects of a fiction reading intervention on sleep quality and related outcomes in these populations, building upon previous research suggesting potential benefits of fiction reading for neuropsychiatric symptoms, including nighttime disturbances (markers of poor sleep quality) and emotional wellbeing (Billington et al., 2013; Claridge & Rimkeit, 2018; Orrell et al., 2019).

The results revealed significant improvements in subjective sleep quality across all participants during the reading intervention, as measured by the Consensus Sleep Diary (CSD; $d = 0.38$) and the Pittsburgh Sleep Quality Index (PSQI; $d = -1.26$). Interestingly, while subjective sleep quality improved, there were no significant changes in objective sleep measures derived from actigraphy. The discrepancy between subjective and objective sleep measures highlights the importance of considering both types of assessments in sleep research, as they may capture different aspects of the sleep experience. Regarding wellbeing, the study found differential effects of the reading intervention between the HOA and SCD groups. The SCD group experienced greater improvements in positive emotion and overall wellbeing during the reading period than the HOA group, as reflected by a significant interaction. This finding suggests that individuals with SCD may benefit more from solitary fiction reading. The study also found a reduction in stress levels by the end of the study for all participants, as measured by the DASS-21. While this reduction could be attributed to the completion of the study, it may also be related to the reading intervention itself, as previous research has shown that reading may have stress-reducing effects (Baikie & Wilhelm, 2005).

While the original plan aimed to replicate the study with 15 participants with VaD, time constraints, COVID-19 disruptions, and recruitment challenges resulted in only three VaD participants completing the study. Consequently, the feasibility of implementing a fiction reading intervention in individuals with VaD was demonstrated through a case study approach. With support from their study partners, three participants completed the 8-week protocol. Although the case studies revealed intriguing patterns in sleep quality, mood, wellbeing, and neuropsychiatric symptoms, the limited sample size and individual variability

restrict the generalisability of these findings and instead demonstrate that the developed protocol is suitable for those with VaD.

Nevertheless, the fiction reading study offers valuable insights into the potential of non-pharmacological interventions for enhancing sleep quality and wellbeing in older adults and individuals with cognitive concerns. The significant improvements in subjective sleep quality and the differential effects on wellbeing between the HOA and SCD suggest that fiction reading may be a promising approach for promoting sleep quality and wellbeing, particularly in individuals experiencing subjective cognitive decline. These findings lay the foundation for future, larger-scale studies to further explore the efficacy of this intervention across various populations experiencing cognitive impairment.

6.5 Chapter 5: Addressing the Challenges of Online Recruitment and Participation in Research Among Older Adults: Insights and Recommendations Based on Reflections from Studies in This Thesis

In response to some of the recruitment issues highlighted in this thesis, Chapter 6 explored the challenges encountered during the recruitment and retention of older adults and individuals with VaD in the online studies conducted as part of this thesis. The low completion rates observed (1.08% for the emotional memory study, 7.01% for the fiction reading study with healthy older adults, and 4.48% for the VaD group) highlight the significant challenges in this area of research. The substantial effort required for recruitment and retention, as evidenced by the 1478 emails and 46.61 hours of telephone and video calls for 42 participants, provides essential information for resource allocation in future studies. The identified challenges included technological barriers, protocol adherence issues, environmental factors, communication and trust concerns, data quality problems, and cognitive capacity variations. These findings align with previous research on the barriers to older adults' participation (Mody et al., 2008; Ridda et al., 2010; Provencher et al., 2014) and extend the literature by focusing on the context of online research.

Based on these challenges, several recommendations were proposed to enhance participant recruitment and retention in future online studies with older adults and individuals with cognitive impairment. These include using multiple communication methods, promoting user-friendly technology, offering flexible data collection approaches, providing ongoing

support, and facilitating trust-building with prospective participants. By addressing these challenges and adopting the suggested strategies, researchers may improve the recruitment and retention of older adults in research and enhance the representativeness of recruited participants by supporting those experiencing difficulties with protocols. These improvements could lead to increased validity of findings, ultimately contributing to a better understanding of the needs and experiences of older adults and individuals with cognitive impairment.

6.6 Limitations

While providing valuable insights into the relationships between sleep, cognition, and wellbeing in older adults and those with VCI, this thesis is subject to several limitations that warrant consideration. A primary limitation of this research was the lack of a substantial VaD sample in the emotional memory study. This limitation was primarily due to COVID-19 disruptions and the complex nature of the research procedures, which contributed to sampling failure, as described in Chapter 5. While the NACC chapter (Chapter 1) included a significant number of VaD participants ($n = 4362$), providing robust data on this population, the thesis is limited in its ability to explore sleep-dependent memory consolidation mechanisms in VaD fully. This gap is particularly notable given the findings from Chapter 2 that memory performance was worse in VaD patients with sleep issues. However, it's important to note that the methodology developed for the emotional memory chapter is complete, providing a foundation for future studies to build upon this work. Moreover, the challenges encountered in this thesis led to the development of an automatic counting tool, representing a significant advancement in memory research. To my knowledge, no other work has created a similar tool, and this contribution will enhance the accuracy and efficiency of future research in this area.

Moreover, in the NACC chapter, to maximise statistical power and determine a more general effect of sleep disturbances on cognitive function, the study combined sleep disorders and sleep disturbances under the 'sleep issue' category. While this approach was appropriate for exploratory research, it limits the ability to distinguish between the potentially differential effects of sleep disorders versus sleep disturbances on cognition. Research has shown that sleep disorders and disturbances can affect cognitive function. For example, some research has shown that sleep parameters such as extremely short and long sleep duration are

associated with lower scores on a variety of cognitive tests but not memory function (Ferrie et al., 2011), whereas other research has shown that sleep disorders such as insomnia are associated with memory impairment (Haimov, 2006). The study may have obscured some of these relationships by combining these categories. However, as a novel study in this area, it was important to first establish more general effects before examining individual factors. Future work should aim to disentangle these effects for a more granular understanding of how specific sleep issues relate to cognitive function in VaD.

Another limitation of the NACC study pertains to the cross-sectional nature of the cognitive outcome data. This design limits our ability to draw inferences about the relationship between sleep issues and cognitive function over time, and test-retest variability and other factors unrelated to sleep disturbances may have influenced cognitive outcomes. For instance, day-to-day fluctuations in cognitive performance and sleep quality, which are common in older adults and particularly those with dementia, could have affected the outcomes. Longitudinal studies are needed to more definitively determine the impact of sleep on cognitive function over time, allowing for the observation of how changes in sleep patterns relate to changes in cognitive performance.

Additionally, the reliance on subjective sleep and proxy-report sleep measures in the NACC database represents another limitation. As demonstrated in the fiction study, discrepancies between subjective and objective sleep measures are common in older adult research. The absence of objective sleep data in the NACC study limits our ability to fully characterise participants' sleep quality and patterns. Moreover, the sleep measures included in the NACC database pertain to neuropsychiatric symptoms, specifically nighttime behaviours. Whilst these do provide a measure of sleep disturbances and have been used in many other studies examining sleep issues in older adults, these are not robust measures of sleep and do not provide data on important sleep parameters such as total sleep time, sleep efficiency, sleep fragmentation, sleep onset latency and sleep quality. Moreover, research has shown that older adults tend to underestimate the severity of their sleep disturbances, while proxies who report neuropsychiatric symptoms tend to overreport. This suggests that the self-reports used in the NACC may not provide a fully representative picture of sleep issues. However, the large sample size and substantial effect sizes provide credibility to the findings despite this limitation.

A limitation of the emotional memory chapter was the small sample size, particularly the lack of participants with VaD. This limitation was primarily due to recruitment challenges and protocol complexities, as detailed in Chapter 5. The small sample size of young adults and the absence of VaD participants limit the generalisability of the findings and prevent the study from drawing conclusions about sleep-dependent emotional memory consolidation across different age groups and cognitive statuses. This is particularly unfortunate given the intriguing findings from Chapter 2 suggesting that memory performance was worse in VaD patients with sleep issues. The lack of VaD participants in the emotional memory study means the study missed an opportunity to directly investigate how sleep might differentially affect emotional memory consolidation in this population. While the study provides a valuable methodological framework and preliminary findings, the limited participant numbers limit our ability to make broader inferences about sleep-dependent emotional memory processes in ageing and dementia. Future research should aim to replicate this study with larger samples, including healthy older adults and individuals with VaD, to provide a more comprehensive understanding of how sleep affects emotional memory across the spectrum of cognitive health and ageing.

In the fiction reading study, a key limitation was the lack of physiological variables examining pre- and post-reading states and detailed mood assessments. This limits our ability to fully understand the mechanisms or potential contributing factors behind the observed improvements in subjective sleep quality, especially given the lack of objective sleep improvements. For instance, measuring heart rate variability, gathering subjective mood perceptions prior to and post-reading, or including physiological measures of arousal (e.g. cortisol levels) before and after reading could have provided insights into the physiological effects of the intervention. Similarly, more frequent and detailed mood assessments could have illuminated the emotional impact of reading and its relationship to sleep perceptions. While the decision to limit these measures was made to reduce participant burden and maximise retention, it represents a trade-off between the depth of data and study completion rates.

Lastly, while providing valuable case study data, the small VaD sample in the fiction study limits our ability to draw conclusions about the efficacy of fiction reading interventions in this population. However, the successful completion of the protocol by these participants,

with the support of study partners, demonstrates the feasibility of this approach for future, larger-scale studies.

6.7 Future studies

The findings and limitations of this thesis point to several promising directions for future research. Building on the NACC database analysis in Chapter 2, future studies should employ longitudinal designs to better understand the mechanisms linking sleep and cognition in VCI to determine how changes in sleep patterns over time correlate with changes in cognitive function (i.e. longitudinal studies). Additionally, experimental designs could provide causal evidence for the role of sleep in cognitive function in VCI. These studies could involve controlled sleep deprivation or enhancement protocols to directly observe the effects on various cognitive domains, particularly executive function and global cognition, highlighted in our findings.

Another important area for future research stemming from this chapter is determining the proportion of variance in cognitive test scores (such as the MMSE and MoCA) that can be accounted for by sleep issues. This information could be used to develop adjusted scoring methods that consider sleep quality, potentially improving the diagnostic accuracy of these tools in clinical settings. Moreover, future research should also aim to compare the effects of sleep on cognition between individuals with vascular Mild Cognitive Impairment (vMCI) and those with VaD to understand how sleep-cognition relationships may change as vascular cognitive impairment progresses.

Regarding the emotional memory study in Chapter 3, a priority for future research should be completing this study with both older adults and individuals with VaD. This would address the limitation of the small sample size in the study and provide insights into how sleep-dependent emotional memory consolidation may differ across age groups and in the presence of VCI. The methodology developed in this thesis, including the automated scoring tool, provides a foundation for this work. Future studies could also explore how emotional memory consolidation might be affected by different stages of VCI.

Building on the fiction reading study in Chapter 4, future research should aim to complete this study with a larger sample of individuals with VaD, examining the potential benefits of reading interventions on sleep quality and wellbeing in this population. To address the

limitations in understanding the mechanisms behind the observed improvements in subjective sleep quality, future studies should incorporate pre- and post-reading physiological measures and mood assessments. This could include measures of heart rate variability to assess nervous system arousal and validated scales to measure pre-sleep arousal and mood states to provide a more detailed understanding of how reading may affect both physiological and psychological states related to sleep. Future research could also explore how the content of the reading material (e.g., genre, emotional valence) might influence its effects on sleep and wellbeing.

The challenges in online research with older adults highlighted in Chapter 5 suggest that future studies should focus on refining and validating online research methodologies for this population. This could include developing more user-friendly interfaces, exploring alternative data collection methods, and investigating ways to provide remote support to participants. Research could also explore how to effectively combine online and in-person methodologies to maximise participation and data quality.

By pursuing these research directions, we can build upon the work provided by this thesis to develop a more comprehensive understanding of the relationships between sleep, cognition, and wellbeing in VCI. This knowledge will be crucial for developing effective interventions and improving the lives of individuals affected by VCI.

6.8 Conclusion

In conclusion, this thesis has made significant contributions to our understanding of the relationship between sleep, emotion, and memory in the context of cognitive impairment and dementia, specifically focusing on Vascular Cognitive Impairment (VCI). The studies presented here have provided new insights into the impact of sleep disturbances on cognitive function in VaD, the development and validation of a novel narrative-based emotional memory task, and the potential of non-pharmacological interventions such as fiction reading for improving sleep quality and well-being in older adults and individuals with cognitive concerns.

The findings from Chapter 2 highlight the importance of considering sleep disturbances as a potential modifiable risk factor for cognitive decline in VaD and emphasise the need for targeted interventions to address sleep issues in this population. These results contribute to

the growing body of evidence supporting the role of sleep in cognitive function and extend the knowledge gained from research in AD to the understudied population of VCI by identifying the cognitive domains most vulnerable to sleep disturbances in VaD.

The development and validation of the emotional memory narrative task in Chapter 3 represent significant methodological advancements in sleep and memory research, providing a valuable tool for assessing sleep-dependent memory consolidation. The general sleep benefit observed in the young adult study aligns with the extensive literature on the role of sleep in declarative memory consolidation, which highlights the potential of this task for investigating sleep-related memory processes in various populations, including those with cognitive impairment and dementia. The automated scoring tool developed in this chapter further enhances the utility of the narrative task by enabling efficient and reliable analysis of large datasets.

The fiction reading study in Chapter 4 demonstrates the potential benefits of bedtime fiction reading for improving subjective sleep quality and wellbeing in healthy older adults and individuals with SCD. The differential effects observed in the SCD group suggest that this intervention may be particularly valuable for individuals at risk of developing dementia, highlighting the importance of early intervention strategies to mitigate cognitive decline and improve quality of life. These findings contribute to the growing body of evidence supporting the use of non-pharmacological interventions for managing sleep disturbances and neuropsychiatric symptoms in older adults and individuals with cognitive impairment.

Finally, the insights gained from Chapter 6 on the challenges of online recruitment and participation in research among older adults provide valuable recommendations for future studies, emphasising the need for adapted methodologies and support strategies to ensure the inclusivity and effectiveness of research involving this population. By addressing these challenges and implementing the proposed recommendations, researchers can improve the representativeness and validity of their findings, ultimately contributing to a better understanding of the needs and experiences of older adults and individuals with cognitive impairment.

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Appendices

Appendix A

Chapter 2 Supplementary Analysis

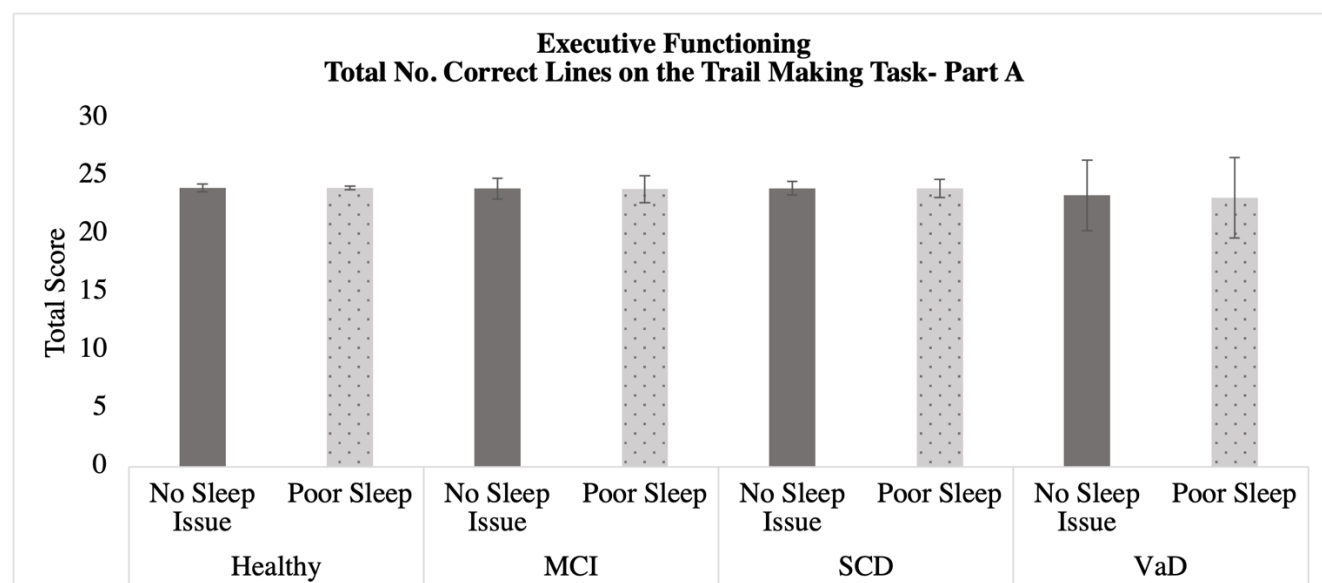
In chapter 2, Trail-A task was removed from the original analysis as it have been shown to be subject to ceiling effects, even in cognitively impaired individuals.

Number of correct lines (max 24)- Part A

Table 1: Total Number of Correct Lines for Part A of the Trail-Making Task

Group	Sleep Condition	N	Mean	SD
HOA	No Sleep Issue	25007	23.99	0.33
	Poor Sleep	3386	23.99	0.16
MCI	No Sleep Issue	9364	23.94	0.90
	Poor Sleep	3613	23.90	1.17
SCD	No Sleep Issue	8314	23.98	0.59
	Poor Sleep	2327	23.95	0.78
VaD	No Sleep Issue	1935	23.36	3.05
	Poor Sleep	654	23.16	3.47

Figure 1: Total number of correct lines on the trail-making task, Part A.



In terms of number of correct lines for Part A (scored out of 24), there was a significant main effect of group $F(3,54583)=341.32$, $p<.001$, $\eta^2p=.02$, sleep condition $F(3,54583)=21.22$, $p<.001$, $\eta^2p<.001$ and a significant interaction between group and sleep condition $F(1,54583)=6.41$, $p<.001$, $\eta^2p<.001$.

In the post hoc comparisons examining sleep issues and their impact on the number of correct lines on the Trail Making Task - Part A, individuals with poor sleep completed 0.06 fewer correct lines than those without sleep issues, $t(4.61) = 0.07$, $p < .001$.

Among the covariates, years of education, age, use of psychotic medication, and depression within the last two years (all p 's $< .05$), and use of beta-blockers ($p=.05$) had significant effects on Trail-A number of correct lines performance, though had small effect sizes (all η^2p 's $<.001$). Conversely, alcohol use ($p=.14$), sex ($p=.23$), use of anxiolytics/hypnotics ($p=.48$), and smoking years ($p=.07$) did not significantly impact TRAILALI performance (all p 's $> .05$).

In terms of group differences in Trail A number of correct lines, post-hoc analysis revealed that the HOA and SCD groups showed the highest scores, with no significant difference between them ($p = 0.7$). They were followed by the MCI group, which had a significantly lower performance compared to the HOA group ($p < .001$) but was significantly better than the VaD group ($p < .001$). Finally, the VaD group demonstrated the poorest performance among all groups, with significant differences noted when compared to all other groups (all p 's $< .001$).

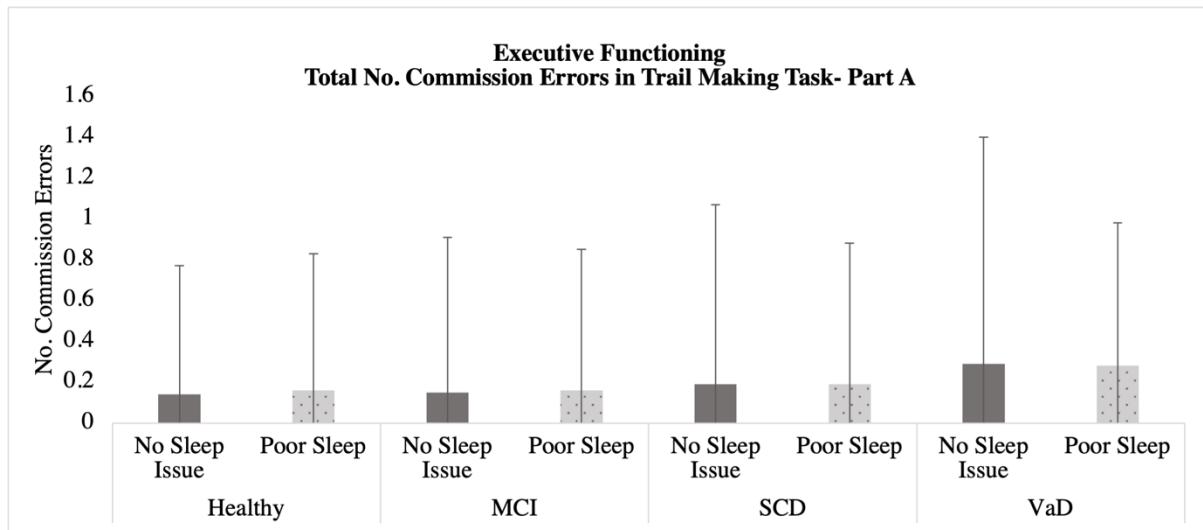
Post-hoc analyses of the interaction between group and sleep condition indicated that only individuals with VaD and sleep issues performed significantly worse on the Trail Making Part A task compared to their counterparts without sleep issues ($p < .001$, $d = -.21$). No such performance differences were found for those with MCI, SCD, or HOAs when sleep issues were considered (all p 's $> .05$). Therefore, the detrimental performance effect of sleep issues was isolated to the VaD group.

Trail Making A- Number of Commission Errors (out of 40)

Table 2: *Total Number of Commission Errors of the Trail-Making Task -Part A*

Group	Sleep Issue	N	Mean	SD
HOA	No Sleep Issue	24471	0.14	0.63
	Poor Sleep	3350	0.16	0.67
MCI	No Sleep Issue	8258	0.15	0.76
	Poor Sleep	2322	0.16	0.69
SCD	No Sleep Issue	9305	0.19	0.88
	Poor Sleep	3601	0.19	0.69
VaD	No Sleep Issue	1917	0.29	1.11
	Poor Sleep	653	0.28	0.7

Figure 2: Total number of commission errors on the trail-making task, Part A.



Results revealed a significant main effect of group $F(3,53860)=20.75$, $p<.001$, $\eta^2p<.001$. However, no significant main effect was found for sleep issues $F(1,53860)=.20$, $p=.65$, $\eta^2p<.001$, nor was there a significant interaction between group and sleep condition $F(3,53860)=.62$, $p=.60$, $\eta^2p<.001$. Among the covariates, only education ($p<.001$), age ($p<.001$) and smoking years ($p=.03$) significantly affected Trail A commission errors, though with small effect sizes (all $\eta^2p's<.001$).

Post-hoc comparisons revealed that all groups differed significantly in terms of Part A commission error performance, except HOAs and SCDs ($p=1.00$, $d<.001$), such that HOAs and SCD showed fewer commission errors than all other groups, and MCI showed fewer commission errors than those with VaD.

Appendix B

This appendix includes all of the Python codes developed for automatic scoring for the 12 stories developed as part of the narrative memory task.

6.8.1 Final code

```
from collections import defaultdict
import re
from IPython.display import display
from ipywidgets import widgets

# Pre-defined target words for each section
first_sentence_words = [
    ("robert", 1, [("he", 1), ("him", 1), ("the man", 1), ("the trainee", 1), ("this individual", 1),
    ("the would-be dentist", 1), ("this young man", 1), ("this person", 1), ("our protagonist", 1),
    ("the student", 1)]),
    ("trainee", 1, [("apprentice", 1), ("intern", 1), ("learner", 1), ("novice", 1), ("pupil", 1),
    ("student", 1), ("probationer", 1), ("cadet", 1), ("recruit", 1), ("practitioner", 1)]),
    ("dentist", 1, [("dental surgeon", 1), ("dentistry", 1), ("orthodontist", 1), ("periodontist", 1),
    ("endodontist", 1), ("prosthodontist", 1), ("dental specialist", 1), ("dental practitioner", 1),
    ("oral health provider", 1), ("tooth doctor", 1), ("stomatologist", 1)]),
    ("school", 1, [("institution", 1), ("academy", 1), ("educational establishment", 1),
    ("institute", 1), ("college", 1), ("centre of learning", 1), ("faculty", 1), ("place of education",
    1), ("learning institution", 1), ("seminary", 1)]),
    ("clinical", 1, [("practical", 1), ("therapeutic", 1), ("medical", 1), ("health-related", 1),
    ("applied", 1), ("healing", 1), ("remedial", 1), ("curative", 1), ("treatable", 1), ("diagnostic",
    1)]),
    ("medicine", 1, [("healthcare", 1), ("medical science", 1), ("therapeutics", 1), ("healing", 1),
    ("medical treatment", 1), ("health science", 1), ("physic", 1), ("remedial treatment", 1),
    ("health care practice", 1), ("cure", 1)])]
```


("edinburgh", 1, [("the capital", 1), ("scottish city", 1), ("the location", 1), ("this place", 1),
 ("the capital of Scotland", 1), ("this city", 1), ("this locale", 1), ("this town", 1), ("this
 metropolis", 1)])
]

main_body_words = [("last", 1, [("final", 1), ("end", 1), ("concluding", 1), ("ultimate", 1),
 ("closing", 1), ("terminal", 1), ("finishing", 1)]),
 ("phase", 1, [("stage", 1), ("step", 1), ("period", 1), ("point", 1), ("chapter", 1),
 ("segment", 1), ("part", 1), ("level", 1), ("juncture", 1), ("portion", 1)]),
 ("training", 1, [("instruction", 1), ("education", 1), ("coaching", 1), ("tutoring", 1),
 ("teaching", 1), ("schooling", 1), ("guidance", 1), ("lessons", 1)]),
 ("perform", 1, [("carry out", 1), ("execute", 1), ("conduct", 1), ("accomplish", 1),
 ("undertake", 1), ("fulfill", 1), ("complete", 1), ("implement", 1), ("administer", 1), ("deliver",
 1)]),
 ("supervised", 1, [("monitored", 1), ("overseen", 1), ("watched", 1), ("controlled", 1),
 ("guided", 1), ("managed", 1), ("directed", 1), ("superintended", 1), ("inspected", 1),
 ("checked", 1)]),
 ("dental", 1, [("oral", 1), ("tooth-related", 1), ("mouth-related", 1), ("dentistry", 1),
 ("periodontal", 1), ("odontological", 1), ("orthodontic", 1), ("stomatological", 1),
 ("endodontic", 1), ("prosthodontic", 1)]),
 ("operation", 1, [("procedure", 1), ("surgery", 1), ("intervention", 1), ("process", 1),
 ("action", 1), ("activity", 1), ("treatment", 1), ("task", 1), ("work", 1), ("function", 1)]),
 ("one", 1, [("single", 1), ("sole", 1), ("lone", 1), ("unique", 1), ("individual", 1),
 ("particular", 1), ("exclusive", 1), ("first", 1), ("initial", 1)]),
 ("ever", 2, [("always", 2), ("at any time", 2), ("at all times", 2), ("forever", 2),
 ("continually", 2), ("constantly", 2), ("invariably", 2), ("perpetually", 2), ("eternally", 2),
 ("endlessly", 2)]),
 ("live", 1, [("real", 1), ("actual", 1), ("living", 1), ("breathing", 1), ("current", 1),
 ("existing", 1), ("flesh-and-blood", 1), ("human", 1), ("in-person", 1), ("present", 1)]),
 ("patient", 1, [("client", 1), ("recipient", 1), ("subject", 1), ("sufferer", 1), ("case", 1),
 ("individual", 1), ("victim", 1), ("customer", 1), ("sick person", 1), ("in-patient", 1)]),
 ("robert", 3, [])

("preparing", 1, [("planning", 1), ("readying", 1), ("setting up", 1), ("organizing", 1), ("getting ready", 1), ("gearing up", 1), ("training", 1), ("studying", 1), ("arranging", 1), ("bracing", 1)]),

("months", 1, [("weeks", 1), ("days", 1), ("a while", 1), ("long period", 1), ("extended time", 1), ("good while", 1), ("some time", 1), ("period", 1), ("lengthy interval", 1), ("time span", 1)]),

("exam", 2, [("test", 1), ("evaluation", 1), ("assessment", 1), ("examination", 1), ("inspection", 1), ("checkup", 1), ("analysis", 1), ("review", 1), ("quiz", 1), ("appraisal", 1)]),

("things", 1, [("events", 1), ("matters", 1), ("situations", 1), ("circumstances", 1), ("developments", 1), ("issues", 1), ("problems", 1), ("scenarios", 1), ("cases", 1), ("affairs", 1)]),

("started", 1, [("began", 1), ("initiated", 1), ("commenced", 1), ("embarked", 1), ("launched", 1), ("opened", 1), ("got underway", 1), ("kicked off", 1), ("set in motion", 1), ("got going", 1)]),

("wrong", 1, [("incorrect", 1), ("mistaken", 1), ("inappropriate", 1), ("unfortunate", 1), ("bad", 1), ("awry", 1)]),

("immediately", 1, [("instantly", 1), ("right away", 1), ("directly", 1), ("promptly", 1), ("swiftly", 1), ("straight away", 1), ("quickly", 1), ("at-once", 1), ("without-delay", 1), ("instantaneously", 1)]),

("drill", 2, [("tool", 1), ("implement", 1), ("instrument", 1), ("machine", 1), ("dental drill", 1), ("apparatus", 1), ("device", 1), ("piece of equipment", 1), ("handpiece", 1), ("mechanism", 1)]),

("slipped", 1, [("skidded", 1), ("slid", 1), ("glided", 1), ("moved", 1), ("shifted", 1), ("slithered", 1), ("swept", 1), ("lost control", 1), ("misstepped", 1), ("slid unintentionally", 1)]),

("pierced", 1, [("punctured", 1), ("penetrated", 1), ("perforated", 1), ("stabbed", 1), ("made a hole in", 1), ("went through", 1), ("cut through", 1), ("broke through", 1), ("poked", 1), ("wounded", 1)]),

("patients", 1, [("clients", 1), ("subjects", 1), ("individuals", 1), ("sufferers", 1), ("cases", 1), ("victims", 1), ("recipients", 1), ("womans", 1), ("her", 1), ("persons", 1)]),

("cheek", 1, [("face", 1), ("facial feature", 1), ("visage", 1), ("aspect", 1), ("side of face", 1), ("flesh", 1), ("jowl", 1), ("side", 1), ("surface", 1), ("part of face", 1)]),

("stem", 1, [("stop", 1), ("halt", 1), ("stanch", 1), ("check", 1), ("arrest", 1), ("curb", 1), ("cut off", 1), ("hinder", 1), ("hold back", 1), ("thwart", 1)]),

("blood", 2, [("hemorrhage", 2), ("bleeding", 2), ("life fluid", 2), ("red fluid", 2),
 ("plasma", 2), ("vital-fluid", 2), ("gore", 2), ("lifeblood", 2), ("blood flow", 2)]),
 ("grabbed", 1, [("seized", 1), ("snatched", 1), ("clutched", 1), ("grasped", 1), ("took", 1),
 ("caught", 1), ("captured", 1), ("nabbed", 1), ("gained", 1), ("snared", 1)]),
 ("towel", 1, [("cloth", 1), ("rag", 1), ("linen", 1), ("napkin", 1), ("wiper", 1), ("swab", 1),
 ("hand towel", 1), ("piece of fabric", 1)]),
 ("nearby", 1, [("close", 1), ("adjacent", 1), ("neighbouring", 1), ("proximate", 1),
 ("around", 1), ("near at hand", 1), ("close by", 1), ("in close proximity", 1), ("accessible", 1),
 ("at hand", 1)]),
 ("rack", 1, [("shelf", 1), ("stand", 1), ("holder", 1), ("frame", 1), ("structure", 1),
 ("hook", 1), ("rest", 1), ("bracket", 1), ("support", 1), ("fixture", 1)]),
 ("only", 2, [("merely", 2), ("just", 2), ("solely", 2), ("purely", 2), ("simply", 2), ("alone",
 2), ("but", 2), ("barely", 2), ("exclusively", 2), ("singularly", 2)]),
 ("served", 1, [("worked", 1), ("functioned", 1), ("acted", 1), ("proved", 1), ("was useful",
 1), ("fulfilled", 1), ("sufficed", 1), ("operated", 1), ("benefited", 1), ("played-a-role", 1)]),
 ("muffle", 1, [("dampen", 1), ("muffled", 1), ("deadened", 1), ("stifle", 1), ("suppress", 1),
 ("smother", 1), ("quiet", 1), ("dim", 1), ("hush", 1), ("soften", 1), ("reduce", 1)]),
 ("womans", 1, [("females", 1), ("ladies", 1), ("her", 1), ("patients", 1), ("individuals", 1),
 ("subjects", 1), ("persons", 1), ("victims", 1), ("sufferers", 1), ("recipients", 1)]),
 ("desperate", 1, [("urgent", 1), ("frantic", 1), ("panicked", 1), ("frightened", 1),
 ("fearful", 1), ("distressed", 1), ("terrified", 1), ("alarmed", 1), ("hysterical", 1), ("wild", 1)]),
 ("screams", 1, [("shriek", 1), ("scream", 1), ("cry", 1), ("yelp", 1), ("screech", 1),
 ("wail", 1), ("yell", 1), ("howl", 1), ("squawk", 1), ("holler", 1), ("bellow", 1)]),
 ("clearly", 1, [("evidently", 1), ("clear", 1), ("obviously", 1), ("unmistakably", 1),
 ("manifestly", 1), ("plainly", 1), ("undoubtedly", 1), ("indubitably", 1), ("patently", 1),
 ("conspicuously", 1), ("noticeably", 1)]),
 ("choking", 1, [("gagging", 1), ("suffocating", 1), ("struggling for breath", 1),
 ("gasping", 1), ("asphyxiating", 1), ("wheezing", 1), ("coughing", 1), ("strangling", 1),
 ("panting", 1), ("fighting for air", 1)]),
 ("own", 1, [("personal", 1), ("individual", 1), ("private", 1), ("self", 1), ("herself", 1),
 ("her own", 1), ("autonomous", 1), ("hers", 1), ("distinct", 1), ("particular", 1)]),
 ("panicking", 1, [("freaking out", 1), ("becoming hysterical", 1), ("overreacting", 1),
 ("losing control", 1), ("getting flustered", 1), ("becoming frantic", 1), ("getting panicked", 1),
 ("feeling terror", 1), ("losing composure", 1), ("experiencing anxiety", 1)]),

("tried", 1, [("attempted", 1), ("endeavored", 1), ("strived", 1), ("worked", 1),
 ("struggled", 1), ("aims", 1), ("sought", 1), ("made an effort", 1), ("pushed", 1), ("gave it a
 shot", 1)]),
 ("extract", 1, [("remove", 1), ("pull out", 1), ("withdraw", 1), ("take out", 1), ("dislodge",
 1), ("retrieve", 1), ("get out", 1), ("eject", 1), ("expel", 1), ("derive", 1)]),
 ("piece", 1, [("part", 1), ("portion", 1), ("section", 1), ("segment", 1), ("fraction", 1),
 ("element", 1), ("component", 1), ("bit", 1), ("chunk", 1), ("slice", 1)]),
 ("smooth", 1, [("steady", 1), ("fluent", 1), ("fluid", 1), ("seamless", 1), ("graceful", 1),
 ("effortless", 1), ("easy", 1), ("unbroken", 1), ("uninterrupted", 1), ("continuous", 1)]),
 ("motion", 1, [("movement", 1), ("action", 1), ("gesture", 1), ("move", 1), ("act", 1),
 ("progress", 1), ("shift", 1), ("step", 1), ("manoeuvre", 1), ("transition", 1)]),
 ("however", 1, [("nonetheless", 1), ("nevertheless", 1), ("yet", 1), ("still", 1), ("but", 1),
 ("despite that", 1), ("even so", 1), ("on the other hand", 1), ("although", 1),
 ("notwithstanding", 1)]),
 ("brought", 1, [("carried", 1), ("transported", 1), ("delivered", 1), ("moved", 1), ("bore",
 1), ("transferred", 1), ("conveyed", 1), ("hauled", 1), ("toted", 1), ("lugged", 1)]),
 ("chunk", 1, [("piece", 1), ("lump", 1), ("block", 1), ("slab", 1), ("portion", 1), ("hunk",
 1), ("slice", 1), ("section", 1), ("bit", 1), ("part", 1)]),
 ("flesh", 1, [("skin", 1), ("tissue", 1), ("meat", 1), ("muscle", 1), ("body", 1), ("fat", 1),
 ("soft part", 1), ("human tissue", 1), ("corporeal part", 1), ("physical structure", 1)]),
 ("tears", 1, [("weeps", 1), ("cries", 1), ("sobbing", 1), ("waterworks", 1), ("teardrops",
 1), ("crying", 1), ("sobs", 1), ("weeping", 1), ("lamentations", 1), ("bawling", 1)]),
 ("cried", 1, [("wept", 1), ("sobbed", 1), ("wailed", 1), ("shouted", 1), ("yelled", 1),
 ("screamed", 1), ("hollered", 1), ("called out", 1), ("bawled", 1), ("yowled", 1)]),
 ("help", 1, [("assistance", 1), ("aid", 1), ("support", 1), ("relief", 1), ("rescue", 1),
 ("intervention", 1), ("helpfulness", 1), ("cooperation", 1), ("help hand", 1), ("collaboration",
 1)]),
 ("examiner", 1, [("inspector", 1), ("supervisor", 1), ("monitor", 1), ("evaluator", 1),
 ("checker", 1), ("assessor", 1), ("investigator", 1), ("observer", 1), ("reviewer", 1), ("analyst",
 1)]),
 ("quickly", 1, [("swiftly", 1), ("speedily", 1), ("rapidly", 1), ("promptly", 1), ("hastily",
 1), ("instantly", 1), ("fast", 1), ("briskly", 1), ("hurriedly", 1), ("speedily", 1)]),
 ("took", 1, [("received", 1), ("grasped", 1), ("captured", 1), ("accepted", 1), ("seized", 1),
 ("got", 1), ("undertook", 1), ("took over", 1), ("assumed", 1), ("handled", 1)]),

("fail", 1, [("lose", 1), ("failed", 1), ("flop", 1), ("flunk", 1), ("bomb", 1), ("miss", 1),
 ("fail to pass", 1), ("not succeed", 1), ("be unsuccessful", 1), ("fall short", 1), ("fail to meet",
 1)]),
 ("fastest", 1, [("quickest", 1), ("speediest", 1), ("most rapid", 1), ("brisk", 1), ("swiftest",
 1), ("most expeditious", 1), ("fleeting", 1), ("lightning", 1), ("fast-track", 1), ("zippy", 1)]),
 ("time", 1, [("moment", 1), ("period", 1), ("duration", 1), ("interval", 1), ("instant", 1),
 ("junction", 1), ("phase", 1), ("spell", 1), ("stretch", 1), ("epoch", 1)]),
 ("recorded", 1, [("documented", 1), ("registered", 1), ("noted", 1), ("logged", 1),
 ("marked", 1), ("charted", 1), ("filed", 1), ("jotted", 1), ("tracked", 1), ("indexed", 1)]),
 ("school", 1, [("institution", 1), ("academy", 1), ("college", 1), ("seminary", 1),
 ("institute", 1), ("educational establishment", 1), ("training center", 1), ("conservatory", 1),
 ("prep school", 1), ("campus", 1)]),
 ("clinical", 1, [("medical", 1), ("health-related", 1), ("therapeutic", 1), ("healing", 1),
 ("remedial", 1), ("curative", 1), ("hospital", 1), ("doctoral", 1), ("surgical", 1), ("patient", 1)]),
 ("medicine", 1, [("healthcare", 1), ("medical science", 1), ("health science", 1),
 ("pharmacology", 1), ("therapeutics", 1), ("cure", 1), ("remedies", 1), ("healing art", 1),
 ("medical practice", 1), ("medical studies", 1)])]

last_sentence_words = [("later", 1, [("afterwards", 1), ("subsequently", 1), ("thereafter", 1),
 ("eventually", 1), ("following", 1), ("after", 1), ("next", 1), ("in time", 1), ("down the line", 1),
 ("at a later date", 1)]),
 ("tell", 1, [("inform", 1), ("told", 1), ("narrate", 1), ("recount", 1), ("relay", 1),
 ("describe", 1), ("reveal", 1), ("chronicle", 1), ("report", 1), ("divulge", 1), ("detail", 1)]),
 ("friends", 1, [("pals", 1), ("buddies", 1), ("comrades", 1), ("associates", 1), ("mates", 1),
 ("companions", 1), ("cohorts", 1), ("chums", 1), ("acquaintances", 1), ("cronies", 1)]),
 ("story", 1, [("tale", 1), ("narrative", 1), ("account", 1), ("saga", 1), ("chronicle", 1),
 ("anecdote", 1), ("yarn", 1), ("record", 1), ("report", 1), ("legend", 1)]),
 ("pub", 1, [("tavern", 1), ("bar", 1), ("inn", 1), ("alehouse", 1), ("saloon", 1), ("bistro",
 1), ("taproom", 1), ("lounge", 1), ("public house", 1), ("brewpub", 1)]),
 ("skimping", 1, [("scrimping", 1), ("sparing", 1), ("saving", 1), ("economizing", 1),
 ("being frugal", 1), ("being sparing", 1), ("holding back", 1), ("restricting", 1), ("being
 economical", 1), ("pinching pennies", 1)])]

```
    ("details", 1, [("particulars", 1), ("specifics", 1), ("facts", 1), ("points", 1), ("features", 1), ("elements", 1), ("aspects", 1), ("components", 1), ("data", 1), ("information", 1)])])
```

```
# Convert list of words to formatted string
```

```
first_sentence_words_str = []
```

```
for word_info in first_sentence_words:
```

```
    word = word_info[0]
```

```
    max_count = word_info[1]
```

```
    synonyms = ','.join([syn[0] for syn in word_info[2]])
```

```
    first_sentence_words_str.append(f'{word}\t{synonyms}\t{max_count}')
```

```
main_body_words_str = []
```

```
for word_info in main_body_words:
```

```
    word = word_info[0]
```

```
    max_count = word_info[1]
```

```
    synonyms = ','.join([syn[0] for syn in word_info[2]])
```

```
    main_body_words_str.append(f'{word}\t{synonyms}\t{max_count}')
```

```
last_sentence_words_str = []
```

```
for word_info in last_sentence_words:
```

```
    word = word_info[0]
```

```
    max_count = word_info[1]
```

```
    synonyms = ','.join([syn[0] for syn in word_info[2]])
```

```
    last_sentence_words_str.append(f'{word}\t{synonyms}\t{max_count}')
```

```
first_sentence_words_str = '\n'.join(first_sentence_words_str)
```

```
main_body_words_str = '\n'.join(main_body_words_str)
```

```
last_sentence_words_str = '\n'.join(last_sentence_words_str)
```

```
# Create input widgets
```

```
first_sentence_input = widgets.Textarea(value="", description='First sentence:')
```

```
first_sentence_word_input = widgets.Textarea(value=first_sentence_words_str, description='Target words:')
```

```

main_body_input = widgets.Textarea(value="", description='Main body:')
main_body_word_input = widgets.Textarea(value=main_body_words_str,
description='Target words:')
last_sentence_input = widgets.Textarea(value="", description='Last sentence:')
last_sentence_word_input = widgets.Textarea(value=last_sentence_words_str,
description='Target words:')
display(first_sentence_input, first_sentence_word_input, main_body_input,
main_body_word_input, last_sentence_input, last_sentence_word_input)

# Define a button to run the analysis
button = widgets.Button(description='Analyze')
output = widgets.Output()
display(button, output)

def analyze_text(b):
    output.clear_output() # Clear the output before each run
    total_count = [0, 0, 0] # Count for first_sentence, main_body, last_sentence
    with output:
        # Get input values
        text_inputs = [first_sentence_input.value.lower(), main_body_input.value.lower(),
last_sentence_input.value.lower()]
        word_inputs = [first_sentence_word_input.value.split('\n'),
main_body_word_input.value.split('\n'), last_sentence_word_input.value.split('\n')]

    for i, (text_input, word_input) in enumerate(zip(text_inputs, word_inputs)):
        current_text = text_input
        # Parse target words and synonyms from input
        set1 = []
        for line in word_input:
            word_parts = line.split('\t')
            if len(word_parts) == 3:
                word = word_parts[0].strip()
                if not word: # skip if word is an empty string
                    continue

```

```

        max_count = int(word_parts[2].strip())
        synonyms = [(syn, 1) for syn in word_parts[1].split(',') if syn] # ensure synonym
is not an empty string
        set1.append((word, max_count, synonyms))

set1_count = 0
counted_words = defaultdict(int)
counted_synonyms = set()

for word_info in set1:
    current_word = word_info[0]
    max_count = word_info[1]
    count_word = len(re.findall(f'\\b{current_word}\\b', current_text))
    count_word = min(count_word, max_count)
    if count_word > 0:
        counted_words[current_word] = count_word
        set1_count += count_word
        current_text = re.sub(f'\\b{current_word}\\b', '\\033[31m' + current_word +
\\033[0m', current_text)

    if current_word not in counted_synonyms:
        for synonym, _ in word_info[2]:
            count_syn = len(re.findall(f'\\b{synonym.strip()}\\b', current_text))
            count_syn = min(count_syn, max_count - count_word)
            if count_syn > 0:
                counted_words[synonym.strip()] = count_syn
                counted_synonyms.add(current_word)
                set1_count += count_syn
                current_text = re.sub(f'\\b{synonym.strip()}\\b', '\\033[31m' +
synonym.strip() + '\\033[0m', current_text)
                break

print(current_text)
print("Set 1 Count: " + str(set1_count))

```



```

total_count[i] += set1_count # Add to total count
for word, count in counted_words.items():
    print(f'Word/Synonym "{word}" (from "{next(w[0] for w in set1 if word in [w[0]]
+ [syn[0] for syn in w[2]])}" was found {count} time(s)')

print(f'First sentence total count: {total_count[0]}')
print(f'Main body total count: {total_count[1]}')
print(f'Last sentence total count: {total_count[2]}')

button.on_click(analyze_text)

```

The Birthday Present

```
from collections import defaultdict
import re
from IPython.display import display
from ipywidgets import widgets

# Target Words + Synonyms in sets

first_sentence_words = ([("annie", 1, [("annie's", 1), ("annies", 1)]),
    ("finished", 1, [("completed", 1), ("ended", 1), ("concluded", 1), ("accomplished", 1),
    ("done", 1), ("finalized", 1), ("wrapped up", 1), ("terminated", 1), ("over", 1), ("culminated",
    1)]),
    ("last", 1, [("final", 1), ("end", 1), ("closing", 1), ("concluding", 1), ("terminal", 1),
    ("ultimate", 1), ("latter", 1), ("ending", 1), ("finish", 1), ("latest", 1)]),
    ("day", 1, [("date", 1), ("time", 1), ("24 hours", 1), ("daytime", 1), ("period", 1),
    ("moment", 1), ("course of the day", 1), ("working day", 1), ("sunlight hours", 1), ("light of
    day", 1)]),
    ("school", 2, [("institution", 1), ("academy", 1), ("education centre", 1), ("learning
    place", 1), ("classrooms", 1), ("study centre", 1), ("teaching establishment", 1), ("educational
    institution", 1), ("schoolhouse", 1), ("place of learning", 1)]),
    ("woodfield", 1, [("woodfields", 1), ("woodfeild", 1)]),
    ("primary", 1, [("elementary", 1), ("first", 1), ("basic", 1), ("fundamental", 1), ("initial",
    1), ("early", 1), ("starting", 1), ("principal", 1), ("chief", 1), ("main", 1)]))

main_body_words = ([("annie", 4, [("annie's", 4), ("annies", 4)]),
    ("birthday", 1, [("anniversary", 1), ("natal day", 1), ("date of birth", 1), ("birth
    anniversary", 1), ("special day", 1), ("yearly celebration", 1), ("birthdate", 1), ("day of birth",
    1), ("personal day", 1), ("celebration of life", 1)]),
    ("eager", 1, [("keen", 1), ("enthusiastic", 1), ("anxious", 1), ("excited", 1), ("willing",
    1), ("zealous", 1), ("ready", 1), ("impatient", 1), ("desirous", 1), ("antsy", 1)]),
```

("return", 1, [("go back", 1), ("come back", 1), ("revert", 1), ("repatriate", 1), ("retrace", 1), ("retreat", 1), ("get back", 1), ("turn back", 1), ("regress", 1), ("re-enter", 1), ("re enter", 1)]),

("home", 2, [("house", 1), ("residence", 1), ("dwelling", 1), ("abode", 1), ("habitat", 1), ("living place", 1), ("homestead", 1), ("domicile", 1), ("habitation", 1), ("domestic establishment", 1)]),

("family", 1, [("kin", 1), ("relatives", 1), ("clan", 1), ("tribe", 1), ("household", 1), ("kinfolk", 1), ("lineage", 1), ("kindred", 1), ("relations", 1), ("blood relations", 1)]),

("celebrations", 1, [("festivities", 1), ("party", 1), ("celebrate", 1), ("celebration", 1), ("parties", 1), ("commemorations", 1), ("gala", 1), ("jubilations", 1), ("observances", 1), ("fêtes", 1), ("jollifications", 1), ("merriments", 1), ("revels", 1)]),

("large", 2, [("big", 1), ("huge", 1), ("sizeable", 1), ("massive", 1), ("extensive", 1), ("spacious", 1), ("voluminous", 1), ("gigantic", 1), ("ample", 1), ("expansive", 1)]),

("wrapped", 1, [("covered", 1), ("enclosed", 1), ("packaged", 1), ("enveloped", 1), ("encased", 1), ("swathed", 1), ("cloaked", 1), ("sheathed", 1), ("clad", 1), ("encircled", 1)]),

("multicoloured", 1, [("varicoloured", 1), ("multi-coloured", 1), ("multicolored", 1), ("multi-colored", 1), ("polychromatic", 1), ("chromatic", 1), ("motley", 1), ("rainbow-coloured", 1), ("diverse", 1), ("prismatic", 1), ("varied", 1), ("kaleidoscopic", 1), ("multi-hued", 1)]),

("box", 2, [("case", 1), ("container", 1), ("carton", 1), ("parcel", 1), ("package", 1), ("encasement", 1), ("crate", 1), ("chest", 1), ("casket", 1), ("receptacle", 1)]),

("placed", 1, [("positioned", 1), ("set", 1), ("put", 1), ("located", 1), ("situated", 1), ("installed", 1), ("rested", 1), ("arranged", 1), ("laid", 1), ("positioned", 1)]),

("middle", 1, [("centre", 1), ("heart", 1), ("hub", 1), ("core", 1), ("midpoint", 1), ("midst", 1), ("centrum", 1), ("median", 1), ("mid", 1), ("central point", 1)]),

("living", 1, [("living area", 1), ("lounge", 1), ("family room", 1), ("parlour", 1), ("sitting room", 1), ("den", 1), ("drawing room", 1), ("common room", 1), ("reception room", 1), ("living space", 1)]),

("room", 1, [("space", 1), ("chamber", 1), ("area", 1), ("place", 1), ("zone", 1), ("quarters", 1), ("locale", 1), ("interior", 1), ("spot", 1), ("environment", 1)]),

("bow", 1, [("ribbon", 1), ("knot", 1), ("tie", 1), ("curlicue", 1), ("decorative knot", 1), ("ornament", 1), ("loop", 1), ("band", 1), ("twirl", 1), ("festoon", 1)]),

("top", 1, [("peak", 1), ("summit", 1), ("pinnacle", 1), ("crown", 1), ("crest", 1), ("apex", 1), ("tip", 1), ("cap", 1), ("vertex", 1), ("zenith", 1)]),

("mother", 1, [("mom", 1), ("mum", 1), ("maternal figure", 1), ("parent", 1),
 ("matriarch", 1), ("mommy", 1), ("mama", 1), ("ma", 1), ("matron", 1), ("birthgiver", 1)]),
 ("open", 1, [("unwrap", 1), ("opened", 1), ("unwrapped", 1), ("opens", 1), ("unwraps",
 1), ("unpack", 1), ("unseal", 1), ("unfasten", 1), ("reveal", 1), ("disclose", 1), ("break open",
 1), ("uncover", 1), ("unroll", 1), ("spread out", 1)]),
 ("present", 1, [("gift", 1), ("offering", 1), ("surprise", 1), ("token", 1), ("tribute", 1),
 ("item", 1), ("donation", 1), ("presentment", 1), ("gratuity", 1), ("endowment", 1)]),
 ("rushed", 1, [("hurried", 1), ("hastened", 1), ("dashed", 1), ("sped", 1), ("raced", 1),
 ("bolted", 1), ("scrambled", 1), ("scuttled", 1), ("skedaddled", 1), ("sprinted", 1)]),
 ("excitement", 1, [("thrill", 1), ("excitedly", 1), ("excite", 1), ("excited", 1),
 ("exhilaration", 1), ("enthusiasm", 1), ("zeal", 1), ("anticipation", 1), ("buzz", 1), ("elation",
 1), ("fervour", 1), ("eagerness", 1), ("hype", 1)]),
 ("ripped", 1, [("tore", 1), ("shred", 1), ("rip", 1), ("rips", 1), ("split", 1), ("severed", 1),
 ("ruptured", 1), ("pulled apart", 1), ("lacerated", 1), ("rived", 1), ("slit", 1)]),
 ("wrapping", 1, [("packaging", 1), ("covering", 1), ("enclosure", 1), ("wrapper", 1),
 ("sheath", 1), ("envelope", 1), ("shroud", 1), ("sleeve", 1), ("casing", 1), ("cloak", 1)]),
 ("paper", 1, [("parchment", 1), ("sheet", 1), ("card", 1), ("folio", 1), ("document", 1),
 ("leaf", 1), ("cardstock", 1), ("stationery", 1), ("material", 1), ("wrap", 1)]),
 ("enthusiastically", 1, [("eagerly", 1), ("zealously", 1), ("passionately", 1), ("ardently",
 1), ("fervently", 1), ("excitedly", 1), ("heartily", 1), ("vivaciously", 1), ("ebulliently", 1),
 ("keenly", 1)]),
 ("tiny", 1, [("small", 1), ("petite", 1), ("miniature", 1), ("minute", 1), ("minuscule", 1),
 ("little", 1), ("pint-sized", 1), ("diminutive", 1), ("teeny", 1), ("compact", 1)]),
 ("labrador", 2, [("dog", 1), ("canine", 1), ("pup", 1), ("pet", 1), ("hound", 1),
 ("retriever", 1), ("companion", 1), ("animal", 1), ("fur-baby", 1), ("furry friend", 1)]),
 ("puppy", 3, [("pup", 1), ("pooch", 1), ("youngster", 1), ("whelp", 1), ("little one", 1),
 ("baby dog", 1), ("furball", 1), ("young dog", 1), ("small dog", 1)]),
 ("brown", 1, [("brunette", 1), ("chestnut", 1), ("hazel", 1), ("chocolate", 1), ("auburn",
 1), ("tawny", 1), ("beige", 1), ("mahogany", 1), ("sepia", 1), ("umber", 1)]),
 ("eyes", 1, [("peepers", 1), ("eye", 1), ("orbs", 1), ("irises", 1), ("optics", 1), ("pupils",
 1), ("gaze", 1), ("eyeballs", 1), ("windows to the soul", 1), ("sight", 1), ("vision", 1)]),
 ("bigger", 1, [("larger", 1), ("greater", 1), ("sizeable", 1), ("broader", 1), ("wider", 1),
 ("heftier", 1), ("more significant", 1), ("more substantial", 1), ("more considerable", 1),
 ("more expansive", 1)]),

("football", 1, [("soccer ball", 1), ("ball", 1), ("sphere", 1), ("orb", 1), ("game ball", 1), ("sport gear", 1), ("kickball", 1), ("plaything", 1), ("sports equipment", 1), ("round object", 1)]),

("seemed", 1, [("appeared", 1), ("looked", 1), ("resembled", 1), ("manifested", 1), ("emanated", 1), ("projected", 1), ("gave the impression", 1), ("felt like", 1), ("came across as", 1), ("displayed", 1)]),

("very", 1, [("really", 1), ("extremely", 1), ("exceptionally", 1), ("highly", 1), ("quite", 1), ("remarkably", 1), ("particularly", 1), ("terribly", 1), ("decidedly", 1), ("profoundly", 1)]),

("happy", 1, [("glad", 1), ("joyful", 1), ("ecstatic", 1), ("pleased", 1), ("content", 1), ("delighted", 1), ("overjoyed", 1), ("elated", 1), ("merry", 1), ("blissful", 1)]),

("wagged", 1, [("flapped", 1), ("swished", 1), ("shook", 1), ("flailed", 1), ("fluttered", 1), ("twirled", 1), ("wiggled", 1), ("flicked", 1), ("beat", 1), ("quivered", 1)]),

("little", 1, [("tiny", 1), ("small", 1), ("petite", 1), ("miniature", 1), ("minute", 1), ("slight", 1), ("compact", 1), ("diminutive", 1), ("teeny", 1), ("wee", 1)]),

("white", 1, [("ivory", 1), ("pale", 1), ("snowy", 1), ("milky", 1), ("alabaster", 1), ("pearly", 1), ("silvery", 1), ("colourless", 1), ("creamy", 1), ("bleached", 1)]),

("tail", 1, [("appendage", 1), ("rear end", 1), ("back end", 1), ("rudder", 1), ("posterior part", 1), ("caudal appendage", 1), ("flapper", 1), ("tracker", 1), ("tush", 1)]),

("jumped", 1, [("leaped", 1), ("hopped", 1), ("bounced", 1), ("sprang", 1), ("vaulted", 1), ("skipped", 1), ("darted", 1), ("pounced", 1), ("sprung", 1), ("dashed", 1)]),

("gently", 1, [("tenderly", 1), ("softly", 1), ("carefully", 1), ("delicately", 1), ("lightly", 1), ("mildly", 1), ("cautiously", 1), ("slowly", 1), ("sweetly", 1), ("quietly", 1)]),

("lifted", 1, [("raised", 1), ("pulled", 1), ("pulls", 1), ("lift", 1), ("lifts", 1), ("hoisted", 1), ("elevated", 1), ("uplifted", 1), ("picked up", 1), ("boosted", 1), ("upraised", 1), ("hailed up", 1), ("elevated", 1), ("took up", 1)]),

("chest", 1, [("torso", 1), ("bust", 1), ("body", 1), ("upper body", 1), ("trunk", 1), ("ribcage", 1), ("bosom", 1), ("heart area", 1), ("breast", 1), ("sternum area", 1)]),

("cuddled", 1, [("embraced", 1), ("hugged", 1), ("snuggled", 1), ("held", 1), ("nuzzled", 1), ("enveloped", 1), ("clasped", 1), ("caressed", 1), ("squeezed", 1), ("nestled", 1)]),

("cried", 1, [("wept", 1), ("sobbed", 1), ("shed tears", 1), ("teared up", 1), ("bawled", 1), ("wailed", 1), ("lamented", 1), ("snivelled", 1), ("mourned", 1), ("howled", 1)]),

("joyously", 1, [("happily", 1), ("delight", 1), ("delighted", 1), ("delightfully", 1), ("cheerfully", 1), ("ecstatically", 1), ("merrily", 1), ("gleefully", 1), ("blissfully", 1), ("elatedly", 1), ("exultantly", 1), ("jubilantly", 1)]),

("licked", 1, [("lap", 1), ("tongued", 1), ("slobbered", 1), ("swiped", 1), ("washed", 1),
 ("groomed", 1), ("tasted", 1), ("brushed", 1), ("kissed", 1), ("smeared", 1)]),
 ("face", 1, [("visage", 1), ("countenance", 1), ("features", 1), ("mug", 1),
 ("physiognomy", 1), ("profile", 1), ("expression", 1), ("look", 1), ("appearance", 1),
 ("demeanour", 1)]),
 ("excitedly", 1, [("enthusiastically", 1), ("eagerly", 1), ("animatedly", 1), ("fervently",
 1), ("zealously", 1), ("ardently", 1), ("passionately", 1), ("ebulliently", 1), ("vibrantly", 1),
 ("intensely", 1)]),
 ("pleased", 1, [("happy", 1), ("content", 1), ("satisfied", 1), ("delighted", 1),
 ("gratified", 1), ("glad", 1), ("cheerful", 1), ("elated", 1), ("contented", 1), ("overjoyed", 1)]),
 ("always", 1, [("constantly", 1), ("continually", 1), ("regularly", 1), ("perpetually", 1),
 ("persistently", 1), ("forever", 1), ("unfailing", 1), ("invariably", 1), ("habitually", 1),
 ("everlastingly", 1)]),
 ("wanted", 1, [("desired", 1), ("craved", 1), ("wished for", 1), ("longed for", 1),
 ("yearned for", 1), ("coveted", 1), ("aspired to", 1), ("sought", 1), ("needed", 1), ("hoped for",
 1)]),
 ("dog", 1, [("canine", 1), ("hound", 1), ("pooch", 1), ("pup", 1), ("mutt", 1), ("pet", 1),
 ("puppy", 1), ("companion", 1), ("domestic animal", 1), ("furry friend", 1)]))
 last_sentence_words = ([("annie", 1, [("annie's", 1), ("annies", 1)]),
 ("mother", 1, [("mothers", 1), ("mom", 1), ("mum", 1), ("parent", 1), ("maternal
 figure", 1), ("matriarch", 1), ("caregiver", 1), ("mommy", 1), ("matron", 1), ("female parent",
 1), ("ma", 1)]),
 ("collected", 1, [("gathered", 1), ("accumulated", 1), ("assembled", 1), ("amassed", 1),
 ("picked up", 1), ("hoarded", 1), ("rounded up", 1), ("harvested", 1), ("compiled", 1),
 ("scooped up", 1)]),
 ("discarded", 1, [("thrown away", 1), ("tossed", 1), ("dumped", 1), ("cast off", 1),
 ("forsaken", 1), ("disposed", 1), ("jettisoned", 1), ("discarded", 1), ("cast aside", 1),
 ("rejected", 1)]),
 ("wrapping", 1, [("packaging", 1), ("covering", 1), ("encasing", 1), ("wrapping
 material", 1), ("casing", 1), ("wrap", 1), ("outer layer", 1), ("packing", 1), ("wrapper", 1),
 ("cover", 1)]),
 ("paper", 1, [("parchment", 1), ("card", 1), ("cardstock", 1), ("material", 1), ("sheet", 1),
 ("folio", 1), ("page", 1), ("leaf", 1), ("newsprint", 1), ("stationery", 1)]),

```

        ("black", 1, [("dark", 1), ("ebony", 1), ("jet", 1), ("pitch-dark", 1), ("inky", 1),
("charcoal", 1), ("sooty", 1), ("raven", 1), ("obsidian", 1), ("onyx", 1)]),
        ("plastic", 1, [("synthetic", 1), ("bin", 1), ("polymer", 1), ("PVC", 1), ("resin", 1),
("plastic material", 1), ("artificial", 1), ("polyethylene", 1), ("acrylic", 1), ("teflon", 1),
("vinyl", 1)]),
        ("bag", 1, [("sack", 1), ("pouch", 1), ("carrier", 1), ("package", 1), ("container", 1),
("tote", 1), ("satchel", 1), ("baggage", 1), ("parcel", 1), ("handbag", 1)]))

```

Convert list of words to formatted string

```

first_sentence_words_str = []
for word_info in first_sentence_words:
    word = word_info[0]
    max_count = word_info[1]
    synonyms = ','.join([syn[0] for syn in word_info[2]])
    first_sentence_words_str.append(f'{word}\t{synonyms}\t{max_count}')

```

```

main_body_words_str = []
for word_info in main_body_words:
    word = word_info[0]
    max_count = word_info[1]
    synonyms = ','.join([syn[0] for syn in word_info[2]])
    main_body_words_str.append(f'{word}\t{synonyms}\t{max_count}')

```

```

last_sentence_words_str = []
for word_info in last_sentence_words:
    word = word_info[0]
    max_count = word_info[1]
    synonyms = ','.join([syn[0] for syn in word_info[2]])
    last_sentence_words_str.append(f'{word}\t{synonyms}\t{max_count}')

```

```

first_sentence_words_str = '\n'.join(first_sentence_words_str)
main_body_words_str = '\n'.join(main_body_words_str)
last_sentence_words_str = '\n'.join(last_sentence_words_str)

```

```

# Create input widgets
first_sentence_input = widgets.Textarea(value="", description='First sentence:')
first_sentence_word_input = widgets.Textarea(value=first_sentence_words_str,
description='Target words:')
main_body_input = widgets.Textarea(value="", description='Main body:')
main_body_word_input = widgets.Textarea(value=main_body_words_str,
description='Target words:')
last_sentence_input = widgets.Textarea(value="", description='Last sentence:')
last_sentence_word_input = widgets.Textarea(value=last_sentence_words_str,
description='Target words:')
display(first_sentence_input, first_sentence_word_input, main_body_input,
main_body_word_input, last_sentence_input, last_sentence_word_input)

# Widget Button

button = widgets.Button(description='Analyze')
output = widgets.Output()
display(button, output)

def analyze_text(b):
    output.clear_output()
    total_count = [0, 0, 0]
    with output:

        text_inputs = [first_sentence_input.value.lower(), main_body_input.value.lower(),
last_sentence_input.value.lower()]
        word_inputs = [first_sentence_word_input.value.split('\n'),
main_body_word_input.value.split('\n'), last_sentence_word_input.value.split('\n')]

        for i, (text_input, word_input) in enumerate(zip(text_inputs, word_inputs)):
            current_text = text_input
            set1 = []
            for line in word_input:

```



```

word_parts = line.split('\t')
if len(word_parts) == 3:
    word = word_parts[0].strip()
    if not word: # skip if word is an empty string
        continue
    max_count = int(word_parts[2].strip())
    synonyms = [(syn, 1) for syn in word_parts[1].split(',') if syn] # Make sure
synonym is not an empty string
    set1.append((word, max_count, synonyms))

set1_count = 0
counted_words = defaultdict(int)
counted_synonyms = set()

for word_info in set1:
    current_word = word_info[0]
    max_count = word_info[1]
    count_word = len(re.findall(f'\\b{current_word}\\b', current_text))
    count_word = min(count_word, max_count)
    if count_word > 0:
        counted_words[current_word] = count_word
        set1_count += count_word
        current_text = re.sub(f'\\b{current_word}\\b', '\033[31m' + current_word +
'\033[0m', current_text)

    if current_word not in counted_synonyms:
        for synonym, _ in word_info[2]:
            count_syn = len(re.findall(f'\\b{synonym.strip()}\\b', current_text))
            count_syn = min(count_syn, max_count - count_word)
            if count_syn > 0:
                counted_words[synonym.strip()] = count_syn
                counted_synonyms.add(current_word)
                set1_count += count_syn

```

```

        current_text = re.sub(f'\\b{synonym.strip()}\\b', '\033[31m' +
synonym.strip() + '\033[0m', current_text)
        break

    print(current_text)
    print("Set 1 Count: " + str(set1_count))
    total_count[i] += set1_count # Add to total count
    for word, count in counted_words.items():
        print(f'Word/Synonym "{word}" (from "{next(w[0] for w in set1 if word in [w[0]]
+ [syn[0] for syn in w[2]])}" was found {count} time(s)')

    print(f'First sentence total count: {total_count[0]}')
    print(f'Main body total count: {total_count[1]}')
    print(f'Last sentence total count: {total_count[2]}')

button.on_click(analyze_text)

```

The Car Purchase

```
from collections import defaultdict
import re
from IPython.display import display
from ipywidgets import widgets

# Pre-defined target words for each section
first_sentence_words = [("grace", 1, [("grace's", 1)]),
    ("wants", 1, [("desire", 1), ("hopes", 1), ("want", 1), ("wish", 1), ("aspire", 1), ("crave",
1), ("covet", 1), ("yearn", 1), ("seek", 1), ("long", 1), ("aim", 1), ("hope", 1)]),
    ("use", 1, [("utilise", 1), ("employ", 1), ("uses", 1), ("apply", 1), ("exploit", 1),
("harness", 1), ("engage", 1)]),
    ("savings", 1, [("reserve", 1), ("saving", 1), ("fund", 1), ("nest egg", 1), ("bank", 1),
("deposit", 1), ("stash", 1), ("hoard", 1), ("stockpile", 1), ("reserve", 1), ("accumulation", 1),
("money", 1)]),
    ("purchase", 1, [("buy", 1), ("buys", 1), ("acquire", 1), ("procure", 1), ("obtain", 1),
("get", 1), ("secure", 1), ("invest in", 1), ("pick up", 1)]),
    ("used", 1, [("pre-owned", 1), ("second-hand", 1), ("pre-loved", 1), ("recycled", 1),
("reused", 1), ("refurbished", 1), ("previously owned", 1), ("hand-me-down", 1), ("veteran",
1), ("old", 1)]),
    ("car", 1, [("automobile", 1), ("vehicle", 1), ("motor", 1), ("auto", 1), ("wheels", 1),
("motorcar", 1), ("ride", 1)])

main_body_words = [("online", 1, [("internet", 1), ("digital", 1), ("web", 1), ("virtual", 1),
("electronic", 1), ("networked", 1), ("cyber", 1), ("e-", 1), ("net", 1), ("wired", 1)]),
    ("finds", 1, [("discover", 1), ("locate", 1), ("uncover", 1), ("identify", 1), ("spot", 1),
("encounter", 1), ("detect", 1), ("notice", 1), ("observe", 1), ("see", 1)]),
    ("small", 3, [("little", 3), ("tiny", 3), ("miniature", 3), ("compact", 3), ("petite", 3),
("minuscule", 3), ("slight", 3), ("mini", 3), ("minor", 3), ("diminutive", 3)]),
    ("blue", 1, [("azure", 1), ("cobalt", 1), ("navy", 1), ("sapphire", 1), ("indigo", 1), ("sky-
blue", 1), ("turquoise", 1), ("cerulean", 1), ("teal", 1)]),
    ("car", 6, [("automobile", 6), ("vehicle", 6), ("motor", 6), ("auto", 6), ("wheels", 6),
("motorcar", 6), ("ride", 6)]),
    ("low", 2, [("reduced", 2), ("limited", 2), ("small", 2), ("minimal", 2), ("minor", 2),
("lessened", 2), ("modest", 2), ("decreased", 2), ("low", 2), ("diminish", 2), ("little", 2)]),
    ("mileage", 1, [("distance", 1), ("length", 1), ("range", 1), ("reach", 1), ("extent", 1),
("span", 1), ("journey", 1)]),
    ("books", 1, [("reserve", 1), ("book", 1), ("arranges", 1), ("schedule", 1), ("arrange", 1),
("register", 1), ("plans", 1), ("secures", 1), ("set up", 1), ("sets up", 1), ("locks in", 1),
("organises", 1)])
```

("appointment", 1, [("meeting", 1), ("meet", 1), ("date", 1), ("engagement", 1),
 ("session", 1), ("consultation", 1), ("interview", 1), ("visit", 1), ("rendezvous", 1),
 ("commitment", 1), ("arrangement", 1)]),
 ("view", 1, [("inspect", 1), ("views", 1), ("sees", 1), ("examine", 1), ("look at", 1),
 ("observe", 1), ("survey", 1), ("check out", 1), ("scrutinize", 1), ("study", 1), ("eye", 1),
 ("see", 1)]),
 ("saturday", 2, [("saturday's", 1)]),
 ("9am", 2, [("9 am", 1)]),
 ("arrives", 1, [("reaches", 1), ("comes", 1), ("arrived", 1), ("came", 1), ("shows up", 1),
 ("appears", 1), ("turns up", 1), ("lands", 1), ("enters", 1), ("pulls in", 1), ("rolls up", 1), ("gets
 there", 1)]),
 ("grace", 5, [("grace's", 5)]),
 ("catches", 1, [("boards", 1), ("takes", 1), ("got on", 1), ("gets", 1), ("got", 1), ("caught",
 1), ("gets on", 1), ("takes", 1), ("hops on", 1), ("jumps on", 1), ("rides", 1), ("climbs aboard",
 1), ("grabs", 1), ("enters", 1), ("secures", 1)]),
 ("train", 1, [("locomotive", 1), ("trains", 1), ("rail", 1), ("railway", 1), ("subway", 1),
 ("metro", 1), ("monorail", 1), ("carriage", 1), ("tram", 1), ("railcar", 1), ("railroad", 1)]),
 ("bus", 1, [("coach", 1), ("shuttle", 1), ("minibus", 1), ("motorbus", 1), ("double-
 decker", 1), ("transit vehicle", 1), ("public transport", 1), ("passenger vehicle", 1)]),
 ("housing", 1, [("residential", 1), ("accommodation", 1), ("dwelling", 1), ("living
 quarters", 1), ("lodging", 1), ("habitation", 1), ("shelter", 1), ("abode", 1), ("residence", 1)]),
 ("estate", 1, [("property", 1), ("grounds", 1), ("lands", 1), ("holdings", 1), ("premises",
 1), ("territory", 1), ("area", 1), ("domain", 1), ("plot", 1)]),
 ("knocks", 1, [("taps", 1), ("knock", 1), ("bangs", 1), ("thumps", 1), ("hits", 1),
 ("strikes", 1), ("bumps", 1), ("clatters", 1), ("pounds", 1), ("drum", 1)]),
 ("door", 1, [("entrance", 1), ("gate", 1), ("portal", 1), ("entry", 1), ("doorway", 1),
 ("threshold", 1), ("exit", 1), ("access", 1), ("opening", 1), ("passage", 1)]),
 ("meets", 1, [("encounters", 1), ("meet", 1), ("met", 1), ("comes across", 1), ("runs
 into", 1), ("faces", 1), ("greet", 1), ("finds", 1), ("engages with", 1), ("confronts", 1),
 ("crosses paths with", 1), ("interacts with", 1)]),
 ("middle-aged", 1, [("mature", 1), ("adult", 1), ("midlife", 1), ("in one's prime", 1),
 ("middle-years", 1), ("mid-years", 1), ("of a certain age", 1), ("matured", 1), ("in the middle
 years", 1), ("middle of life", 1)]),
 ("woman", 1, [("lady", 1), ("female", 1), ("gal", 1), ("dame", 1), ("lass", 1), ("maiden",
 1), ("miss", 1)]),
 ("blonde", 1, [("fair-haired", 1), ("light-haired", 1), ("golden-haired", 1), ("flaxen-
 haired", 1), ("yellow-haired", 1), ("towheaded", 1), ("platinum", 1), ("strawberry blonde", 1),
 ("goldilocks", 1), ("ash-blond", 1)]),
 ("hair", 1, [("locks", 1), ("mane", 1), ("tresses", 1), ("strands", 1), ("follicles", 1),
 ("curls", 1), ("hairdo", 1)]),
 ("called", 1, [("named", 1), ("known as", 1), ("termed", 1), ("dubbed", 1), ("labelled",
 1), ("referred to as", 1), ("titled", 1), ("christened", 1), ("denoted", 1)]),

("sandra", 4, [{"the seller", 4}, {"the woman", 4}, {"the owner", 4}, {"the driver", 4}, {"the blonde woman", 4}, {"the resident", 4}, {"the middle-aged lady", 4}, {"the host", 4}, {"the guide", 4}, {"the lady", 4}]),
 ("asks", 2, [{"requests", 2}, {"inquires", 2}, {"queries", 2}, {"questions", 2}, {"asks for", 2}, {"seeks", 2}, {"proposes", 2}, {"invites", 2}, {"solicits", 2}, {"demands", 2}]),
 ("wait", 1, [{"standby", 1}, {"pause", 1}, {"hold on", 1}, {"delay", 1}, {"hesitate", 1}, {"await", 1}, {"linger", 1}, {"stay", 1}, {"bide", 1}]),
 ("outside", 1, [{"outdoors", 1}, {"externally", 1}, {"exterior", 1}, {"out", 1}, {"open-air", 1}, {"outer", 1}, {"external", 1}, {"outward", 1}, {"outside of", 1}, {"open", 1}]),
 ("collects", 1, [{"gathers", 1}, {"gets", 1}, {"retrieves", 1}, {"picks up", 1}, {"gets", 1}, {"amasses", 1}, {"acquires", 1}, {"assembles", 1}, {"accumulates", 1}, {"procures", 1}, {"secures", 1}]),
 ("keys", 1, [{"key set", 1}, {"openers", 1}, {"unlocks", 1}, {"access tools", 1}, {"door openers", 1}, {"key cards", 1}, {"master keys", 1}, {"passkeys", 1}, {"fobs", 1}, {"latchkeys", 1}]),
 ("go", 1, [{"proceed", 1}, {"travel", 1}, {"move", 1}, {"journey", 1}, {"depart", 1}, {"progress", 1}, {"head", 1}, {"drive", 1}, {"walk", 1}, {"navigate", 1}]),
 ("test", 1, [{"trial", 1}, {"check", 1}, {"evaluate", 1}, {"inspect", 1}, {"assess", 1}, {"verification", 1}, {"review", 1}, {"analyse", 1}, {"screen", 1}, {"try", 1}]),
 ("drive", 2, [{"ride", 2}, {"journey", 2}, {"travel", 2}, {"cruise", 2}, {"trek", 2}, {"jaunt", 2}, {"tour", 2}, {"expedition", 2}, {"trip", 2}, {"voyage", 2}]),
 ("pair", 1, [{"duo", 1}, {"couple", 1}, {"twosome", 1}, {"tandem", 1}, {"team", 1}, {"partnership", 1}, {"duet", 1}, {"double", 1}]),
 ("local", 2, [{"nearby", 2}, {"neighbourhood", 2}, {"community", 2}, {"proximate", 2}, {"surrounding", 2}, {"regional", 2}, {"vicinal", 2}, {"adjacent", 2}, {"close", 2}, {"area", 2}]),
 ("shops", 1, [{"store", 1}, {"outlet", 1}, {"retailer", 1}, {"market", 1}, {"boutiques", 1}, {"vendor", 1}, {"malls", 1}, {"emporium", 1}, {"merchant", 1}, {"bazaar", 1}]),
 ("notices", 1, [{"observes", 1}, {"detects", 1}, {"recognizes", 1}, {"discerns", 1}, {"sees", 1}, {"spots", 1}, {"discovers", 1}, {"identifies", 1}, {"notes", 1}, {"perceives", 1}]),
 ("air", 2, [{"oxygen", 2}, {"draft", 2}, {"ventilation", 2}, {"", 2}, {"", 2}, {"", 2}, {"", 2}, {"", 2}, {"", 2}, {"", 2}]),
 ("conditioning", 2, [{"cooling", 2}, {"ventilation", 2}, {"climate control", 2}, {"ac", 2}, {"air system", 2}, {"hvac", 2}, {"air cooling", 2}, {"aircon", 2}, {"coolant system", 2}, {"", 2}]),
 ("work", 1, [{"operate", 1}, {"function", 1}, {"run", 1}, {"perform", 1}, {"go", 1}, {"serve", 1}, {"act", 1}, {"work properly", 1}, {"be in operation", 1}, {"functional", 1}]),
 ("fixed", 1, [{"repair", 1}, {"fix", 1}, {"fixes", 1}, {"mend", 1}, {"rectified", 1}, {"correct", 1}, {"restore", 1}, {"amend", 1}, {"resolve", 1}, {"service", 1}, {"adjusted", 1}, {"remedied", 1}]),
 ("gives", 1, [{"provides", 1}, {"offers", 1}, {"present", 1}, {"grants", 1}, {"hands over", 1}, {"delivers", 1}, {"give out", 1}, {"furnishes", 1}, {"bestow", 1}, {"supplies", 1}, {"supply", 1}]),
 ("name", 1, [{"designation", 1}, {"title", 1}, {"label", 1}, {"tag", 1}, {"names", 1}, {"identifier", 1}]),

("business", 1, [("company", 1), ("enterprise", 1), ("firm", 1), ("establishment", 1),
 ("operation", 1), ("corporation", 1), ("industry", 1), ("trade", 1), ("outfit", 1), ("venture", 1)]),
 ("repairs", 1, [("fixes", 1), ("mends", 1), ("restores", 1), ("services", 1), ("rectifies", 1),
 ("renovates", 1), ("reconditions", 1), ("overhauls", 1), ("rebuilds", 1), ("refurbishes", 1)]),
 ("cost", 1, [("price", 1), ("charge", 1), ("expense", 1), ("rate", 1), ("value", 1),
 ("amount", 1), ("fee", 1), ("expenditure", 1), ("payment", 1), ("outlay", 1)]),
 ("satisfied", 1, [("pleased", 1), ("content", 1), ("happy", 1), ("fulfilled", 1), ("gratified",
 1), ("sated", 1), ("appeased", 1), ("comfortable", 1), ("contented", 1), ("reassured", 1)]),
 ("agrees", 1, [("consents", 1), ("accepts", 1), ("assents", 1), ("concur", 1), ("approves",
 1), ("accedes", 1), ("commits", 1), ("decides", 1), ("settles", 1), ("complies", 1)]),
 ("purchase", 1, [("buy", 1), ("purchases", 1), ("buys", 1), ("acquire", 1), ("procure", 1),
 ("obtain", 1), ("secure", 1), ("invest in", 1), ("pick up", 1), ("take", 1), ("pay for", 1), ("get",
 1)]),
 ("drives", 1, [("operates", 1), ("guides", 1), ("", 1), ("steers", 1), ("", 1), ("", 1),
 ("navigates", 1), ("directs", 1), ("", 1), ("moves", 1)]),
 ("home", 1, [("residence", 1), ("house", 1), ("abode", 1), ("domicile", 1), ("dwelling",
 1), ("habitat", 1), ("residence", 1), ("place", 1), ("homestead", 1), ("living quarters", 1)])]

last_sentence_words = ([("home", 1, [("residence", 1), ("house", 1), ("abode", 1), ("domicile",
 1), ("dwelling", 1), ("habitat", 1), ("residence", 1), ("place", 1), ("homestead", 1), ("living
 quarters", 1)]),

("grace", 1, [("grace's", 1)]),
 ("makes", 1, [("prepares", 1), ("brews", 1), ("creates", 1), ("produces", 1), ("forms", 1),
 ("whips up", 1), ("constructs", 1), ("puts together", 1), ("assembles", 1), ("cooks up", 1)]),
 ("hot", 1, [("warm", 1), ("boiling", 1), ("heated", 1), ("steaming", 1), ("piping", 1),
 ("toasty", 1), ("scalding", 1), ("sizzling", 1), ("burning", 1), ("torrid", 1)]),
 ("cup", 1, [("mug", 1), ("glass", 1), ("beaker", 1), ("tumbler", 1), ("container", 1),
 ("vessel", 1), ("drinkware", 1), ("flask", 1), ("jar", 1), ("tankard", 1)]),
 ("tea", 1, [("brew", 1), ("infusion", 1), ("beverage", 1), ("drink", 1), ("chai", 1),
 ("potation", 1), ("refreshment", 1), ("tisane", 1), ("cuppa", 1), ("herbal", 1)]),
 ("calls", 1, [("phones", 1), ("contacts", 1), ("rings up", 1), ("dials", 1), ("reaches out to",
 1), ("connects with", 1), ("communicates with", 1), ("gets in touch with", 1), ("buzzes", 1),
 ("telephones", 1)]),
 ("father", 1, [("dad", 1), ("papa", 1), ("pa", 1), ("pops", 1), ("daddy", 1), ("old man", 1),
 ("sire", 1), ("patriarch", 1), ("pop", 1), ("paternal figure", 1)])])

Convert list of words to formatted string

first_sentence_words_str = []

for word_info in first_sentence_words:

word = word_info[0]

max_count = word_info[1]

synonyms = ', '.join([syn[0] for syn in word_info[2]])

first_sentence_words_str.append(f'{word}\t{synonyms}\t{max_count}')

```

main_body_words_str = []
for word_info in main_body_words:
    word = word_info[0]
    max_count = word_info[1]
    synonyms = ','.join([syn[0] for syn in word_info[2]])
    main_body_words_str.append(f'{word}\t{synonyms}\t{max_count}')

last_sentence_words_str = []
for word_info in last_sentence_words:
    word = word_info[0]
    max_count = word_info[1]
    synonyms = ','.join([syn[0] for syn in word_info[2]])
    last_sentence_words_str.append(f'{word}\t{synonyms}\t{max_count}')

first_sentence_words_str = '\n'.join(first_sentence_words_str)
main_body_words_str = '\n'.join(main_body_words_str)
last_sentence_words_str = '\n'.join(last_sentence_words_str)

# Create input widgets
first_sentence_input = widgets.Textarea(value="", description='First sentence:')
first_sentence_word_input = widgets.Textarea(value=first_sentence_words_str,
description='Target words:')
main_body_input = widgets.Textarea(value="", description='Main body:')
main_body_word_input = widgets.Textarea(value=main_body_words_str,
description='Target words:')
last_sentence_input = widgets.Textarea(value="", description='Last sentence:')
last_sentence_word_input = widgets.Textarea(value=last_sentence_words_str,
description='Target words:')
display(first_sentence_input, first_sentence_word_input, main_body_input,
main_body_word_input, last_sentence_input, last_sentence_word_input)

# Define a button to run the analysis
button = widgets.Button(description='Analyze')
output = widgets.Output()
display(button, output)

def analyze_text(b):
    output.clear_output() # Clear the output before each run
    total_count = [0, 0, 0] # Count for first_sentence, main_body, last_sentence
    with output:
        # Get input values
        text_inputs = [first_sentence_input.value.lower(), main_body_input.value.lower(),
last_sentence_input.value.lower()]

```

```

word_inputs = [first_sentence_word_input.value.split('\n'),
main_body_word_input.value.split('\n'), last_sentence_word_input.value.split('\n')]

for i, (text_input, word_input) in enumerate(zip(text_inputs, word_inputs)):
    current_text = text_input
    # Parse target words and synonyms from input
    set1 = []
    for line in word_input:
        word_parts = line.split('\t')
        if len(word_parts) == 3:
            word = word_parts[0].strip()
            if not word: # skip if word is an empty string
                continue
            max_count = int(word_parts[2].strip())
            synonyms = [(syn, 1) for syn in word_parts[1].split(',') if syn] # ensure synonym
is not an empty string
            set1.append((word, max_count, synonyms))

    set1_count = 0
    counted_words = defaultdict(int)
    counted_synonyms = set()

    for word_info in set1:
        current_word = word_info[0]
        max_count = word_info[1]
        count_word = len(re.findall(f'\\b{current_word}\\b', current_text))
        count_word = min(count_word, max_count)
        if count_word > 0:
            counted_words[current_word] = count_word
            set1_count += count_word
            current_text = re.sub(f'\\b{current_word}\\b', '\033[31m' + current_word +
'\033[0m', current_text)

        if current_word not in counted_synonyms:
            for synonym, _ in word_info[2]:
                count_syn = len(re.findall(f'\\b{synonym.strip()}\\b', current_text))
                count_syn = min(count_syn, max_count - count_word)
                if count_syn > 0:
                    counted_words[synonym.strip()] = count_syn
                    counted_synonyms.add(current_word)
                    set1_count += count_syn
                    current_text = re.sub(f'\\b{synonym.strip()}\\b', '\033[31m' +
synonym.strip() + '\033[0m', current_text)
                    break

```



```

print(current_text)
print("Set 1 Count: " + str(set1_count))
total_count[i] += set1_count # Add to total count
for word, count in counted_words.items():
    print(f'Word/Synonym "{word}" (from "{next(w[0] for w in set1 if word in [w[0]]
+ [syn[0] for syn in w[2]])}" was found {count} time(s)')

print(f'First sentence total count: {total_count[0]}')
print(f'Main body total count: {total_count[1]}')
print(f'Last sentence total count: {total_count[2]}')

button.on_click(analyze_text)

```

The Cinema Trip

```
from collections import defaultdict
import re
from IPython.display import display
from ipywidgets import widgets

# Pre-defined target words for each section
first_sentence_words = [
    ("jemma", 1, [("jemma", 1), ("gemma", 1)]),
    ("friend", 1, [("buddy", 1), ("friends", 1), ("bud", 1), ("pal", 1), ("confidant", 1), ("mate",
1), ("acquaintance", 1), ("associate", 1)]),
    ("beth", 1, [("beth", 1)]),
    ("making", 1, [("create", 1), ("creating", 1), ("bring", 1), ("generate", 1), ("generating",
1), ("produce", 1), ("producing", 1), ("form", 1), ("develop", 1)]),
    ("plans", 1, [("strategy", 1), ("plan", 1), ("planning", 1), ("strategizing", 1), ("preparing",
1), ("prep", 1), ("design", 1), ("organise", 1), ("organising", 1), ("arranging", 1), ("arrange",
1), ("schedule", 1), ("scheduling", 1), ("plot", 1)]),
    ("evening", 1, [("afternoon", 1), ("twilight", 1), ("night", 1), ("end of the day", 1)])]

main_body_words = [("pair", 2, [("couple", 2), ("duo", 2), ("partnership", 2), ("twosome", 2),
("dyad", 2), ("team", 2)]),
    ("decide", 2, [("plan", 2), ("decided", 2), ("planned", 2), ("arrange", 2), ("settle", 2),
("determine", 2), ("choose", 2), ("establish", 2), ("agree", 2), ("resolve", 2), ("organise", 2),
("schedule", 2), ("formulate", 2), ("prepare", 2), ("lay out", 2), ("coordinate", 2), ("design",
2), ("work out", 2), ("devise", 2)]),
    ("go", 2, [("attend", 2), ("visit", 2), ("head to", 2), ("proceed to", 2), ("journey to", 2),
("move toward", 2), ("venture to", 2), ("make one's way to", 2), ("reach", 2), ("travel to", 2),
("arrive at", 2), ("get to", 2), ("patronize", 2), ("show up at", 2), ("be present at", 2), ("pop
into", 2), ("drop by", 2), ("step into", 2), ("pay a visit to", 2), ("experience", 2)]),
    ("cinema", 3, [("movie theatre", 3), ("film house", 3), ("picture house", 3), ("cineplex",
3), ("movie palace", 3), ("multiplex", 3), ("theatre", 3), ("movie hall", 3), ("picture theatre",
3), ("film venue", 3), ("movie screen", 3), ("film cinema", 3), ("flick house", 3), ("motion
picture theatre", 3), ("film centre", 3), ("cine-plex", 3), ("film showcase", 3), ("silver screen",
3), ("movie house", 3), ("big screen", 3)]),
    ("watch", 1, [("view", 1), ("observe", 1), ("witness", 1), ("see", 1), ("take in", 1), ("look
at", 1), ("attend", 1), ("eye", 1), ("check out", 1), ("gaze at", 1)]),
    ("documentary", 1, [("nonfiction film", 1), ("factual film", 1), ("docufilm", 1),
("informative film", 1), ("exposé", 1), ("educational film", 1), ("investigative film", 1),
("historical film", 1), ("nonfictional film", 1), ("authentic film", 1), ("nonfiction storytelling",
1)]),
    ("space", 2, [("astro", 2)]),
    ("engineering", 1, [("management", 1])],
```

("raining", 1, [("pour", 1), ("drizzling", 1), ("drizzle", 1), ("showery", 1), ("shower", 1), ("precipitating", 1), ("precipitation", 1), ("precipitate", 1), ("wet weather", 1), ("rainfall", 1), ("showering", 1), ("sprinkling", 1), ("downpour", 1), ("deluge", 1)]),
 ("women", 2, [("ladies", 2), ("lady", 2), ("females", 2), ("female", 2), ("girls", 2), ("girl", 2), ("gals", 2), ("gal", 2), ("damsels", 2), ("dames", 2), ("lasses", 2), ("lass", 2)]),
 ("wear", 1, [("don", 1), ("put on", 1), ("sport", 1), ("dress", 1), ("have on", 1), ("clothe", 1), ("slip into", 1)]),
 ("waterproof", 1, [("water-resistant", 1), ("rainproof", 1), ("weatherproof", 1), ("hydrophobic", 1), ("moisture-resistant", 1), ("showerproof", 1), ("water-repellent", 1), ("waterproofed", 1), ("impermeable", 1), ("sealed", 1)]),
 ("coats", 1, [("jacket", 1), ("outerwear", 1), ("raincoat", 1), ("parka", 1), ("anorak", 1), ("shell", 1), ("trench coat", 1), ("macintosh", 1), ("windbreaker", 1), ("waterproof garment", 1), ("overcoat", 1), ("waterproof jacket", 1), ("poncho", 1), ("cape", 1), ("all-weather coat", 1), ("weatherproof coat", 1), ("storm coat", 1)]),
 ("way", 1, [("route", 1), ("path", 1), ("journey", 1), ("course", 1), ("passage", 1), ("travel", 1), ("approach", 1), ("passage", 1)]),
 ("queue", 1, [("line", 1), ("waiting", 1), ("lineup", 1), ("file", 1), ("queueing", 1), ("stand", 1)]),
 ("beth", 2, [("beth", 2)]),
 ("sees", 1, [("spot", 1), ("saw", 1), ("notice", 1), ("observe", 1), ("perceive", 1), ("detect", 1), ("identify", 1), ("identifies", 1), ("take note of", 1), ("view", 1), ("glance", 1), ("glimpse", 1), ("lay eyes on", 1), ("recognise", 1), ("examine", 1)]),
 ("poster", 1, [("advertisement", 1), ("advert", 1), ("ad", 1), ("billboard", 1), ("sign", 1), ("signboard", 1), ("display", 1), ("placard", 1), ("flyer", 1), ("notice", 1), ("bulletin", 1), ("promotional material", 1), ("print", 1), ("graphic", 1), ("artwork", 1)]),
 ("film", 2, [("movie", 2), ("motion picture", 2), ("flick", 2), ("picture", 2), ("feature", 2), ("cinema", 2), ("moving image", 2), ("screenplay", 2), ("video", 2), ("moving picture", 2), ("reel", 2), ("documentary", 2), ("motion image", 2)]),
 ("shows", 2, [("depict", 2), ("present", 2), ("portray", 2), ("illustrate", 2), ("exhibit", 2), ("reveal", 2), ("display", 2), ("highlight", 2), ("represent", 2), ("demonstrate", 2), ("exhibits", 2), ("project", 2), ("convey", 2)]),
 ("team", 1, [("group", 1), ("workers", 1), ("crew", 1), ("squad", 1), ("unit", 1), ("staff", 1), ("ensemble", 1), ("collective", 1), ("company", 1), ("band", 1), ("task force", 1), ("workforce", 1), ("association", 1), ("organisation", 1), ("cohort", 1), ("assembly", 1), ("brigade", 1), ("worker", 1), ("gang", 1)]),
 ("people", 1, [("individual", 1), ("personnel", 1), ("staff", 1), ("employee", 1), ("worker", 1), ("team member", 1), ("colleagues", 1), ("colleague", 1), ("associate", 1), ("crew", 1), ("co-worker", 1), ("collaborator", 1), ("member", 1), ("group", 1), ("workforce", 1), ("staff member", 1), ("professional", 1), ("teammate", 1), ("operator", 1), ("expert", 1)]),
 ("working", 1, [("operating", 1), ("operate", 1), ("function", 1), ("performing", 1), ("perform", 1), ("engage", 1), ("employ", 1), ("productive", 1), ("labouring", 1), ("labour", 1), ("collaborate", 1), ("collaborating", 1), ("task", 1), ("executing", 1), ("execute", 1), ("carrying out", 1), ("undertaking", 1), ("undertake", 1), ("operating on", 1), ("occupied", 1), ("tackling", 1), ("busy", 1)]),

("computers", 1, [("pc", 1), ("computer", 1), ("personal computer", 1), ("workstation", 1), ("desktop", 1), ("laptop", 1), ("machine", 1), ("terminal", 1), ("computing", 1), ("console", 1)]),
 ("command", 1, [("control", 1), ("authority", 1), ("leadership", 1), ("power", 1), ("governance", 1), ("headquarters", 1)]),
 ("centre", 1, [("headquarters", 1), ("base", 1), ("room", 1), ("post", 1), ("hub", 1), ("command", 1), ("station", 1), ("control", 1), ("main control", 1), ("facility", 1), ("depot", 1), ("core facility", 1), ("base", 1)]),
 ("worker", 1, [("employee", 1), ("staff", 1), ("operator", 1), ("team", 1), ("personnel", 1), ("staffer", 1), ("officer", 1), ("agent", 1), ("technician", 1), ("specialist", 1), ("operator", 1), ("performer", 1), ("attendant", 1), ("labour", 1), ("operative", 1), ("professional", 1), ("executing member", 1)]),
 ("wearing", 1, [("donning", 1), ("sporting", 1), ("clad", 1), ("attire", 1), ("decked out in", 1), ("garb", 1), ("clothed", 1), ("adorned", 1), ("outfitted", 1)]),
 ("red", 1, [("crimson", 1), ("scarlet", 1), ("ruby", 1), ("cherry", 1), ("burgundy", 1), ("vermilion", 1), ("maroon", 1), ("carmine", 1), ("brick", 1), ("blood-red", 1), ("rose", 1), ("rust", 1), ("garnet", 1), ("cardinal", 1), ("mahogany", 1), ("coral", 1), ("poppy", 1), ("ruddy", 1)]),
 ("blue", 1, [("cobalt", 1), ("azure", 1), ("sapphire", 1), ("indigo", 1), ("navy", 1), ("sky-blue", 1), ("cerulean", 1), ("teal", 1), ("marine", 1), ("turquoise", 1)]),
 ("striped", 1, [("line", 1), ("banded", 1), ("streak", 1), ("striated", 1), ("variegated", 1), ("pinstripe", 1), ("grooved", 1), ("ribbon", 1), ("barred", 1), ("veined", 1)]),
 ("shirt", 1, [("top", 1), ("jersey", 1), ("tee", 1), ("tunic", 1), ("garment", 1), ("button-down", 1), ("button down", 1)]),
 ("ushers", 1, [("escort", 1), ("usher", 1), ("guide", 1), ("lead", 1), ("direct", 1), ("shos", 1), ("marshal", 1), ("steer", 1), ("shepherd", 1), ("chaperone", 1)]),
 ("screen", 3, [("display", 3), ("monitor", 3), ("projection", 3), ("viewing area", 3), ("visual", 3), ("frame", 3)]),
 ("number", 1, []),
 ("opening", 1, [("beginning", 1), ("start", 1), ("initiation", 1), ("initiate", 1), ("commencement", 1), ("prelude", 1), ("onset", 1), ("first", 1)]),
 ("scene", 1, [("sequence", 1), ("act", 1), ("setting", 1), ("passage", 1), ("moment", 1)]),
 ("rocket", 1, [("spacecraft", 1), ("shuttle", 1), ("probe", 1), ("missile", 1), ("satellite", 1), ("vessel", 1), ("capsule", 1), ("craft", 1), ("vehicle", 1), ("module", 1)]),
 ("propelled", 1, [("launch", 1), ("thrust", 1), ("drive", 1), ("push", 1), ("eject", 1), ("force", 1), ("shot", 1), ("shoot", 1), ("boost", 1), ("impel", 1), ("project", 1)]),
 ("suddenly", 1, [("abruptly", 1), ("instantly", 1), ("immediately", 1), ("unexpectedly", 1), ("swiftly", 1), ("promptly", 1), ("instantaneously", 1), ("rapidly", 1), ("all of a sudden", 1), ("without warning", 1), ("sudden", 1)]),
 ("goes", 1, [("turn", 1), ("become", 1), ("became", 1), ("transition", 1), ("change", 1), ("shift", 1), ("transform", 1), ("alter", 1), ("convert", 1)]),
 ("black", 1, [("dark", 1), ("pitch", 1), ("blank", 1)]),
 ("audio", 1, [("sound", 1), ("acoustic", 1), ("auditory", 1), ("noise", 1), ("resonance", 1), ("harmonic", 1), ("audible", 1), ("phonics", 1), ("audio", 1)]),

("cuts", 1, [("interrupt", 1), ("break", 1), ("stop", 1), ("halt", 1), ("pauses", 1),
 ("discontinue", 1), ("cease", 1), ("suspend", 1), ("disrupt", 1), ("breaks off", 1)]),
 ("message", 1, [("communication", 1), ("notice", 1), ("information", 1),
 ("announcement", 1), ("statement", 1), ("dispatch", 1), ("memo", 1), ("report", 1), ("bulletin",
 1), ("notification", 1)]),
 ("appears", 1, [("emerges", 1), ("shows", 1), ("reveals", 1), ("manifests", 1), ("exhibits",
 1), ("surfaces", 1), ("presents", 1), ("arrives", 1), ("becomes visible", 1)]),
 ("informing", 1, [("advising", 1), ("telling", 1), ("updating", 1), ("notifying", 1),
 ("briefing", 1), ("apprising", 1), ("alerting", 1), ("announcing", 1), ("enlightening", 1),
 ("disclosing", 1), ("noting", 1)]),
 ("audience", 1, [("viewer", 1), ("spectator", 1), ("observer", 1), ("watcher", 1), ("crowd",
 1), ("attendee", 1), ("public", 1), ("listener", 1), ("patron", 1), ("onlooker", 1)]),
 ("technical", 1, [("mechanical", 1), ("technological", 1), ("specialised", 1),
 ("professional", 1), ("industrial", 1), ("specific", 1)]),
 ("difficulty", 1, [("problem", 1), ("difficulties", 1), ("problems", 1), ("challenge", 1),
 ("issue", 1), ("complication", 1), ("obstacle", 1), ("hindrance", 1), ("trouble", 1), ("barrier", 1),
 ("fault", 1)]),
 ("jemma", 2, [("jemma", 2)]),
 ("walk", 1, [("stroll", 1), ("march", 1), ("stride", 1), ("pace", 1), ("amble", 1), ("wander",
 1), ("go", 1)]),
 ("customer", 1, [("client", 1), ("consumer", 1), ("patron", 1), ("buyer", 1), ("purchaser",
 1), ("user", 1), ("shopper", 1), ("guest", 1), ("clientele", 1)]),
 ("service", 1, [("assistance", 1), ("help", 1), ("support", 1), ("aid", 1), ("facility", 1),
 ("helpdesk", 1), ("customer care", 1)]),
 ("told", 1, [("informed", 1), ("advised", 1), ("said", 1), ("explained", 1), ("notified", 1),
 ("apprised", 1), ("disclosed to", 1), ("briefed", 1), ("revealed to", 1), ("communicated to",
 1)]),
 ("attend", 1, [("join", 1), ("participate in", 1), ("go to", 1), ("be present at", 1), ("turn up
 for", 1), ("show up for", 1), ("appear at", 1), ("arrive at", 1), ("check into", 1), ("visit", 1)]),
 ("viewing", 2, [("showing", 2), ("view", 2), ("screening", 2), ("presentation", 2),
 ("demonstration", 2), ("exhibition", 2), ("broadcast", 2), ("projection", 2), ("telecast", 2),
 ("display", 2), ("show", 2)]),
 ("minutes", 1, [("moment", 1), ("bits", 1), ("period", 1), ("little while", 1)]),
 ("agree", 1, [("consent", 1), ("", 1), ("concur", 1), ("accord", 1), ("approve", 1),
 ("accept", 1), ("acknowledge", 1), ("comply", 1), ("subscribe", 1), ("decide", 1), ("say yes",
 1)]
]

last_sentence_words = [("film", 2, [("movie", 2), ("picture", 2), ("cinema", 2), ("motion
 picture", 2), ("feature", 2), ("documentary", 2), ("screenplay", 2)]),
 ("women", 1, [("ladies", 1), ("females", 1), ("girls", 1), ("individuals", 1), ("people", 1),
 ("viewers", 1), ("attendees", 1), ("movie-goers", 1)]),
 ("head", 1, [("proceed", 1), ("move", 1), ("advance", 1), ("travel", 1), ("go", 1),
 ("journey", 1), ("journeyed", 1), ("walk", 1), ("made way", 1)]),

```

        ("home", 1, [("residence", 1), ("house", 1), ("abode", 1), ("dwelling", 1), ("habitat", 1),
("living space", 1), ("habitation", 1), ("household", 1)]),
        ("chatting", 1, [("talk", 1), ("talking", 1), ("talked", 1), ("discussing", 1), ("telling", 1),
("discuss", 1), ("converse", 1), ("conversing", 1), ("communicate", 1), ("communicating", 1),
("speak", 1), ("gossip", 1)]),
        ("parts", 1, [("segment", 1), ("section", 1), ("component", 1), ("portion", 1), ("piece", 1),
("element", 1), ("aspect", 1), ("part", 1), ("detail", 1), ("facet", 1)]])

```

```

# Convert list of words to formatted string

```

```

first_sentence_words_str = []
for word_info in first_sentence_words:
    word = word_info[0]
    max_count = word_info[1]
    synonyms = ','.join([syn[0] for syn in word_info[2]])
    first_sentence_words_str.append(f'{word}\t{synonyms}\t{max_count}')

```

```

main_body_words_str = []
for word_info in main_body_words:
    word = word_info[0]
    max_count = word_info[1]
    synonyms = ','.join([syn[0] for syn in word_info[2]])
    main_body_words_str.append(f'{word}\t{synonyms}\t{max_count}')

```

```

last_sentence_words_str = []
for word_info in last_sentence_words:
    word = word_info[0]
    max_count = word_info[1]
    synonyms = ','.join([syn[0] for syn in word_info[2]])
    last_sentence_words_str.append(f'{word}\t{synonyms}\t{max_count}')

```

```

first_sentence_words_str = '\n'.join(first_sentence_words_str)
main_body_words_str = '\n'.join(main_body_words_str)
last_sentence_words_str = '\n'.join(last_sentence_words_str)

```

```

# Create input widgets

```

```

first_sentence_input = widgets.Textarea(value="", description='First sentence:')
first_sentence_word_input = widgets.Textarea(value=first_sentence_words_str,
description='Target words:')
main_body_input = widgets.Textarea(value="", description='Main body:')
main_body_word_input = widgets.Textarea(value=main_body_words_str,
description='Target words:')
last_sentence_input = widgets.Textarea(value="", description='Last sentence:')

```

```

last_sentence_word_input = widgets.Textarea(value=last_sentence_words_str,
description='Target words:')
display(first_sentence_input, first_sentence_word_input, main_body_input,
main_body_word_input, last_sentence_input, last_sentence_word_input)

# Define a button to run the analysis
button = widgets.Button(description='Analyze')
output = widgets.Output()
display(button, output)

def analyze_text(b):
    output.clear_output() # Clear the output before each run
    total_count = [0, 0, 0] # Count for first_sentence, main_body, last_sentence
    with output:
        # Get input values
        text_inputs = [first_sentence_input.value.lower(), main_body_input.value.lower(),
last_sentence_input.value.lower()]
        word_inputs = [first_sentence_word_input.value.split('\n'),
main_body_word_input.value.split('\n'), last_sentence_word_input.value.split('\n')]

        for i, (text_input, word_input) in enumerate(zip(text_inputs, word_inputs)):
            current_text = text_input
            # Parse target words and synonyms from input
            set1 = []
            for line in word_input:
                word_parts = line.split('\t')
                if len(word_parts) == 3:
                    word = word_parts[0].strip()
                    if not word: # skip if word is an empty string
                        continue
                    max_count = int(word_parts[2].strip())
                    synonyms = [(syn, 1) for syn in word_parts[1].split(',') if syn] # ensure synonym
is not an empty string
                    set1.append((word, max_count, synonyms))

            set1_count = 0
            counted_words = defaultdict(int)
            counted_synonyms = set()

            for word_info in set1:
                current_word = word_info[0]
                max_count = word_info[1]
                count_word = len(re.findall(f'\\b{current_word}\\b', current_text))
                count_word = min(count_word, max_count)

```

```

    if count_word > 0:
        counted_words[current_word] = count_word
        set1_count += count_word
        current_text = re.sub(f'\\b{current_word}\\b', '\033[31m' + current_word +
'\033[0m', current_text)

    if current_word not in counted_synonyms:
        for synonym, _ in word_info[2]:
            count_syn = len(re.findall(f'\\b{synonym.strip()}\\b', current_text))
            count_syn = min(count_syn, max_count - count_word)
            if count_syn > 0:
                counted_words[synonym.strip()] = count_syn
                counted_synonyms.add(current_word)
                set1_count += count_syn
                current_text = re.sub(f'\\b{synonym.strip()}\\b', '\033[31m' +
synonym.strip() + '\033[0m', current_text)
                break

    print(current_text)
    print("Set 1 Count: " + str(set1_count))
    total_count[i] += set1_count # Add to total count
    for word, count in counted_words.items():
        print(f'Word/Synonym "{word}" (from "{next(w[0] for w in set1 if word in [w[0]]
+ [syn[0] for syn in w[2]])}" was found {count} time(s)')

    print(f'First sentence total count: {total_count[0]}')
    print(f'Main body total count: {total_count[1]}')
    print(f'Last sentence total count: {total_count[2]}')

button.on_click(analyze_text)

```


The Date

```
from collections import defaultdict
import re
from IPython.display import display
from ipywidgets import widgets

# Pre-defined target words for each section
first_sentence_words = [("samantha", 1, [("samantha", 1)]),
                        ("works", 1, [("perform", 1), ("toil", 1), ("labours", 1)]),
                        ("hard", 1, [("intently", 1), ("vigorously", 1), ("diligent", 1), ("active", 1), ("purpose", 1),
                        ("intense", 1)]),
                        ("planning", 1, [("strategy", 1), ("strategizing", 1), ("preparing", 1), ("prep", 1),
                        ("design", 1), ("organise", 1), ("organising", 1), ("arranging", 1), ("arrange", 1)]),
                        ("day", 1, []),
                        ("week", 1, [])]

main_body_words = [("saturday", 1, []),
                   ("got", 1, [("caught", 1), ("took", 1), ("catch", 1), ("take", 1)]),
                   ("train", 1, [("locomotive", 1)]),
                   ("south", 1, [("lower", 1), ("low", 1)]),
                   ("kensington", 1, []),
                   ("visit", 1, [("see", 1), ("go", 1), ("call", 1), ("drop", 1)]),
                   ("natural", 1, []),
                   ("history", 1, []),
                   ("museum", 3, []),
                   ("planning", 2, [("strategy", 2), ("planned", 2), ("strategizing", 2), ("preparing", 2),
                   ("prep", 2), ("design", 2), ("organise", 2), ("organising", 2), ("arranging", 2), ("arrange", 2)]),
                   ("meet", 1, [("greet", 1), ("see", 1), ("visit", 1), ("go", 1)]),
                   ("suitor", 1, [("boyfriend", 1), ("lover", 1), ("man", 1), ("fellow", 1), ("beau", 1),
                   ("admirer", 1), ("date", 1), ("wooer", 1)]),
                   ("met", 1, [("meet", 1), ("meeting", 1), ("encountered", 1), ("greeted", 1)]),
                   ("dating", 1, [("romance", 1), ("courtship", 1), ("courting", 1), ("suit", 1), ("romancing",
                   1)]),
                   ("website", 1, [("internet", 1), ("net", 1), ("site", 1), ("online", 1)]),
                   ("arrival", 1, [("getting in", 1), ("coming", 1), ("landing", 1), ("getting there", 1)]),
                   ("saw", 3, [("notice", 3), ("spot", 3), ("seen", 3), ("spotted", 3), ("view", 3), ("observe",
                   3), ("regard", 3)]),
                   ("tall", 1, [("lofty", 1), ("high", 1), ("towering", 1)]),
                   ("man", 2, [("guy", 2), ("male", 2), ("gentleman", 2), ("bloke", 2), ("dude", 2), ("lad", 2),
                   ("fellow", 2), ("fella", 2), ("gent", 2), ("chap", 2), ("person", 2)]),
                   ("talking", 1, [("speak", 1), ("spoke", 1), ("chat", 1), ("chatter", 1), ("chatting", 1)])]
```

("tourists", 2, [("traveller", 2), ("traveler", 2), ("visitor", 2), ("sightseer", 2), ("tripper", 2)]),
 ("asked", 1, [("request", 1), ("question", 1)]),
 ("take", 1, [("grab", 1), ("get", 1), ("catch", 1), ("capture", 1), ("took", 1), ("shoot", 1)]),
 ("photo", 2, [("pic", 2), ("photos", 2), ("snap", 2), ("photograph", 2), ("selfie", 2), ("image", 2)]),
 ("quickly", 1, [("rapidly", 1), ("swiftly", 1), ("fast", 1), ("quick", 1), ("promptly", 1), ("immediately", 1), ("hastily", 1), ("soon", 1)]),
 ("prospective", 1, [("potential", 1), ("future", 1), ("possible", 1)]),
 ("date", 1, [("boyfriend", 1), ("lover", 1), ("man", 1), ("fellow", 1), ("beau", 1), ("admirer", 1), ("wooer", 1)]),
 ("chris", 1, []),
 ("wearing", 1, [("attire", 1), ("apparel", 1)]),
 ("different", 1, [("distinct", 1)]),
 ("jacket", 1, [("vest", 1), ("garment", 1), ("attire", 1)]),
 ("originally", 1, [("initially", 1), ("primarily", 1), ("to start with", 1), ("at first", 1)]),
 ("profile", 1, [("site", 1)]),
 ("went", 1, [("proceeded", 1), ("go", 1), ("departed", 1), ("walked", 1), ("travelled", 1)]),
 ("coffee", 1, [("drink", 1)]),
 ("talked", 1, [("spoke", 1), ("chatted", 1), ("chat", 1), ("conversed", 1), ("discuss", 1)]),
 ("politics", 1, []),
 ("vote", 1, []),
 ("next", 1, [("following", 1), ("ensuing", 1), ("second", 1), ("coming", 1), ("subsequent", 1)]),
 ("election", 1, [("nomination", 1), ("choice", 1), ("selection", 1), ("decision", 1)]),
 ("later", 1, [("after", 1), ("afterward", 1), ("thereafter", 1), ("subsequently", 1), ("next", 1), ("then", 1)]),
 ("on", 1, []),
 ("gift", 1, [("present", 1)]),
 ("shop", 1, [("store", 1), ("market", 1)]),
 ("bought", 1, [("spend", 1), ("brought", 1), ("buy", 1), ("purchase", 1), ("obtain", 1)]),
 ("book", 1, [("volume", 1), ("bunch", 1), ("assortment", 1), ("lot", 1), ("package", 1), ("cluster", 1)]),
 ("stamps", 1, []),
 ("postcards", 1, [("card", 1), ("mail", 1)]),
 ("write", 1, [("pen", 1), ("author", 1), ("compose", 1)]),
 ("top", 1, [("complete", 1), ("finish", 1), ("finalise", 1), ("polish", 1)]),
 ("day", 1, [("time", 1)]),
 ("walked", 1, [("stroll", 1), ("wander", 1), ("went", 1)]),
 ("geology", 1, []),
 ("exhibit", 1, [("display", 1), ("exhibition", 1)]),
 ("floor", 1, [])

last_sentence_words = [("samantha", 1, [])]

```

("eventually", 1, [("finally", 1), ("ultimately", 1), ("ultimate", 1), ("soon", 1)]),
("made", 1, [("gave", 1), ("offered", 1), ("present", 1), ("offer", 1)]),
("excuses", 1, [("justification", 1), ("justify", 1), ("reason", 1), ("explain", 1)]),
("left", 1, [("leave", 1), ("deserted", 1), ("went", 1)]),
("catching", 1, [("got", 1), ("caught", 1), ("took", 1), ("take", 1), ("get", 1)]),
("train", 1, [("locomotive", 1)]),
("back", 1, []),
("home", 1, [("house", 1), ("abode", 1), ("residence", 1), ("dwelling", 1), ("apartment",
1), ("cottage", 1), ("habitation", 1)])]

```

```

# Convert list of words to formatted string

```

```

first_sentence_words_str = []
for word_info in first_sentence_words:
    word = word_info[0]
    max_count = word_info[1]
    synonyms = ','.join([syn[0] for syn in word_info[2]])
    first_sentence_words_str.append(f'{word}\t{synonyms}\t{max_count}')

```

```

main_body_words_str = []
for word_info in main_body_words:
    word = word_info[0]
    max_count = word_info[1]
    synonyms = ','.join([syn[0] for syn in word_info[2]])
    main_body_words_str.append(f'{word}\t{synonyms}\t{max_count}')

```

```

last_sentence_words_str = []
for word_info in last_sentence_words:
    word = word_info[0]
    max_count = word_info[1]
    synonyms = ','.join([syn[0] for syn in word_info[2]])
    last_sentence_words_str.append(f'{word}\t{synonyms}\t{max_count}')

```

```

first_sentence_words_str = '\n'.join(first_sentence_words_str)
main_body_words_str = '\n'.join(main_body_words_str)
last_sentence_words_str = '\n'.join(last_sentence_words_str)

```

```

# Create input widgets

```

```

first_sentence_input = widgets.Textarea(value="", description='First sentence:')
first_sentence_word_input = widgets.Textarea(value=first_sentence_words_str,
description='Target words:')
main_body_input = widgets.Textarea(value="", description='Main body:')

```

```

main_body_word_input = widgets.Textarea(value=main_body_words_str,
description='Target words:')
last_sentence_input = widgets.Textarea(value="", description='Last sentence:')
last_sentence_word_input = widgets.Textarea(value=last_sentence_words_str,
description='Target words:')
display(first_sentence_input, first_sentence_word_input, main_body_input,
main_body_word_input, last_sentence_input, last_sentence_word_input)

# Define a button to run the analysis
button = widgets.Button(description='Analyze')
output = widgets.Output()
display(button, output)

def analyze_text(b):
    output.clear_output() # Clear the output before each run
    total_count = [0, 0, 0] # Count for first_sentence, main_body, last_sentence
    with output:
        # Get input values
        text_inputs = [first_sentence_input.value.lower(), main_body_input.value.lower(),
last_sentence_input.value.lower()]
        word_inputs = [first_sentence_word_input.value.split('\n'),
main_body_word_input.value.split('\n'), last_sentence_word_input.value.split('\n')]

        for i, (text_input, word_input) in enumerate(zip(text_inputs, word_inputs)):
            current_text = text_input
            # Parse target words and synonyms from input
            set1 = []
            for line in word_input:
                word_parts = line.split('\t')
                if len(word_parts) == 3:
                    word = word_parts[0].strip()
                    if not word: # skip if word is an empty string
                        continue
                    max_count = int(word_parts[2].strip())
                    synonyms = [(syn, 1) for syn in word_parts[1].split(',') if syn] # ensure synonym
is not an empty string
                    set1.append((word, max_count, synonyms))

            set1_count = 0
            counted_words = defaultdict(int)
            counted_synonyms = set()

            for word_info in set1:
                current_word = word_info[0]

```

```

max_count = word_info[1]
count_word = len(re.findall(f'\\b{current_word}\\b', current_text))
count_word = min(count_word, max_count)
if count_word > 0:
    counted_words[current_word] = count_word
    set1_count += count_word
    current_text = re.sub(f'\\b{current_word}\\b', '\033[31m' + current_word +
'\033[0m', current_text)

    if current_word not in counted_synonyms:
        for synonym, _ in word_info[2]:
            count_syn = len(re.findall(f'\\b{synonym.strip()}\\b', current_text))
            count_syn = min(count_syn, max_count - count_word)
            if count_syn > 0:
                counted_words[synonym.strip()] = count_syn
                counted_synonyms.add(current_word)
                set1_count += count_syn
                current_text = re.sub(f'\\b{synonym.strip()}\\b', '\033[31m' +
synonym.strip() + '\033[0m', current_text)
                break

print(current_text)
print("Set 1 Count: " + str(set1_count))
total_count[i] += set1_count # Add to total count
for word, count in counted_words.items():
    print(f'Word/Synonym "{word}" (from "{next(w[0] for w in set1 if word in [w[0]]
+ [syn[0] for syn in w[2]])}" was found {count} time(s)')

print(f'First sentence total count: {total_count[0]}')
print(f'Main body total count: {total_count[1]}')
print(f'Last sentence total count: {total_count[2]}')

button.on_click(analyze_text)

```

The Dental Exam

```
from collections import defaultdict
import re
from IPython.display import display
from ipywidgets import widgets

# Pre-defined target words for each section
first_sentence_words = [
    ("robert", 1, [("he", 1), ("him", 1), ("the man", 1), ("the trainee", 1), ("this individual", 1),
    ("the would-be dentist", 1), ("this young man", 1), ("this person", 1), ("our protagonist", 1),
    ("the student", 1)]),
    ("trainee", 1, [("apprentice", 1), ("intern", 1), ("learner", 1), ("novice", 1), ("pupil", 1),
    ("student", 1), ("probationer", 1), ("cadet", 1), ("recruit", 1), ("practitioner", 1)]),
    ("dentist", 1, [("dental surgeon", 1), ("dentistry", 1), ("orthodontist", 1), ("periodontist", 1),
    ("endodontist", 1), ("prosthodontist", 1), ("dental specialist", 1), ("dental practitioner", 1),
    ("oral health provider", 1), ("tooth doctor", 1), ("stomatologist", 1)]),
    ("school", 1, [("institution", 1), ("academy", 1), ("educational establishment", 1),
    ("institute", 1), ("college", 1), ("centre of learning", 1), ("faculty", 1), ("place of education",
    1), ("learning institution", 1), ("seminary", 1)]),
    ("clinical", 1, [("practical", 1), ("therapeutic", 1), ("medical", 1), ("health-related", 1),
    ("applied", 1), ("healing", 1), ("remedial", 1), ("curative", 1), ("treatable", 1), ("diagnostic",
    1)]),
    ("medicine", 1, [("healthcare", 1), ("medical science", 1), ("therapeutics", 1), ("healing", 1),
    ("medical treatment", 1), ("health science", 1), ("physic", 1), ("remedial treatment", 1),
    ("health care practice", 1), ("cure", 1)]),
    ("edinburgh", 1, [("the capital", 1), ("scottish city", 1), ("the location", 1), ("this place", 1),
    ("the capital of Scotland", 1), ("this city", 1), ("this locale", 1), ("this town", 1), ("this
    metropolis", 1)])
]

main_body_words = [("last", 1, [("final", 1), ("end", 1), ("concluding", 1), ("ultimate", 1),
    ("closing", 1), ("terminal", 1), ("finishing", 1)]),
    ("phase", 1, [("stage", 1), ("step", 1), ("period", 1), ("point", 1), ("chapter", 1),
    ("segment", 1), ("part", 1), ("level", 1), ("juncture", 1), ("portion", 1)]),
    ("training", 1, [("instruction", 1), ("trained", 1), ("trains", 1), ("train", 1), ("education",
    1), ("coaching", 1), ("tutoring", 1), ("teaching", 1), ("schooling", 1), ("guidance", 1),
    ("lessons", 1)]),
    ("perform", 1, [("carry out", 1), ("execute", 1), ("conduct", 1), ("accomplish", 1),
    ("undertake", 1), ("fulfill", 1), ("complete", 1), ("implement", 1), ("administer", 1), ("deliver",
    1)])
```

("supervised", 1, [("monitored", 1), ("overseen", 1), ("watched", 1), ("controlled", 1),
 ("guided", 1), ("managed", 1), ("directed", 1), ("superintended", 1), ("inspected", 1),
 ("checked", 1)]),
 ("dental", 1, [("oral", 1), ("tooth-related", 1), ("mouth-related", 1), ("dentistry", 1),
 ("periodontal", 1), ("odontological", 1), ("orthodontic", 1), ("stomatological", 1),
 ("endodontic", 1), ("prosthodontic", 1)]),
 ("operation", 1, [("procedure", 1), ("surgery", 1), ("intervention", 1), ("process", 1),
 ("action", 1), ("activity", 1), ("treatment", 1), ("task", 1), ("work", 1), ("function", 1)]),
 ("one", 1, [("single", 1), ("sole", 1), ("lone", 1), ("unique", 1), ("individual", 1),
 ("particular", 1), ("exclusive", 1), ("first", 1), ("initial", 1)]),
 ("ever", 2, [("always", 2), ("at any time", 2), ("at all times", 2), ("forever", 2),
 ("continually", 2), ("constantly", 2), ("invariably", 2), ("perpetually", 2), ("eternally", 2),
 ("endlessly", 2)]),
 ("live", 1, [("real", 1), ("actual", 1), ("living", 1), ("breathing", 1), ("current", 1),
 ("existing", 1), ("flesh-and-blood", 1), ("human", 1), ("in-person", 1), ("present", 1)]),
 ("patient", 1, [("client", 1), ("patient's", 1), ("recipient", 1), ("subject", 1), ("sufferer", 1),
 ("case", 1), ("individual", 1), ("victim", 1), ("customer", 1), ("sick person", 1), ("in-patient",
 1)]),
 ("robert", 3, [("robert's", 3)]),
 ("preparing", 1, [("planning", 1), ("practicing", 1), ("readying", 1), ("setting up", 1),
 ("organizing", 1), ("getting ready", 1), ("gearing up", 1), ("training", 1), ("studying", 1),
 ("arranging", 1), ("bracing", 1)]),
 ("months", 1, [("weeks", 1), ("days", 1), ("a while", 1), ("long period", 1), ("extended
 time", 1), ("good while", 1), ("some time", 1), ("period", 1), ("lengthy interval", 1), ("time
 span", 1)]),
 ("exam", 2, [("test", 1), ("evaluation", 1), ("assessment", 1), ("examination", 1),
 ("inspection", 1), ("checkup", 1), ("analysis", 1), ("review", 1), ("quiz", 1), ("appraisal", 1)]),
 ("things", 1, [("events", 1), ("matters", 1), ("situations", 1), ("circumstances", 1),
 ("developments", 1), ("issues", 1), ("problems", 1), ("scenarios", 1), ("cases", 1), ("affairs",
 1)]),
 ("started", 1, [("began", 1), ("initiated", 1), ("commenced", 1), ("embarked", 1),
 ("launched", 1), ("opened", 1), ("got underway", 1), ("kicked off", 1), ("set in motion", 1),
 ("got going", 1)]),
 ("wrong", 1, [("incorrect", 1), ("mistaken", 1), ("inappropriate", 1), ("unfortunate", 1),
 ("bad", 1), ("awry", 1)]),
 ("immediately", 1, [("instantly", 1), ("immediate", 1), ("beginning", 1), ("right away",
 1), ("directly", 1), ("promptly", 1), ("swiftly", 1), ("straight away", 1), ("quickly", 1), ("at-
 once", 1), ("without-delay", 1), ("instantaneously", 1)]),
 ("drill", 2, [("tool", 1), ("implement", 1), ("instrument", 1), ("machine", 1), ("dental
 drill", 1), ("apparatus", 1), ("device", 1), ("piece of equipment", 1), ("handpiece", 1),
 ("mechanism", 1)]),
 ("slipped", 1, [("skidded", 1), ("slips", 1), ("slip", 1), ("slipping", 1), ("slid", 1),
 ("glided", 1), ("moved", 1), ("shifted", 1), ("slithered", 1), ("swept", 1), ("lost control", 1),
 ("misstepped", 1), ("slid unintentionally", 1)]),

("pierced", 1, [("punctured", 1), ("pierces", 1), ("piercing", 1), ("pierce", 1),
 ("penetrated", 1), ("perforated", 1), ("stabbed", 1), ("made a hole in", 1), ("went through", 1),
 ("cut through", 1), ("broke through", 1), ("poked", 1), ("wounded", 1)]),
 ("patients", 1, [("clients", 1), ("patient's", 1), ("patient", 1), ("subjects", 1),
 ("individuals", 1), ("sufferers", 1), ("cases", 1), ("victims", 1), ("recipients", 1), ("womans",
 1), ("her", 1), ("persons", 1)]),
 ("cheek", 1, [("face", 1), ("facial feature", 1), ("visage", 1), ("aspect", 1), ("side of face",
 1), ("flesh", 1), ("jowl", 1), ("side", 1), ("surface", 1), ("part of face", 1)]),
 ("stem", 1, [("stop", 1), ("stemming", 1), ("stems", 1), ("halt", 1), ("stanch", 1),
 ("check", 1), ("arrest", 1), ("curb", 1), ("cut off", 1), ("hinder", 1), ("hold back", 1), ("thwart",
 1)]),
 ("blood", 2, [("hemorrhage", 2), ("bleeding", 2), ("life fluid", 2), ("red fluid", 2),
 ("plasma", 2), ("vital-fluid", 2), ("gore", 2), ("lifeblood", 2), ("blood flow", 2)]),
 ("grabbed", 1, [("seized", 1), ("grabs", 1), ("grab", 1), ("snatched", 1), ("clutched", 1),
 ("grasped", 1), ("took", 1), ("caught", 1), ("captured", 1), ("nabbed", 1), ("gained", 1),
 ("snared", 1)]),
 ("towel", 1, [("cloth", 1), ("rag", 1), ("linen", 1), ("napkin", 1), ("wiper", 1), ("swab", 1),
 ("hand towel", 1), ("piece of fabric", 1)]),
 ("nearby", 1, [("close", 1), ("near", 1), ("adjacent", 1), ("neighbouring", 1),
 ("proximate", 1), ("around", 1), ("near at hand", 1), ("close by", 1), ("in close proximity", 1),
 ("accessible", 1), ("at hand", 1)]),
 ("rack", 1, [("shelf", 1), ("stand", 1), ("holder", 1), ("frame", 1), ("structure", 1),
 ("hook", 1), ("rest", 1), ("bracket", 1), ("support", 1), ("fixture", 1)]),
 ("only", 2, [("merely", 2), ("just", 2), ("solely", 2), ("purely", 2), ("simply", 2), ("alone",
 2), ("barely", 2), ("exclusively", 2), ("singularly", 2)]),
 ("served", 1, [("worked", 1), ("serve", 1), ("serves", 1), ("serving", 1), ("functioned", 1),
 ("acted", 1), ("proved", 1), ("was useful", 1), ("fulfilled", 1), ("sufficed", 1), ("operated", 1),
 ("benefited", 1), ("played-a-role", 1)]),
 ("muffle", 1, [("dampen", 1), ("muffles", 1), ("muffling", 1), ("muffled", 1), ("deaden",
 1), ("stifle", 1), ("suppress", 1), ("smother", 1), ("quiet", 1), ("dim", 1), ("hush", 1), ("soften",
 1), ("reduce", 1)]),
 ("womans", 1, [("females", 1), ("woman's", 1), ("ladys", 1), ("her", 1), ("patients", 1),
 ("individuals", 1), ("subjects", 1), ("persons", 1), ("victims", 1), ("sufferers", 1), ("recipients",
 1)]),
 ("desperate", 1, [("urgent", 1), ("frantic", 1), ("panicked", 1), ("frightened", 1),
 ("fearful", 1), ("distressed", 1), ("terrified", 1), ("alarmed", 1), ("hysterical", 1), ("wild", 1)]),
 ("screams", 1, [("shriek", 1), ("screaming", 1), ("scream", 1), ("cry", 1), ("yelp", 1),
 ("screech", 1), ("wail", 1), ("yell", 1), ("howl", 1), ("squawk", 1), ("holler", 1), ("bellow",
 1)]),
 ("clearly", 1, [("evidently", 1), ("clear", 1), ("obviously", 1), ("unmistakably", 1),
 ("manifestly", 1), ("plainly", 1), ("undoubtedly", 1), ("indubitably", 1), ("patently", 1),
 ("conspicuously", 1), ("noticeably", 1)]),

("choking", 1, [("gagging", 1), ("choked", 1), ("choke", 1), ("suffocating", 1),
 ("struggling for breath", 1), ("gasping", 1), ("asphyxiating", 1), ("wheezing", 1), ("coughing",
 1), ("strangling", 1), ("panting", 1), ("fighting for air", 1)]),
 ("own", 1, [("personal", 1), ("individual", 1), ("private", 1), ("self", 1), ("herself", 1),
 ("her own", 1), ("autonomous", 1), ("hers", 1), ("distinct", 1), ("particular", 1)]),
 ("panicking", 1, [("freaking out", 1), ("becoming hysterical", 1), ("overreacting", 1),
 ("losing control", 1), ("getting flustered", 1), ("becoming frantic", 1), ("getting panicked", 1),
 ("feeling terror", 1), ("losing composure", 1), ("experiencing anxiety", 1)]),
 ("tried", 1, [("attempted", 1), ("endeavored", 1), ("strived", 1), ("worked", 1),
 ("struggled", 1), ("aims", 1), ("sought", 1), ("made an effort", 1), ("pushed", 1), ("gave it a
 shot", 1)]),
 ("extract", 1, [("remove", 1), ("pull out", 1), ("withdraw", 1), ("take out", 1), ("dislodge",
 1), ("retrieve", 1), ("get out", 1), ("eject", 1), ("expel", 1), ("derive", 1)]),
 ("piece", 1, [("part", 1), ("portion", 1), ("section", 1), ("segment", 1), ("fraction", 1),
 ("element", 1), ("component", 1), ("bit", 1), ("chunk", 1), ("slice", 1)]),
 ("smooth", 1, [("steady", 1), ("fluent", 1), ("fluid", 1), ("seamless", 1), ("graceful", 1),
 ("effortless", 1), ("easy", 1), ("unbroken", 1), ("uninterrupted", 1), ("continuous", 1)]),
 ("motion", 1, [("movement", 1), ("action", 1), ("gesture", 1), ("move", 1), ("act", 1),
 ("progress", 1), ("shift", 1), ("step", 1), ("manoeuvre", 1), ("transition", 1)]),
 ("however", 1, [("nonetheless", 1), ("nevertheless", 1), ("yet", 1), ("still", 1), ("but", 1),
 ("despite that", 1), ("even so", 1), ("on the other hand", 1), ("although", 1),
 ("notwithstanding", 1)]),
 ("brought", 1, [("carried", 1), ("transported", 1), ("delivered", 1), ("moved", 1), ("bore",
 1), ("transferred", 1), ("conveyed", 1), ("hailed", 1), ("toted", 1), ("lugged", 1)]),
 ("chunk", 1, [("piece", 1), ("lump", 1), ("block", 1), ("slab", 1), ("portion", 1), ("hunk",
 1), ("slice", 1), ("section", 1), ("bit", 1), ("part", 1)]),
 ("flesh", 1, [("skin", 1), ("tissue", 1), ("meat", 1), ("muscle", 1), ("body", 1), ("fat", 1),
 ("soft part", 1), ("human tissue", 1), ("corporeal part", 1), ("physical structure", 1)]),
 ("tears", 1, [("weeps", 1), ("cries", 1), ("sobbing", 1), ("waterworks", 1), ("teardrops",
 1), ("crying", 1), ("sobs", 1), ("weeping", 1), ("lamentations", 1), ("bawling", 1)]),
 ("cried", 1, [("wept", 1), ("cry", 1), ("sobbed", 1), ("wailed", 1), ("shouted", 1), ("yelled",
 1), ("screamed", 1), ("hollered", 1), ("called out", 1), ("bawled", 1), ("yowled", 1)]),
 ("help", 1, [("assistance", 1), ("aid", 1), ("support", 1), ("relief", 1), ("rescue", 1),
 ("intervention", 1), ("helpfulness", 1), ("cooperation", 1), ("help hand", 1), ("collaboration",
 1)]),
 ("examiner", 1, [("inspector", 1), ("supervisor", 1), ("monitor", 1), ("evaluator", 1),
 ("checker", 1), ("assessor", 1), ("investigator", 1), ("observer", 1), ("reviewer", 1), ("analyst",
 1)]),
 ("quickly", 1, [("swiftly", 1), ("speedily", 1), ("rapidly", 1), ("promptly", 1), ("hastily",
 1), ("instantly", 1), ("fast", 1), ("briskly", 1), ("hurriedly", 1), ("speedily", 1)]),
 ("took", 1, [("took over", 1), ("handled", 1), ("take over", 1)]),
 ("fail", 1, [("lose", 1), ("failed", 1), ("flop", 1), ("flunk", 1), ("bomb", 1), ("miss", 1),
 ("fail to pass", 1), ("not succeed", 1), ("be unsuccessful", 1), ("fall short", 1), ("fail to meet",
 1)]),

("fastest", 1, [("quickest", 1), ("shortest", 1), ("speediest", 1), ("most rapid", 1), ("brisk", 1), ("swiftest", 1), ("most expeditious", 1), ("fleeting", 1), ("lightning", 1), ("fast-track", 1), ("zippy", 1)]),
 ("time", 1, [("moment", 1), ("period", 1), ("duration", 1), ("interval", 1), ("instant", 1), ("junction", 1), ("phase", 1), ("spell", 1), ("stretch", 1), ("epoch", 1)]),
 ("recorded", 1, [("documented", 1), ("registered", 1), ("noted", 1), ("logged", 1), ("marked", 1), ("charted", 1), ("filed", 1), ("jotted", 1), ("tracked", 1), ("indexed", 1)]),
 ("school", 1, [("institution", 1), ("academy", 1), ("college", 1), ("seminary", 1), ("institute", 1), ("educational establishment", 1), ("training center", 1), ("conservatory", 1), ("prep school", 1), ("campus", 1)]),
 ("clinical", 1, [("medical", 1), ("health-related", 1), ("therapeutic", 1), ("healing", 1), ("remedial", 1), ("curative", 1), ("hospital", 1), ("doctoral", 1), ("surgical", 1), ("patient", 1)]),
 ("medicine", 1, [("healthcare", 1), ("medical science", 1), ("health science", 1), ("pharmacology", 1), ("therapeutics", 1), ("cure", 1), ("remedies", 1), ("healing art", 1), ("medical practice", 1), ("medical studies", 1)])]

last_sentence_words = [("later", 1, [("afterwards", 1), ("subsequently", 1), ("thereafter", 1), ("eventually", 1), ("following", 1), ("after", 1), ("next", 1), ("in time", 1), ("down the line", 1), ("at a later date", 1)]),
 ("tell", 1, [("inform", 1), ("told", 1), ("narrate", 1), ("recount", 1), ("relay", 1), ("describe", 1), ("reveal", 1), ("chronicle", 1), ("report", 1), ("divulge", 1), ("detail", 1)]),
 ("friends", 1, [("pals", 1), ("buddies", 1), ("comrades", 1), ("associates", 1), ("mates", 1), ("companions", 1), ("cohorts", 1), ("chums", 1), ("acquaintances", 1), ("cronies", 1)]),
 ("story", 1, [("tale", 1), ("narrative", 1), ("account", 1), ("saga", 1), ("chronicle", 1), ("anecdote", 1), ("yarn", 1), ("record", 1), ("report", 1), ("legend", 1)]),
 ("pub", 1, [("tavern", 1), ("pubs", 1), ("bar", 1), ("inn", 1), ("alehouse", 1), ("saloon", 1), ("bistro", 1), ("taproom", 1), ("lounge", 1), ("public house", 1), ("brewpub", 1)]),
 ("skimping", 1, [("scrimping", 1), ("sparing", 1), ("saving", 1), ("economizing", 1), ("being frugal", 1), ("being sparing", 1), ("holding back", 1), ("restricting", 1), ("being economical", 1), ("pinching pennies", 1)]),
 ("details", 1, [("particulars", 1), ("specifics", 1), ("facts", 1), ("points", 1), ("features", 1), ("elements", 1), ("aspects", 1), ("components", 1), ("data", 1), ("information", 1)])]

Convert list of words to formatted string

first_sentence_words_str = []

for word_info in first_sentence_words:

word = word_info[0]

max_count = word_info[1]

synonyms = ', '.join([syn[0] for syn in word_info[2]])

first_sentence_words_str.append(f'{word}\t{synonyms}\t{max_count}')

```

main_body_words_str = []
for word_info in main_body_words:
    word = word_info[0]
    max_count = word_info[1]
    synonyms = ','.join([syn[0] for syn in word_info[2]])
    main_body_words_str.append(f'{word}\t{synonyms}\t{max_count}')

last_sentence_words_str = []
for word_info in last_sentence_words:
    word = word_info[0]
    max_count = word_info[1]
    synonyms = ','.join([syn[0] for syn in word_info[2]])
    last_sentence_words_str.append(f'{word}\t{synonyms}\t{max_count}')

first_sentence_words_str = '\n'.join(first_sentence_words_str)
main_body_words_str = '\n'.join(main_body_words_str)
last_sentence_words_str = '\n'.join(last_sentence_words_str)

# Create input widgets
first_sentence_input = widgets.Textarea(value="", description='First sentence:')
first_sentence_word_input = widgets.Textarea(value=first_sentence_words_str,
description='Target words:')
main_body_input = widgets.Textarea(value="", description='Main body:')
main_body_word_input = widgets.Textarea(value=main_body_words_str,
description='Target words:')
last_sentence_input = widgets.Textarea(value="", description='Last sentence:')
last_sentence_word_input = widgets.Textarea(value=last_sentence_words_str,
description='Target words:')
display(first_sentence_input, first_sentence_word_input, main_body_input,
main_body_word_input, last_sentence_input, last_sentence_word_input)

# Define a button to run the analysis
button = widgets.Button(description='Analyze')
output = widgets.Output()
display(button, output)

def analyze_text(b):
    output.clear_output() # Clear the output before each run
    total_count = [0, 0, 0] # Count for first_sentence, main_body, last_sentence
    with output:
        # Get input values
        text_inputs = [first_sentence_input.value.lower(), main_body_input.value.lower(),
last_sentence_input.value.lower()]

```

```

word_inputs = [first_sentence_word_input.value.split('\n'),
main_body_word_input.value.split('\n'), last_sentence_word_input.value.split('\n')]

for i, (text_input, word_input) in enumerate(zip(text_inputs, word_inputs)):
    current_text = text_input
    # Parse target words and synonyms from input
    set1 = []
    for line in word_input:
        word_parts = line.split('\t')
        if len(word_parts) == 3:
            word = word_parts[0].strip()
            if not word: # skip if word is an empty string
                continue
            max_count = int(word_parts[2].strip())
            synonyms = [(syn, 1) for syn in word_parts[1].split(',') if syn] # ensure synonym
is not an empty string
            set1.append((word, max_count, synonyms))

    set1_count = 0
    counted_words = defaultdict(int)
    counted_synonyms = set()

    for word_info in set1:
        current_word = word_info[0]
        max_count = word_info[1]
        count_word = len(re.findall(f'\\b{current_word}\\b', current_text))
        count_word = min(count_word, max_count)
        if count_word > 0:
            counted_words[current_word] = count_word
            set1_count += count_word
            current_text = re.sub(f'\\b{current_word}\\b', '\033[31m' + current_word +
'\033[0m', current_text)

            if current_word not in counted_synonyms:
                for synonym, _ in word_info[2]:
                    count_syn = len(re.findall(f'\\b{synonym.strip()}\\b', current_text))
                    count_syn = min(count_syn, max_count - count_word)
                    if count_syn > 0:
                        counted_words[synonym.strip()] = count_syn
                        counted_synonyms.add(current_word)
                        set1_count += count_syn
                        current_text = re.sub(f'\\b{synonym.strip()}\\b', '\033[31m' +
synonym.strip() + '\033[0m', current_text)
                        break

```

```

print(current_text)
print("Set 1 Count: " + str(set1_count))
total_count[i] += set1_count # Add to total count
for word, count in counted_words.items():
    print(f'Word/Synonym "{word}" (from "{next(w[0] for w in set1 if word in [w[0]]
+ [syn[0] for syn in w[2]])}") was found {count} time(s)')

print(f'First sentence total count: {total_count[0]}')
print(f'Main body total count: {total_count[1]}')
print(f'Last sentence total count: {total_count[2]}')

button.on_click(analyze_text)

```

The Hospital Visit

```
from collections import defaultdict
import re
from IPython.display import display
from ipywidgets import widgets

# Pre-defined target words for each section
first_sentence_words = [("mother", 1, [("mom", 1), ("mum", 1), ("parent", 1), ("mammy", 1),
("mam", 1), ("mommy", 1), ("mama", 1), ("ma", 1)]),
    ("son", 1, [("boy", 1), ("son's", 1), ("offspring", 1), ("child", 1), ("dependent", 1),
("junior", 1)]),
    ("leaving", 1, [("go", 1), ("goes", 1), ("leave", 1), ("leaves", 1)]),
    ("home", 1, [("house", 1), ("residence", 1), ("abode", 1), ("dwelling", 1), ("lodging", 1),
("place", 1)]),
    ("morning", 1, [("morn", 1), ("early", 1), ("daybreak", 1), ("dawn", 1)])]

main_body_words = [("taking", 1, [("take", 1), ("took", 1), ("takes", 1)]),
    ("visit", 1, [("see", 1), ("visits", 1), ("sees", 1)]),
    ("father", 2, [("dad", 2), ("dad's", 1), ("father's", 1), ("daddy", 2), ("pa", 2), ("papa", 2),
("poppa", 2), ("parent", 2)]),
    ("workplace", 1, [("factory", 1), ("studio", 1), ("workshop", 1), ("plant", 1), ("works", 1),
("workroom", 1), ("work", 1), ("shop", 1)]),
    ("morning", 1, [("morn", 1), ("early", 1), ("daybreak", 1), ("dawn", 1)]),
    ("laboratory", 1, [("laboratory", 1)]),
    ("victoria", 1, [("victoria", 1)]),
    ("memorial", 1, [("memorial", 1)]),
    ("technician", 1, [("specialist", 1), ("consultant", 1), ("professional", 1), ("expert", 1),
("operator", 1)]),
    ("check", 1, [("glance", 1), ("look", 1), ("checks", 1), ("peek", 1), ("glimpse", 1),
("inspect", 1), ("audit", 1), ("examine", 1), ("survey", 1), ("scan", 1), ("scrutinise", 1)]),
    ("crossing", 1, [("traverse", 1), ("navigate", 1), ("walk", 1), ("travel", 1)]),
    ("busy", 1, [("buzzing", 1), ("vibrant", 1), ("crowded", 1), ("thriving", 1), ("humming",
1), ("lively", 1)]),
    ("road", 1, [("highway", 1), ("roads", 1), ("streets", 1), ("street", 1), ("throughfare", 1),
("freeway", 1), ("expressway", 1), ("route", 1), ("roadway", 1), ("boulevard", 1)]),
    ("walking", 1, [("treading", 1), ("walk", 1), ("strolling", 1), ("stepping", 1),
("wandering", 1), ("marching", 1), ("sauntering", 1)]),
    ("along", 1, [("forward", 1), ("onward", 1), ("forth", 1)]),
    ("receives", 1, [("get", 1), ("gets", 1), ("recieve", 1), ("obtain", 1), ("gain", 1), ("acquire",
1), ("came by", 1)]),
    ("phone", 3, [("dial", 3), ("telephone", 3), ("call", 3)]),
    ("call", 2, [("dial", 2), ("phone", 2)])]
```

("say", 1, [("tell", 1), ("saying", 1), ("telling", 1), ("inform", 1), ("informs", 1),
 ("informing", 1), ("stating", 1), ("express", 1), ("state", 1), ("put", 1), ("describe", 1),
 ("mention", 1)]),
 ("sister", 1, [("sibling", 1), ("sisters", 1)]),
 ("given", 1, [("given", 1), ("gave", 1)]),
 ("birth", 1, [("labour", 1), ("labor", 1), ("deliver", 1), ("produce", 1), ("bore", 1)]),
 ("mother", 3, [("mom", 3), ("mum", 3), ("parent", 3), ("mammy", 3), ("mam", 3),
 ("mommy", 3), ("mama", 3), ("ma", 3)]),
 ("excitedly", 1, [("eager", 1), ("elated", 1), ("eagerly", 1), ("excited", 1), ("interested", 1),
 ("enthusiastic", 1), ("keen", 1), ("anxious", 1)]),
 ("told", 1, [("said", 1), ("tells", 1), ("says", 1), ("say", 1), ("state", 1), ("report", 1),
 ("recount", 1), ("describe", 1), ("narrate", 1)]),
 ("son", 1, [("boy", 1), ("offspring", 1), ("child", 1), ("dependent", 1), ("junior", 1)]),
 ("new", 1, [("novel", 1), ("fresh", 1), ("original", 1), ("newborn", 1)]),
 ("baby", 3, [("child", 3), ("infant", 3), ("newborn", 3), ("kid", 3), ("babe", 3), ("neonate",
 3), ("girl", 3)]),
 ("cousin", 2, [("relative", 2), ("family", 2), ("relation", 2), ("relative", 2), ("kin", 2)]),
 ("called", 1, [("dubbed", 1), ("named", 1), ("termed", 1), ("labelled", 1), ("nicknamed",
 1), ("titled", 1)]),
 ("sophie", 1, [("sophie", 1), ("soph", 1)]),
 ("hospital", 2, [("clinic", 2), ("infirmary", 2), ("medical center", 2), ("medical centre",
 2)]),
 ("boy", 2, [("kid", 2), ("lad", 2), ("teenager", 2), ("adolescent", 2)]),
 ("rushes", 1, [("hurries", 1), ("hurry", 1), ("scurry", 1), ("scurries", 1), ("trot", 1),
 ("speed", 1), ("sped", 1), ("travel", 1), ("drives", 1), ("flies", 1), ("chase", 1), ("race", 1),
 ("jump", 1), ("zip", 1), ("run", 1), ("buzz", 1)]),
 ("auntie", 2, [("aunty", 2), ("anutie's", 2), ("aunty's", 2)]),
 ("bedside", 1, [("bed", 1)]),
 ("hold", 1, [("hold", 1), ("held", 1)]),
 ("time", 1, [("moment", 1), ("occasion", 1), ("minute", 1), ("second", 1)]),
 ("yawned", 1, [("yawn", 1), ("yawns", 1)]),
 ("making", 1, [("make", 1), ("made", 1), ("makes", 1), ("produce", 1), ("create", 1),
 ("producing", 1), ("creating", 1), ("manufacture", 1), ("manufacturing", 1)]),
 ("cute", 1, [("beautiful", 1), ("lovely", 1), ("gorgeous", 1), ("pretty", 1), ("handsome", 1),
 ("charming", 1), ("stunning", 1)]),
 ("babbling", 1, [("babbling", 1), ("babble", 1), ("babbles", 1), ("babbled", 1), ("cooing",
 1)]),
 ("noises", 1, [("noise", 1), ("sound", 1), ("sounds", 1)]),
 ("looked", 1, [("look", 1), ("seem", 1), ("looks", 1), ("looking", 1), ("seems", 1)]),
 ("healthy", 1, [("well", 1), ("robust", 1), ("wholesome", 1), ("strong", 1), ("hale", 1),
 ("sturdy", 1), ("whole", 1), ("fit", 1), ("thriving", 1), ("health", 1)]),
 ("happy", 1, [("pleased", 1), ("delight", 1), ("satisfied", 1), ("satisfy", 1), ("glad", 1),
 ("glee", 1), ("thankful", 1)]),

```

("rosy", 1, [("glow", 1), ("ruddy", 1), ("red", 1), ("tanned", 1), ("warm", 1), ("bright",
1)]),
("ward", 1, [("ward", 1), ("nurses", 1), ("nurse", 1)]),
("staff", 1, [("workforce", 1), ("personnel", 1), ("manpower", 1), ("crew", 1),
("employee", 1), ("worker", 1), ("nurse", 1), ("team", 1)]),
("took", 1, [("got", 1), ("caught", 1), ("snapped", 1)]),
("photograph", 1, [("photo", 1), ("photos", 1), ("picture", 1), ("pictures", 1), ("pic", 1),
("snap", 1), ("snapshot", 1), ("print", 1), ("shot", 1)]),
("smiling", 1, [("laughing", 1), ("giggling", 1), ("chuckling", 1), ("giggle", 1),
("chuckle", 1), ("laugh", 1), ("beam", 1), ("amuse", 1), ("jovial", 1)]),
("duo", 1, [("pair", 1), ("two", 1), ("couple", 1), ("twain", 1), ("twosome", 1)]),
("left", 1, [("went", 1), ("leave", 1), ("leaves", 1), ("go", 1), ("goes", 1), ("depart", 1),
("exit", 1), ("part", 1)]),
("other", 1, [("different", 1), ("diverse", 1)]),
("child", 3, [("kid", 3), ("child's", 3)]),
("preschool", 2, [("pre-school", 2), ("pre school", 2), ("school", 2), ("nursery", 2),
("kindergarten", 2)]),
("morning", 1, [("morn", 1), ("daybreak", 1), ("dawn", 1)]),
("feeling", 1, [("emotion", 1), ("sense", 1)]),
("elated", 1, [("ecstatic", 1), ("giddy", 1), ("thrilled", 1), ("excited", 1), ("delight", 1),
("please", 1)]),
("tell", 1, [("said", 1), ("informs", 1), ("inform", 1), ("say", 1), ("tells", 1), ("says", 1),
("stated", 1), ("report", 1), ("recount", 1), ("describe", 1), ("narrate", 1)]),
("soon", 1, [("shortly", 1), ("momentarily", 1), ("promptly", 1)]),
("pick", 2, [("collect", 2), ("round up", 2), ("gather", 2)])

last_sentence_words = [("pick", 1, [("collect", 1), ("get", 1), ("round up", 1), ("gather", 1)]),
("heading", 1, [("going", 1), ("went", 1), ("lead", 1), ("leaving", 1), ("leaves", 1)]),
("child", 1, [("kid", 1)]),
("hails", 1, [("summon", 1), ("summons", 1), ("grab", 1), ("call", 1), ("grabs", 1),
("calls", 1), ("asks", 1), ("request", 1), ("order", 1), ("beckon", 1)]),
("taxi", 1, [("taxi", 1)]),
("number", 1, [("number", 1)]),
("bus", 1, [("car", 1), ("automobile", 1)]),
("stop", 1, [("stop", 1)])

```

```
# Convert list of words to formatted string
```

```
first_sentence_words_str = []
```

```
for word_info in first_sentence_words:
```

```
    word = word_info[0]
```

```
    max_count = word_info[1]
```

```
    synonyms = ', '.join([syn[0] for syn in word_info[2]])
```

```
    first_sentence_words_str.append(f'{word}\t{synonyms}\t{max_count}')
```



```

main_body_words_str = []
for word_info in main_body_words:
    word = word_info[0]
    max_count = word_info[1]
    synonyms = ','.join([syn[0] for syn in word_info[2]])
    main_body_words_str.append(f'{word}\t{synonyms}\t{max_count}')

last_sentence_words_str = []
for word_info in last_sentence_words:
    word = word_info[0]
    max_count = word_info[1]
    synonyms = ','.join([syn[0] for syn in word_info[2]])
    last_sentence_words_str.append(f'{word}\t{synonyms}\t{max_count}')

first_sentence_words_str = '\n'.join(first_sentence_words_str)
main_body_words_str = '\n'.join(main_body_words_str)
last_sentence_words_str = '\n'.join(last_sentence_words_str)

# Create input widgets
first_sentence_input = widgets.Textarea(value="", description='First sentence:')
first_sentence_word_input = widgets.Textarea(value=first_sentence_words_str,
description='Target words:')
main_body_input = widgets.Textarea(value="", description='Main body:')
main_body_word_input = widgets.Textarea(value=main_body_words_str,
description='Target words:')
last_sentence_input = widgets.Textarea(value="", description='Last sentence:')
last_sentence_word_input = widgets.Textarea(value=last_sentence_words_str,
description='Target words:')
display(first_sentence_input, first_sentence_word_input, main_body_input,
main_body_word_input, last_sentence_input, last_sentence_word_input)

# Define a button to run the analysis
button = widgets.Button(description='Analyze')
output = widgets.Output()
display(button, output)

def analyze_text(b):
    output.clear_output() # Clear the output before each run
    total_count = [0, 0, 0] # Count for first_sentence, main_body, last_sentence
    with output:
        # Get input values
        text_inputs = [first_sentence_input.value.lower(), main_body_input.value.lower(),
last_sentence_input.value.lower()]

```

```

word_inputs = [first_sentence_word_input.value.split('\n'),
main_body_word_input.value.split('\n'), last_sentence_word_input.value.split('\n')]

for i, (text_input, word_input) in enumerate(zip(text_inputs, word_inputs)):
    current_text = text_input
    # Parse target words and synonyms from input
    set1 = []
    for line in word_input:
        word_parts = line.split('\t')
        if len(word_parts) == 3:
            word = word_parts[0].strip()
            if not word: # skip if word is an empty string
                continue
            max_count = int(word_parts[2].strip())
            synonyms = [(syn, 1) for syn in word_parts[1].split(',') if syn] # ensure synonym
is not an empty string
            set1.append((word, max_count, synonyms))

    set1_count = 0
    counted_words = defaultdict(int)
    counted_synonyms = set()

    for word_info in set1:
        current_word = word_info[0]
        max_count = word_info[1]
        count_word = len(re.findall(f'\\b{current_word}\\b', current_text))
        count_word = min(count_word, max_count)
        if count_word > 0:
            counted_words[current_word] = count_word
            set1_count += count_word
            current_text = re.sub(f'\\b{current_word}\\b', '\033[31m' + current_word +
'\033[0m', current_text)

            if current_word not in counted_synonyms:
                for synonym, _ in word_info[2]:
                    count_syn = len(re.findall(f'\\b{synonym.strip()}\\b', current_text))
                    count_syn = min(count_syn, max_count - count_word)
                    if count_syn > 0:
                        counted_words[synonym.strip()] = count_syn
                        counted_synonyms.add(current_word)
                        set1_count += count_syn
                        current_text = re.sub(f'\\b{synonym.strip()}\\b', '\033[31m' +
synonym.strip() + '\033[0m', current_text)
                        break

```

```

print(current_text)
print("Set 1 Count: " + str(set1_count))
total_count[i] += set1_count # Add to total count
for word, count in counted_words.items():
    print(f'Word/Synonym "{word}" (from "{next(w[0] for w in set1 if word in [w[0]]
+ [syn[0] for syn in w[2]])}" was found {count} time(s)')

print(f'First sentence total count: {total_count[0]}')
print(f'Main body total count: {total_count[1]}')
print(f'Last sentence total count: {total_count[2]}')

button.on_click(analyze_text)

```

The Paris Trip

```
from collections import defaultdict
import re
from IPython.display import display
from ipywidgets import widgets

# Pre-defined target words for each section
first_sentence_words = [
    ("bella", 1, [("the woman", 1), ("the traveller", 1), ("the tourist", 1), ("the vacationer", 1),
    ("the worker", 1), ("the guest", 1), ("the friend", 1), ("the visitor", 1), ("the lady", 1), ("the
    globetrotter", 1)]),
    ("earned", 1, [("gained", 1), ("earnt", 1), ("earns", 1), ("receives", 1), ("achieved", 1),
    ("received", 1), ("acquired", 1), ("accumulated", 1), ("gathered", 1), ("obtained", 1),
    ("collected", 1), ("garnered", 1), ("won", 1)]),
    ("holiday", 1, [("vacation", 1), ("break", 1), ("recess", 1), ("leave", 1), ("time off", 1),
    ("respite", 1), ("leisure time", 1), ("getaway", 1), ("sabbatical", 1), ("retreat", 1)]),
    ("allowance", 1, [("quota", 1), ("share", 1), ("allocation", 1), ("portion", 1), ("entitlement",
    1), ("provision", 1), ("grant", 1), ("stipend", 1), ("ration", 1), ("assignment", 1)]),
    ("work", 1, [("job", 1), ("employment", 1), ("occupation", 1), ("profession", 1),
    ("vocation", 1), ("career", 1), ("business", 1), ("trade", 1), ("labour", 1), ("service", 1)]),
    ("books", 1, [("reserves", 1), ("schedules", 1), ("secures", 1), ("arranges", 1), ("confirms",
    1), ("plans", 1), ("sets up", 1), ("organizes", 1), ("registers", 1), ("orders", 1)]),
    ("short", 1, [("brief", 1), ("quick", 1), ("swift", 1), ("speedy", 1), ("rapid", 1), ("fast", 1),
    ("little", 1), ("mini", 1), ("temporary", 1), ("compact", 1)]),
    ("trip", 1, [("journey", 1), ("tour", 1), ("excursion", 1), ("expedition", 1), ("voyage", 1),
    ("jaunt", 1), ("adventure", 1), ("getaway", 1), ("travel", 1), ("visit", 1)]),
    ("paris", 1, [("the french capital", 1), ("the city", 1), ("the city of love", 1), ("the city of
    lights", 1), ("the destination", 1), ("the metropolis", 1), ("the european city", 1), ("the capital",
    1), ("the tourist spot", 1), ("the historical city", 1)])]

main_body_words = [
```

("landing", 1, [("arriving", 1), ("arrived", 1), ("arrive", 1), ("arrives", 1), ("touching down", 1), ("settling", 1), ("alighting", 1), ("descending", 1), ("dismounting", 1), ("docking", 1), ("coming down", 1), ("debarking", 1), ("grounding", 1)]),
 ("airport", 1, [("airfield", 1), ("aerodrome", 1), ("flight terminal", 1), ("airstrip", 1), ("airbase", 1), ("aviation hub", 1), ("jetport", 1), ("air station", 1), ("field", 1), ("terminal", 1)]),
 ("taxi", 1, [("cab", 1), ("taxicab", 1), ("ride", 1), ("hack", 1), ("minicab", 1), ("vehicle", 1), ("car", 1), ("transport", 1), ("limo", 1), ("shuttle", 1)]),
 ("hotel", 1, [("inn", 1), ("lodge", 1), ("motel", 1), ("hostel", 1), ("guesthouse", 1), ("accommodation", 1), ("boarding house", 1), ("resort", 1), ("bed and breakfast", 1), ("establishment", 1)]),
 ("brings", 1, [("carries", 1), ("transports", 1), ("conveys", 1), ("totes", 1), ("lugs", 1), ("hauls", 1), ("moves", 1), ("drags", 1), ("schleps", 1), ("delivers", 1)]),
 ("bags", 1, [("luggage", 1), ("suitcases", 1), ("sacks", 1), ("packs", 1), ("duffel", 1), ("carry-ons", 1), ("baggage", 1), ("belongings", 1), ("cases", 1), ("holdalls", 1)]),
 ("strolling", 1, [("walking", 1), ("wander", 1), ("walk", 1), ("stroll", 1), ("walking", 1), ("strolls", 1), ("strolled", 1), ("roaming", 1), ("ambling", 1), ("sauntering", 1), ("wandering", 1), ("rambling", 1), ("pacing", 1), ("trekking", 1), ("perambulating", 1), ("meandering", 1)]),
 ("centre", 1, [("middle", 1), ("heart", 1), ("core", 1), ("hub", 1), ("central part", 1), ("midpoint", 1), ("nucleus", 1), ("epicentre", 1), ("focal point", 1), ("axis", 1)]),
 ("french", 1, [("gallic", 1), ("frankish", 1), ("parisian", 1)]),
 ("city", 1, [("metropolis", 1), ("town", 1), ("urban area", 1), ("municipality", 1), ("capital", 1), ("borough", 1), ("megacity", 1), ("metropole", 1), ("conurbation", 1), ("cosmopolis", 1)]),
 ("bella", 3, [("the woman", 3), ("the traveller", 3), ("the tourist", 3), ("the vacationer", 3), ("the observer", 3), ("the sightseer", 3), ("the spotter", 3), ("the passer by", 3), ("the explorer", 3), ("the visitor", 3)]),
 ("spots", 1, [("sees", 1), ("notices", 1), ("observes", 1), ("discerns", 1), ("detects", 1), ("identifies", 1), ("recognizes", 1), ("espies", 1), ("discovers", 1), ("locates", 1)]),
 ("old", 2, [("former", 2), ("past", 2), ("previous", 2), ("bygone", 2), ("early", 2), ("elder", 2), ("aged", 2), ("ancient", 2), ("antecedent", 2), ("prior", 2)]),
 ("school", 2, [("educational", 2), ("academic", 2), ("scholastic", 2), ("collegiate", 2), ("pedagogic", 2), ("high school", 2), ("elementary school", 2), ("secondary school", 2), ("grammar school", 2), ("prep school", 2)]),

("friend", 4, [("companion", 4), ("buddy", 4), ("pal", 4), ("comrade", 4), ("ally", 4),
 ("mate", 4), ("chum", 4), ("cohort", 4), ("compeer", 4), ("colleague", 4)]),
 ("years", 1, [("annum", 1), ("seasons", 1), ("cycles", 1), ("ages", 1), ("periods", 1), ("time",
 1), ("epochs", 1), ("decades", 1), ("duration", 1), ("span", 1)]),
 ("shouts", 1, [("yells", 1), ("cries", 1), ("calls out", 1), ("screams", 1), ("hoots", 1),
 ("bawls", 1), ("exclaims", 1), ("hails", 1), ("roars", 1), ("hollers", 1)]),
 ("turns", 1, [("rotates", 1), ("swivels", 1), ("twists", 1), ("revolves", 1), ("spins", 1),
 ("pivots", 1), ("wheels", 1), ("swings", 1), ("whirls", 1), ("circles", 1)]),
 ("warm", 1, [("friendly", 1), ("affectionate", 1), ("welcoming", 1), ("cordial", 1), ("hearty",
 1), ("genial", 1), ("affable", 1), ("kind", 1), ("amiable", 1), ("gracious", 1)]),
 ("smile", 1, [("grin", 1), ("beam", 1), ("smirk", 1), ("chuckle", 1), ("simper", 1), ("twinkle",
 1), ("grin", 1), ("laugh", 1), ("gloat", 1), ("sneer", 1)]),
 ("runs", 1, [("sprints", 1), ("dashes", 1), ("races", 1), ("hurries", 1), ("scampers", 1),
 ("trots", 1), ("rushes", 1), ("speeds", 1), ("charges", 1), ("hastes", 1)]),
 ("cobblestone", 1, [("paved", 1), ("cobbled", 1), ("cobblestones", 1), ("stony", 1),
 ("pebbled", 1), ("rocky", 1), ("flagged", 1), ("stone-paved", 1), ("brick", 1), ("boulder-
 strewn", 1), ("paver", 1), ("stone-laid", 1)]),
 ("street", 1, [("road", 1), ("streets", 1), ("avenue", 1), ("lane", 1), ("boulevard", 1), ("drive",
 1), ("way", 1), ("pathway", 1), ("thoroughfare", 1), ("passage", 1), ("alley", 1)]),
 ("excitedly", 1, [("enthusiastically", 1), ("eagerly", 1), ("passionately", 1), ("anxiously", 1),
 ("zealously", 1), ("animatedly", 1), ("ardently", 1), ("fervently", 1), ("vibrantly", 1),
 ("spiritedly", 1)]),
 ("embraces", 1, [("hugs", 1), ("hug", 1), ("embrace", 1), ("holds", 1), ("enfolds", 1),
 ("clasps", 1), ("grasps", 1), ("snuggles", 1), ("wraps", 1), ("squeezes", 1), ("encircles", 1),
 ("cuddles", 1)]),
 ("grinning", 1, [("smiling", 1), ("beaming", 1), ("chuckling", 1), ("gleaming", 1),
 ("laughing", 1), ("smirking", 1), ("snickering", 1), ("glowing", 1), ("giggling", 1),
 ("twinkling", 1)]),
 ("women", 1, [("ladies", 1), ("females", 1), ("girls", 1), ("dames", 1), ("lasses", 1),
 ("maidens", 1), ("misses", 1), ("matrons", 1), ("wives", 1), ("gals", 1)]),
 ("shocked", 1, [("astonished", 1), ("stunned", 1), ("amazed", 1), ("surprised", 1),
 ("dumbfounded", 1), ("aghast", 1), ("startled", 1), ("flabbergasted", 1), ("baffled", 1),
 ("bewildered", 1)]),

("surprised", 1, [("astounded", 1), ("startled", 1), ("stunned", 1), ("shocked", 1), ("amazed", 1), ("taken aback", 1), ("flabbergasted", 1), ("dumbfounded", 1), ("astonished", 1), ("thunderstruck", 1)]),

("bumped", 1, [("met", 1), ("bump", 1), ("bumps", 1), ("encountered", 1), ("ran into", 1), ("came across", 1), ("collided with", 1), ("chanced upon", 1), ("stumbled upon", 1), ("found", 1), ("crossed paths with", 1), ("ran across", 1)]),

("paris", 1, [("the city", 1), ("the metropolis", 1), ("the capital", 1), ("the french capital", 1), ("city of love", 1), ("city of lights", 1), ("the city of romance", 1)]),

("very", 1, [("really", 1), ("extremely", 1), ("highly", 1), ("quite", 1), ("exceedingly", 1), ("exceptionally", 1), ("incredibly", 1), ("particularly", 1), ("tremendously", 1), ("immensely", 1)]),

("pleased", 1, [("happy", 1), ("delighted", 1), ("content", 1), ("satisfied", 1), ("gratified", 1), ("thrilled", 1), ("elated", 1), ("joyful", 1), ("contented", 1), ("glad", 1)]),

("eager", 1, [("keen", 1), ("anxious", 1), ("enthusiastic", 1), ("excited", 1), ("antsy", 1), ("impatient", 1), ("zealous", 1), ("avid", 1), ("ardent", 1), ("yearning", 1)]),

("tell", 1, [("inform", 1), ("narrate", 1), ("relate", 1), ("describe", 1), ("recount", 1), ("report", 1), ("disclose", 1), ("divulge", 1), ("detail", 1), ("convey", 1)]),

("life", 1, [("existence", 1), ("living", 1), ("being", 1), ("lifestyle", 1), ("experience", 1), ("reality", 1), ("world", 1), ("biography", 1), ("history", 1), ("journey", 1)]),

("pair", 1, [("duo", 1), ("couple", 1), ("twosome", 1), ("pairing", 1), ("dyad", 1), ("duad", 1), ("double", 1), ("two", 1), ("binary", 1), ("brace", 1)]),

("decide", 1, [("choose", 1), ("decided", 1), ("determine", 1), ("opt", 1), ("conclude", 1), ("resolve", 1), ("settle", 1), ("decides", 1), ("elect", 1), ("finalize", 1), ("establish", 1)]),

("go", 1, [("proceed", 1), ("move", 1), ("travel", 1), ("head", 1), ("progress", 1), ("continue", 1), ("advance", 1), ("depart", 1), ("trek", 1), ("journey", 1)]),

("wine", 1, [("alcoholic", 1), ("vino", 1), ("liquor", 1), ("beverage", 1), ("drink", 1), ("drinks", 1), ("vinous", 1), ("grape", 1), ("tipple", 1), ("booze", 1), ("spirit", 1)]),

("bar", 1, [("pub", 1), ("tavern", 1), ("saloon", 1), ("club", 1), ("joint", 1), ("lounge", 1), ("bistro", 1), ("inn", 1), ("drinkery", 1), ("taproom", 1)]),

("catch", 1, [("engage", 1), ("talk", 1), ("share", 1), ("enjoy", 1), ("experience", 1), ("savour", 1), ("converse", 1), ("participate", 1), ("dine", 1), ("engross", 1), ("delight", 1)]),

("dinner", 1, [("supper", 1), ("meal", 1), ("feast", 1), ("banquet", 1), ("repast", 1), ("spread", 1), ("food", 1), ("cuisine", 1), ("fare", 1), ("table", 1)]),

("fond", 1, [("dear", 1), ("fondly", 1), ("loving", 1), ("affectionate", 1), ("cherished", 1),
 ("adored", 1), ("treasured", 1), ("beloved", 1), ("favoured", 1), ("warm", 1), ("tender", 1)]),
 ("stories", 2, [("tales", 2), ("narratives", 2), ("accounts", 2), ("yarns", 2), ("anecdotes", 2),
 ("sagas", 2), ("chronicles", 2), ("legends", 2), ("fables", 2), ("narrations", 2)]),
 ("childhood", 1, [("youth", 1), ("children", 1), ("infancy", 1), ("early years", 1),
 ("boyhood/girlhood", 1), ("adolescence", 1), ("juвенescence", 1), ("tender years", 1), ("early
 life", 1), ("young days", 1), ("formative years", 1)]),
 ("laughing", 1, [("chuckling", 1), ("giggling", 1), ("chortling", 1), ("guffawing", 1),
 ("sniggering", 1), ("cackling", 1), ("tittering", 1), ("roaring", 1), ("snickering", 1), ("smiling",
 1)]),
 ("over", 1, [("about", 1), ("concerning", 1), ("regarding", 1), ("around", 1), ("on", 1),
 ("pertaining to", 1), ("with respect to", 1), ("in relation to", 1), ("touching on", 1),
 ("involving", 1)]),
 ("funny", 1, [("humorous", 1), ("hilarious", 1), ("amusing", 1), ("comical", 1),
 ("entertaining", 1), ("witty", 1), ("jocular", 1), ("laughable", 1), ("droll", 1), ("farcical", 1)]),
 ("later", 1, [("afterward", 1), ("subsequently", 1), ("following", 1), ("eventually", 1),
 ("then", 1), ("thereafter", 1), ("after", 1), ("next", 1), ("soon", 1), ("later on", 1)]),
 ("part", 1, [("separate", 1), ("depart", 1), ("split", 1), ("leave", 1), ("disunite", 1), ("divorce",
 1), ("sever", 1), ("break", 1), ("detach", 1), ("disjoin", 1)]),
 ("plans", 1, [("arrangements", 1), ("arrange", 1), ("arranges", 1), ("arranged", 1),
 ("schedules", 1), ("strategies", 1), ("designs", 1), ("intentions", 1), ("proposals", 1),
 ("blueprints", 1), ("agendas", 1), ("programmes", 1), ("outlines", 1)]),
 ("meet", 1, [("encounter", 1), ("gather", 1), ("convene", 1), ("reunite", 1), ("congregate", 1),
 ("assemble", 1), ("meet up", 1), ("reassemble", 1), ("come together", 1), ("muster", 1)]),
 ("next", 1, [("following", 1), ("upcoming", 1), ("subsequent", 1), ("succeeding", 1),
 ("forthcoming", 1), ("ensuing", 1), ("future", 1), ("near", 1), ("later", 1), ("immediate", 1)]),
 ("day", 1, [("date", 1), ("time", 1), ("occasion", 1), ("moment", 1), ("period", 1), ("point",
 1), ("dawn", 1), ("sunrise to sunset", 1), ("24-hour period", 1), ("daytime", 1)])]

last_sentence_words = [

("bella", 1, [("the woman", 1), ("the traveller", 1), ("the tourist", 1), ("the vacationer", 1),
 ("the observer", 1), ("the sightseer", 1), ("the spotter", 1), ("the passer by", 1), ("the explorer",
 1), ("the visitor", 1)])],

("hails", 1, [("signals", 1), ("flags down", 1), ("beckons", 1), ("calls", 1), ("waves down", 1), ("whistles for", 1), ("gestures", 1), ("summons", 1), ("stops", 1), ("catches", 1)]),
 ("taxi", 1, [("cab", 1), ("hack", 1), ("taxicab", 1), ("minicab", 1), ("car service", 1), ("hackney carriage", 1), ("uber", 1), ("lyft", 1), ("vehicle for hire", 1), ("ride", 1)]),
 ("take", 1, [("transport", 1), ("carry", 1), ("convey", 1), ("drive", 1), ("bring", 1), ("escort", 1), ("conduct", 1), ("lead", 1), ("guide", 1), ("ferry", 1)]),
 ("back", 1, [("return", 1), ("returned", 1), ("returns", 1), ("rearward", 1), ("behind", 1), ("in return", 1), ("to the original place", 1), ("homeward", 1), ("backward", 1), ("in reverse", 1), ("again", 1), ("revert", 1)]),
 ("hotel", 1, [("inn", 1), ("lodge", 1), ("motel", 1), ("guesthouse", 1), ("hostel", 1), ("resort", 1), ("boarding house", 1), ("b&b (bed and breakfast)", 1), ("accommodation", 1), ("suites", 1)]])

Convert list of words to formatted string

```
first_sentence_words_str = []
```

```
for word_info in first_sentence_words:
```

```
    word = word_info[0]
```

```
    max_count = word_info[1]
```

```
    synonyms = ','.join([syn[0] for syn in word_info[2]])
```

```
    first_sentence_words_str.append(f'{word}\t{synonyms}\t{max_count}')
```

```
main_body_words_str = []
```

```
for word_info in main_body_words:
```

```
    word = word_info[0]
```

```
    max_count = word_info[1]
```

```
    synonyms = ','.join([syn[0] for syn in word_info[2]])
```

```
    main_body_words_str.append(f'{word}\t{synonyms}\t{max_count}')
```

```
last_sentence_words_str = []
```

```
for word_info in last_sentence_words:
```

```
    word = word_info[0]
```

```
    max_count = word_info[1]
```

```

synonyms = ','.join([syn[0] for syn in word_info[2]])
last_sentence_words_str.append(f'{word}\t{synonyms}\t{max_count}')

first_sentence_words_str = '\n'.join(first_sentence_words_str)
main_body_words_str = '\n'.join(main_body_words_str)
last_sentence_words_str = '\n'.join(last_sentence_words_str)

# Create input widgets
first_sentence_input = widgets.Textarea(value="", description='First sentence:')
first_sentence_word_input = widgets.Textarea(value=first_sentence_words_str,
description='Target words:')
main_body_input = widgets.Textarea(value="", description='Main body:')
main_body_word_input = widgets.Textarea(value=main_body_words_str,
description='Target words:')
last_sentence_input = widgets.Textarea(value="", description='Last sentence:')
last_sentence_word_input = widgets.Textarea(value=last_sentence_words_str,
description='Target words:')
display(first_sentence_input, first_sentence_word_input, main_body_input,
main_body_word_input, last_sentence_input, last_sentence_word_input)

# Define a button to run the analysis
button = widgets.Button(description='Analyze')
output = widgets.Output()
display(button, output)

def analyze_text(b):
    output.clear_output() # Clear the output before each run
    total_count = [0, 0, 0] # Count for first_sentence, main_body, last_sentence
    with output:
        # Get input values
        text_inputs = [first_sentence_input.value.lower(), main_body_input.value.lower(),
last_sentence_input.value.lower()]
        word_inputs = [first_sentence_word_input.value.split('\n'),
main_body_word_input.value.split('\n'), last_sentence_word_input.value.split('\n')]

```

```

for i, (text_input, word_input) in enumerate(zip(text_inputs, word_inputs)):
    current_text = text_input
    # Parse target words and synonyms from input
    set1 = []
    for line in word_input:
        word_parts = line.split('\t')
        if len(word_parts) == 3:
            word = word_parts[0].strip()
            if not word: # skip if word is an empty string
                continue
            max_count = int(word_parts[2].strip())
            synonyms = [(syn, 1) for syn in word_parts[1].split(',') if syn] # ensure synonym
is not an empty string
            set1.append((word, max_count, synonyms))

set1_count = 0
counted_words = defaultdict(int)
counted_synonyms = set()

for word_info in set1:
    current_word = word_info[0]
    max_count = word_info[1]
    count_word = len(re.findall(f'\b{current_word}\b', current_text))
    count_word = min(count_word, max_count)
    if count_word > 0:
        counted_words[current_word] = count_word
        set1_count += count_word
        current_text = re.sub(f'\b{current_word}\b', '\033[31m' + current_word +
'\033[0m', current_text)

    if current_word not in counted_synonyms:
        for synonym, _ in word_info[2]:
            count_syn = len(re.findall(f'\b{synonym.strip()}\b', current_text))

```

```

count_syn = min(count_syn, max_count - count_word)
if count_syn > 0:
    counted_words[synonym.strip()] = count_syn
    counted_synonyms.add(current_word)
    set1_count += count_syn
    current_text = re.sub(f'\\b{synonym.strip()}\\b', '\033[31m' +
synonym.strip() + '\033[0m', current_text)
    break

print(current_text)
print("Set 1 Count: " + str(set1_count))
total_count[i] += set1_count # Add to total count
for word, count in counted_words.items():
    print(f'Word/Synonym "{word}" (from "{next(w[0] for w in set1 if word in [w[0]]
+ [syn[0] for syn in w[2]])}") was found {count} time(s)')

print(f'First sentence total count: {total_count[0]}')
print(f'Main body total count: {total_count[1]}')
print(f'Last sentence total count: {total_count[2]}')

button.on_click(analyze_text)

```

The Presentation

```
from collections import defaultdict
import re
from IPython.display import display
from ipywidgets import widgets
```

```
# Target Words + Synonyms in sets
```

```
first_sentence_words = ([("richard", 1, [("richard's", 1)]),
    ("wearing", 1, [("donning", 1), ("sporting", 1), ("clad in", 1), ("dressed in", 1), ("decked
out in", 1), ("attired in", 1), ("adorned in", 1), ("clothed in", 1), ("garbed in", 1), ("outfitted
in", 1), ("wore", 1), ("donned", 1), ("dressed", 1), ("wears", 1)]),
    ("blue", 1, [("azure", 1), ("cobalt", 1), ("navy", 1), ("sky-blue", 1), ("sapphire", 1),
("cerulean", 1), ("indigo", 1), ("teal", 1), ("turquoise", 1)]),
    ("shirt", 1, []),
    ("black", 1, [("jet", 1), ("charcoal", 1), ("onyx", 1), ("coal", 1), ("pitch", 1),
("midnight", 1), ("raven", 1), ("obsidian", 1), ("dark", 1)]),
    ("striped", 1, [("banded", 1), ("lined", 1), ("streaked", 1), ("barred", 1), ("pinstriped",
1), ("candy-striped", 1), ("variegated", 1), ("stripy", 1), ("ribboned", 1), ("veined", 1),
("stripe", 1)]),
    ("tie", 1, [("necktie", 1)]))
```

```
main_body_words = [("wanted", 1, [("desired", 1), ("wished", 1), ("hoped", 1), ("aspired", 1),
("aimed", 1), ("planned", 1), ("intended", 1), ("craved", 1), ("coveted", 1), ("yearned", 1),
("want", 1), ("wish", 1), ("crave", 1), ("wants", 1), ("desire", 1)]),
    ("smart", 1, [("sharp", 1), ("elegant", 1), ("classy", 1), ("sophisticated", 1), ("stylish",
1), ("polished", 1), ("dapper", 1), ("chic", 1), ("neat", 1), ("snazzy", 1), ("smartly", 1)]),
    ("give", 1, [("deliver", 1), ("present", 1), ("offer", 1), ("convey", 1), ("provide", 1),
("furnish", 1), ("impart", 1), ("render", 1), ("administer", 1), ("hand over", 1), ("gave", 1),
("delivered", 1), ("delivers", 1), ("gives", 1)]),
    ("presentation", 2, [("speech", 2), ("talk", 2), ("lecture", 2), ("address", 2), ("briefing",
2), ("demonstration", 2), ("display", 2), ("seminar", 2)]),
    ("hundreds", 1, [("scores", 1), ("many", 1), ("numerous", 1), ("multitudes", 1),
("countless", 1), ("several", 1), ("loads", 1), ("heaps", 1), ("tons", 1), ("crowds", 1),
("hundred", 1)]),
    ("people", 2, [("individuals", 2), ("persons", 2), ("folks", 2), ("audience", 2),
("attendees", 2), ("spectators", 2), ("crowd", 2), ("participants", 2), ("viewers", 2),
("listeners", 2)]),
    ("feeling", 1, [("sensing", 1), ("experiencing", 1), ("undergoing", 1), ("perceiving", 1),
("felt", 1), ("feels", 1), ("experienced", 1)]),
```

("extremely", 1, [("intensely", 1), ("highly", 1), ("very", 1), ("particularly", 1),
 ("exceedingly", 1), ("remarkably", 1), ("profoundly", 1), ("tremendously", 1), ("enormously",
 1), ("incredibly", 1), ("extreme", 1)]),
 ("nervous", 1, [("anxious", 1), ("apprehensive", 1), ("tense", 1), ("jittery", 1), ("uneasy",
 1), ("worried", 1), ("edgy", 1), ("fidgety", 1), ("stressed", 1), ("perturbed", 1), ("nerves", 1),
 ("nervously", 1)]),
 ("make", 1, [("made", 1), ("makes", 1)]),
 ("good", 1, [("positive", 1), ("favourable", 1), ("excellent", 1), ("decent", 1),
 ("admirable", 1), ("pleasing", 1), ("fine", 1), ("quality", 1), ("superb", 1), ("outstanding", 1)]),
 ("impression", 1, [("impact", 1), ("effect", 1), ("mark", 1), ("influence", 1),
 ("impression", 1), ("perception", 1), ("feeling", 1), ("image", 1), ("notion", 1), ("sense", 1),
 ("impressions", 1)]),
 ("colleagues", 1, [("coworkers", 1), ("peers", 1), ("comrades", 1), ("associates", 1),
 ("fellow employees", 1), ("co-associates", 1), ("teammates", 1), ("workmates", 1), ("partners",
 1), ("counterparts", 1), ("co-workers", 1), ("colleague", 1), ("team", 1)]),
 ("richard", 3, [("richard's", 3)]),
 ("walked", 1, [("strolled", 1), ("strutted", 1), ("marched", 1), ("tread", 1), ("paced", 1),
 ("ambled", 1), ("stepped", 1), ("trudged", 1), ("wandered", 1), ("sauntered", 1), ("walks", 1),
 ("walking", 1), ("walk", 1)]),
 ("anxiously", 1, [("nervously", 1), ("apprehensively", 1), ("worriedly", 1), ("uneasily",
 1), ("tensely", 1), ("fretfully", 1), ("agitatedly", 1), ("concernedly", 1), ("fearfully", 1),
 ("restlessly", 1), ("anxious", 1)]),
 ("stage", 3, [("platform", 3), ("podium", 3), ("stand", 3), ("arena", 3), ("dais", 3),
 ("stage", 3), ("scene", 3), ("forum", 3), ("spotlight", 3), ("rostrum", 3)]),
 ("begin", 1, [("start", 1), ("initiate", 1), ("commence", 1), ("kick off", 1), ("launch", 1),
 ("embark", 1), ("opens", 1), ("open", 1), ("set out", 1), ("get going", 1), ("undertake", 1),
 ("begin", 1), ("started", 1), ("starts", 1), ("begins", 1)]),
 ("speech", 1, [("talk", 1), ("address", 1), ("lecture", 1), ("discourse", 1), ("presentation",
 1), ("oratory", 1), ("monologue", 1), ("recital", 1), ("homily", 1), ("soliloquy", 1)]),
 ("tripped", 1, [("stumbled", 1), ("slipped", 1), ("tumbled", 1), ("fell", 1), ("stagged",
 1), ("faltered", 1), ("bumbled", 1), ("teetered", 1), ("toppled", 1), ("blundered", 1), ("trip", 1),
 ("trips", 1), ("tripping", 1)]),
 ("loose", 1, [("unsecured", 1), ("detached", 1), ("unfastened", 1), ("slack", 1), ("free",
 1), ("unfixed", 1), ("lax", 1), ("unattached", 1), ("unrestrained", 1), ("unanchored", 1)]),
 ("cable", 1, [("wire", 1), ("cord", 1), ("line", 1), ("rope", 1), ("lead", 1), ("conduit", 1),
 ("flex", 1), ("strand", 1), ("thread", 1), ("coil", 1), ("cables", 1), ("wires", 1)]),
 ("fell", 1, [("tumbled", 1), ("collapsed", 1), ("plunged", 1), ("dropped", 1), ("sank", 1),
 ("crashed", 1), ("slumped", 1), ("flopped", 1), ("toppled", 1), ("dove", 1), ("fall", 1),
 ("falling", 1), ("tumble", 1)]),
 ("headfirst", 1, [("headlong", 1), ("face-first", 1), ("plunging", 1), ("diving", 1),
 ("forward", 1), ("prone", 1), ("direct", 1), ("straight", 1), ("precipitously", 1), ("head-on", 1),
 ("head first", 1), ("head-first", 1)]),
 ("audience", 2, [("spectators", 2), ("observers", 2), ("viewers", 2), ("attendees", 2),
 ("listeners", 2), ("onlookers", 2), ("crowd", 2), ("assembly", 2), ("public", 2), ("gallery", 2)]),

("excruciating", 1, [("intense", 1), ("agonizing", 1), ("severe", 1), ("torturous", 1),
 ("unbearable", 1), ("extreme", 1), ("terrible", 1), ("racking", 1), ("piercing", 1), ("harrowing",
 1)]),
 ("pain", 1, [("suffering", 1), ("discomfort", 1), ("agony", 1), ("hurt", 1), ("soreness", 1),
 ("throbbing", 1), ("ache", 1), ("sting", 1), ("distress", 1), ("twinge", 1), ("painful", 1)]),
 ("fall", 2, [("tumble", 2), ("falling", 2), ("collapse", 2), ("plunge", 2), ("stumble", 2),
 ("drop", 2), ("trip", 2), ("dive", 2), ("crash", 2), ("slump", 2), ("slip", 2), ("fell", 2)]),
 ("caused", 2, [("induced", 2), ("led to", 2), ("produced", 2), ("provoked", 2), ("triggered",
 2), ("generated", 2), ("resulted in", 2), ("brought about", 2), ("created", 2), ("initiated", 2),
 ("causing", 2), ("cause", 2)]),
 ("shoulder", 1, [("joint", 1), ("scapula", 1), ("upper arm", 1), ("shoulder joint", 1),
 ("shoulder blade", 1), ("arm", 1)]),
 ("dislocate", 1, [("misplace", 1), ("dislocating", 1), ("dislodge", 1), ("disarrange", 1),
 ("displace", 1), ("unseat", 1), ("disturb", 1), ("shift", 1), ("disjoint", 1), ("upset", 1), ("jumble",
 1), ("dislocated", 1), ("dislocates", 1)]),
 ("laughed", 1, [("chuckled", 1), ("snickered", 1), ("guffawed", 1), ("cackled", 1),
 ("sniggered", 1), ("tittered", 1), ("chortled", 1), ("roared", 1), ("smiled", 1), ("grinned", 1),
 ("laugh", 1), ("laughing", 1), ("laughs", 1)]),
 ("realising", 1, [("recognising", 1), ("understanding", 1), ("comprehending", 1),
 ("grasping", 1), ("noticing", 1), ("discerning", 1), ("acknowledging", 1), ("perceiving", 1),
 ("apprehending", 1), ("identifying", 1), ("realises", 1), ("realised", 1), ("realize", 1),
 ("realizes", 1), ("realized", 1), ("realizing", 1)]),
 ("seriously", 1, [("severely", 1), ("critically", 1), ("gravely", 1), ("significantly", 1),
 ("badly", 1), ("profoundly", 1), ("seriously", 1), ("heavily", 1), ("considerably", 1),
 ("dangerously", 1), ("serious", 1)]),
 ("hurt", 1, [("injured", 1), ("damaged", 1), ("wounded", 1), ("harmed", 1), ("afflicted", 1),
 ("suffered", 1), ("battered", 1), ("bruised", 1), ("impaired", 1), ("pained", 1), ("injury", 1),
 ("injure", 1), ("hurts", 1)]),
 ("matters", 1, [("issues", 1), ("problems", 1), ("situations", 1), ("concerns", 1), ("affairs",
 1), ("circumstances", 1), ("things", 1), ("details", 1), ("topics", 1), ("elements", 1), ("issue",
 1), ("matter", 1), ("situation", 1)]),
 ("worse", 1, [("more serious", 1), ("more severe", 1), ("graver", 1), ("more critical", 1),
 ("more dire", 1), ("more drastic", 1), ("more extreme", 1), ("more dangerous", 1), ("more
 unfavourable", 1), ("more difficult", 1)]),
 ("table", 1, [("counter", 1), ("stand", 1), ("workbench", 1), ("platform", 1), ("surface", 1),
 ("trestle", 1), ("fixture", 1)]),
 ("tip", 1, [("tilt", 1), ("overturn", 1), ("topple", 1), ("capsize", 1), ("upend", 1), ("flip", 1),
 ("upset", 1), ("knock over", 1), ("overbalance", 1), ("spill", 1), ("tipped", 1), ("tips", 1),
 ("tilts", 1), ("tilted", 1)]),
 ("spilling", 1, [("pouring", 1), ("leaking", 1), ("splashing", 1), ("overflowing", 1),
 ("dribbling", 1), ("slopping", 1), ("trickling", 1), ("discharging", 1), ("dropping", 1),
 ("running", 1), ("spills", 1), ("spilt", 1), ("spill", 1), ("spilled", 1)]),

("boiling", 1, [("scalding", 1), ("blazing", 1), ("roasting", 1), ("sizzling", 1), ("steaming", 1), ("sweltering", 1), ("hot", 1), ("piping", 1), ("scorching", 1), ("torrid", 1), ("boiled", 1), ("boils", 1)]),
 ("hot", 1, [("warm", 1), ("heated", 1), ("high-temperature", 1), ("steaming", 1), ("scorching", 1), ("torrid", 1), ("sweltering", 1), ("burning", 1), ("piping", 1), ("blistering", 1)]),
 ("drinks", 1, [("beverages", 1), ("fluids", 1), ("liquids", 1), ("refreshments", 1), ("drinkables", 1), ("drink", 1), ("refreshment", 1), ("liquid", 1), ("fluid", 1), ("beverage", 1)]),
 ("people", 1, [("people's", 1), ("peoples", 1)]),
 ("climbed", 1, [("ascended", 1), ("mounted", 1), ("scaled", 1), ("rose", 1), ("clambered", 1), ("elevated", 1), ("surged", 1), ("crept", 1), ("crawled", 1), ("scrambled", 1), ("climbs", 1), ("climb", 1)]),
 ("continue", 1, [("persist", 1), ("carry on", 1), ("keep going", 1), ("proceed", 1), ("maintain", 1), ("sustain", 1), ("persevere", 1), ("resume", 1), ("prolong", 1), ("extend", 1), ("kept going", 1), ("continued", 1), ("continues", 1)]),
 ("attempt", 1, [("try", 1), ("endeavor", 1), ("strive", 1), ("aim", 1), ("seek", 1), ("pursue", 1), ("effort", 1), ("bid", 1), ("shot", 1), ("crack", 1), ("attempted", 1), ("attempts", 1), ("tried", 1), ("tries", 1)]),
 ("improve", 1, [("enhance", 1), ("better", 1), ("amend", 1), ("upgrade", 1), ("boost", 1), ("elevate", 1), ("advance", 1), ("refine", 1), ("rectify", 1), ("progress", 1), ("improved", 1), ("improves", 1)]),
 ("situation", 1, [("circumstance", 1), ("condition", 1), ("scenario", 1), ("context", 1), ("case", 1), ("predicament", 1), ("state", 1), ("position", 1), ("plight", 1), ("setup", 1), ("circumstances", 1)]),
 ("however", 1, [("nonetheless", 1), ("nevertheless", 1), ("still", 1), ("yet", 1), ("but", 1), ("though", 1), ("albeit", 1), ("despite", 1), ("even so", 1), ("regardless", 1)]),
 ("found", 1, [("discovered", 1), ("detected", 1), ("identified", 1), ("located", 1), ("noticed", 1), ("found out", 1), ("unearthed", 1), ("spotted", 1), ("recognized", 1), ("revealed", 1), ("find", 1)]),
 ("difficult", 1, [("hard", 1), ("challenging", 1), ("tough", 1), ("tricky", 1), ("complex", 1), ("complicated", 1), ("arduous", 1), ("daunting", 1), ("strenuous", 1), ("taxing", 1)]),
 ("cry", 1, [("weep", 1), ("sob", 1), ("wail", 1), ("bawl", 1), ("tear up", 1), ("mourn", 1), ("snivel", 1), ("lament", 1), ("whine", 1), ("howl", 1), ("cried", 1), ("cries", 1), ("wept", 1), ("crying", 1)]),
 ("due", 1, [("because of", 1), ("owing to", 1), ("as a result of", 1), ("resulting from", 1), ("attributable to", 1), ("thanks to", 1), ("caused by", 1), ("stemming from", 1), ("following", 1), ("in view of", 1)]),
 ("pain", 1, [("agony", 1), ("hurt", 1), ("discomfort", 1), ("suffering", 1), ("torment", 1), ("ache", 1), ("distress", 1), ("misery", 1), ("soreness", 1), ("throes", 1)]),
 ("embarrassment", 1, [("shame", 1), ("humiliation", 1), ("discomfort", 1), ("awkwardness", 1), ("disgrace", 1), ("mortification", 1), ("chagrin", 1), ("abashment", 1), ("discomfiture", 1), ("self-consciousness", 1), ("embarrassed", 1), ("embarrassing", 1), ("embarrasses", 1)]),

("tearful", 1, [("crying", 1), ("tears", 1), ("weeping", 1), ("sobbing", 1), ("watery-eyed", 1), ("teary", 1), ("lachrymose", 1), ("misty-eyed", 1), ("sorrowful", 1), ("grieving", 1), ("tearfully", 1), ("snivelling", 1)]),

("apologised", 1, [("said sorry", 1), ("expressed regret", 1), ("begged pardon", 1), ("made amends", 1), ("asked forgiveness", 1), ("showed remorse", 1), ("expressed sorrow", 1), ("took the blame", 1), ("showed contrition", 1), ("made apology", 1), ("apologise", 1), ("apologises", 1), ("apology", 1), ("said sorry", 1), ("say sorry", 1)]),

("peers", 1, [("colleagues", 1), ("comrades", 1), ("fellows", 1), ("associates", 1), ("companions", 1), ("coworkers", 1), ("counterparts", 1), ("equals", 1), ("mates", 1)]),

("left", 1, [("departed", 1), ("exited", 1), ("went away", 1), ("retreated", 1), ("withdrew", 1), ("vacated", 1), ("moved out", 1), ("took off", 1), ("cleared out", 1), ("absconded", 1), ("leave", 1), ("leaving", 1), ("leaves", 1)]])

last_sentence_words = [("richard", 1, [("richards", 1)]),

("immediately", 1, [("instantly", 1), ("right away", 1), ("directly", 1), ("promptly", 1), ("swiftly", 1), ("quickly", 1), ("straightaway", 1), ("speedily", 1), ("instantaneously", 1), ("without delay", 1), ("immediate", 1), ("quick", 1)]),

("called", 1, [("phoned", 1), ("dialled", 1), ("rang", 1), ("contacted", 1), ("reached out", 1), ("connected", 1), ("got in touch", 1), ("communicated", 1), ("made a call", 1), ("signalled", 1), ("calls", 1), ("calling", 1), ("call", 1)]),

("wife", 1, [("spouse", 1), ("partner", 1), ("significant other", 1), ("life partner", 1), ("other half", 1)]),

("ask", 1, [("request", 1), ("inquire", 1), ("query", 1), ("seek", 1), ("demand", 1), ("plead", 1), ("appeal", 1), ("call on", 1), ("solicit", 1), ("propose", 1), ("asked", 1), ("asking", 1), ("asks", 1)]),

("collect", 1, [("pick up", 1), ("pick him up", 1), ("retrieve", 1), ("gather", 1), ("acquire", 1), ("receive", 1), ("fetch", 1), ("attain", 1), ("obtain", 1), ("secure", 1), ("procure", 1), ("collected", 1), ("collects", 1), ("collecting", 1)]])

Convert list of words to formatted string

first_sentence_words_str = []

for word_info in first_sentence_words:

word = word_info[0]

max_count = word_info[1]

synonyms = ','.join([syn[0] for syn in word_info[2]])

first_sentence_words_str.append(f'{word}\t{synonyms}\t{max_count}')

main_body_words_str = []

for word_info in main_body_words:

word = word_info[0]

max_count = word_info[1]

synonyms = ','.join([syn[0] for syn in word_info[2]])

```

main_body_words_str.append(f'{word}\t{synonyms}\t{max_count}')

last_sentence_words_str = []
for word_info in last_sentence_words:
    word = word_info[0]
    max_count = word_info[1]
    synonyms = ','.join([syn[0] for syn in word_info[2]])
    last_sentence_words_str.append(f'{word}\t{synonyms}\t{max_count}')

first_sentence_words_str = '\n'.join(first_sentence_words_str)
main_body_words_str = '\n'.join(main_body_words_str)
last_sentence_words_str = '\n'.join(last_sentence_words_str)

# Create input widgets
first_sentence_input = widgets.Textarea(value="", description='First sentence:')
first_sentence_word_input = widgets.Textarea(value=first_sentence_words_str,
description='Target words:')
main_body_input = widgets.Textarea(value="", description='Main body:')
main_body_word_input = widgets.Textarea(value=main_body_words_str,
description='Target words:')
last_sentence_input = widgets.Textarea(value="", description='Last sentence:')
last_sentence_word_input = widgets.Textarea(value=last_sentence_words_str,
description='Target words:')
display(first_sentence_input, first_sentence_word_input, main_body_input,
main_body_word_input, last_sentence_input, last_sentence_word_input)

# Widget Button

button = widgets.Button(description='Analyze')
output = widgets.Output()
display(button, output)

def analyze_text(b):
    output.clear_output()
    total_count = [0, 0, 0]
    with output:

        text_inputs = [first_sentence_input.value.lower(), main_body_input.value.lower(),
last_sentence_input.value.lower()]
        word_inputs = [first_sentence_word_input.value.split('\n'),
main_body_word_input.value.split('\n'), last_sentence_word_input.value.split('\n')]

        for i, (text_input, word_input) in enumerate(zip(text_inputs, word_inputs)):
            current_text = text_input

```

```

set1 = []
for line in word_input:
    word_parts = line.split('\t')
    if len(word_parts) == 3:
        word = word_parts[0].strip()
        if not word: # skip if word is an empty string
            continue
        max_count = int(word_parts[2].strip())
        synonyms = [(syn, 1) for syn in word_parts[1].split(',') if syn] # Make sure
synonym is not an empty string
        set1.append((word, max_count, synonyms))

set1_count = 0
counted_words = defaultdict(int)
counted_synonyms = set()

for word_info in set1:
    current_word = word_info[0]
    max_count = word_info[1]
    count_word = len(re.findall(f'\\b{current_word}\\b', current_text))
    count_word = min(count_word, max_count)
    if count_word > 0:
        counted_words[current_word] = count_word
        set1_count += count_word
        current_text = re.sub(f'\\b{current_word}\\b', '\033[31m' + current_word +
'\033[0m', current_text)

    if current_word not in counted_synonyms:
        for synonym, _ in word_info[2]:
            count_syn = len(re.findall(f'\\b{synonym.strip()}\\b', current_text))
            count_syn = min(count_syn, max_count - count_word)
            if count_syn > 0:
                counted_words[synonym.strip()] = count_syn
                counted_synonyms.add(current_word)
                set1_count += count_syn
                current_text = re.sub(f'\\b{synonym.strip()}\\b', '\033[31m' +
synonym.strip() + '\033[0m', current_text)
                break

print(current_text)
print("Set 1 Count: " + str(set1_count))
total_count[i] += set1_count # Add to total count
for word, count in counted_words.items():

```

```
print(f'Word/Synonym "{word}" (from "{next(w[0] for w in set1 if word in [w[0]]  
+ [syn[0] for syn in w[2]])}" was found {count} time(s)')
```

```
print(f'First sentence total count: {total_count[0]}')
```

```
print(f'Main body total count: {total_count[1]}')
```

```
print(f'Last sentence total count: {total_count[2]}')
```

```
button.on_click(analyze_text)
```

The Radio Contest

```
from collections import defaultdict
import re
from IPython.display import display
from ipywidgets import widgets
```

```
# Target Words + Synonyms in sets
```

```
first_sentence_words = ([("emma", 1, [("emma's", 1)]),
    ("begins", 1, [("starts", 1), ("started", 1), ("began", 1), ("initiates", 1), ("commences",
1), ("kicks off", 1), ("launches", 1), ("embarks on", 1), ("opens", 1), ("sets out", 1), ("gets
going", 1), ("leads off", 1)]),
    ("commute", 1, [("journey", 1), ("travel", 1), ("ride", 1), ("drive", 1), ("transit", 1),
("trip", 1), ("voyage", 1), ("expedition", 1), ("trek", 1), ("tour", 1)]),
    ("car", 1, [("automobile", 1), ("vehicle", 1), ("motor", 1), ("auto", 1), ("machine", 1),
("wheels", 1), ("motorcar", 1), ("ride", 1), ("transport", 1), ("", 1)]),
    ("long", 1, [("extended", 1), ("prolonged", 1), ("lengthy", 1), ("protracted", 1),
("lasting", 1), ("extensive", 1), ("drawn-out", 1), ("enduring", 1), ("continuous", 1),
("sustained", 1)]),
    ("day", 1, [("shift", 1), ("days", 1), ("working day", 1), ("workday", 1), ("time", 1),
("period", 1), ("session", 1), ("", 1), ("span", 1), ("", 1), ("", 1)]),
    ("work", 1, [("job", 1), ("profession", 1), ("employment", 1), ("occupation", 1),
("career", 1), ("vocation", 1), ("business", 1), ("trade", 1), ("labour", 1), ("duty", 1)]))

main_body_words = ([("puts", 1, [("sets", 1), ("put", 1), ("places", 1), ("arranges", 1), ("sets
up", 1), ("adjusts", 1), ("tunes", 1), ("positions", 1), ("fixes", 1), ("establishes", 1),
("determines", 1)]),
    ("favourite", 1, [("preferred", 1), ("beloved", 1), ("cherished", 1), ("adored", 1),
("treasured", 1), ("prized", 1), ("top", 1), ("best-liked", 1), ("choice", 1), ("best", 1)]),
    ("radio", 2, [("broadcast", 2), ("airwaves", 2), ("transmitter", 2), ("receiver", 2), ("radio
set", 2), ("wireless", 2), ("transceiver", 2), ("tuner", 2), ("broadcasting device", 2), ("radio
receiver", 2)]),
```

("station", 3, [("channel", 3), ("service", 3), ("airwave", 3), ("platform", 3), ("provider", 3)]),
 ("sun fm", 1, [("sun f m", 1)]),
 ("host", 4, [("presenter", 4), ("announcer", 4), ("broadcaster", 4), ("disc jockey", 4), ("dj", 4)]),
 ("listeners", 2, [("audience", 2), ("hearers", 2), ("eavesdroppers", 2), ("observers", 2), ("auditors", 2), ("spectators", 2), ("viewers", 2), ("followers", 2), ("subscribers", 2), ("fans", 2)]),
 ("time", 1, [("moment", 1), ("instance", 1), ("occasion", 1), ("period", 1), ("interval", 1), ("point", 1), ("stage", 1), ("phase", 1), ("session", 1), ("junction", 1)]),
 ("competition", 1, [("contest", 1), ("challenge", 1), ("game", 1), ("tournament", 1), ("event", 1), ("match", 1), ("showdown", 1), ("trial", 1), ("face-off", 1), ("race", 1)]),
 ("listeners", 1, [("audience", 1), ("hearers", 1), ("eavesdroppers", 1), ("observers", 1), ("auditors", 1), ("spectators", 1), ("viewers", 1), ("followers", 1), ("subscribers", 1), ("fans", 1)]),
 ("identify", 1, [("recognize", 1), ("determine", 1), ("discern", 1), ("spot", 1), ("notice", 1), ("detect", 1), ("name", 1), ("define", 1), ("classify", 1), ("specify", 1)]),
 ("two", 1, [("2", 1)]),
 ("songs", 1, [("melodies", 1), ("song", 1), ("tune", 1), ("track", 1), ("ballad", 1), ("number", 1), ("piece", 1), ("ditty", 1), ("ditties", 1), ("anthem", 1), ("hymn", 1), ("chorus", 1)]),
 ("row", 1, [("sequence", 1), ("series", 1), ("line", 1), ("chain", 1), ("succession", 1), ("continuum", 1), ("stream", 1), ("course", 1), ("progression", 1), ("run", 1)]),
 ("played", 1, [("broadcasted", 1), ("plays", 1), ("play", 1), ("aired", 1), ("streamed", 1), ("transmitted", 1), ("presented", 1), ("run", 1), ("featured", 1), ("showed", 1), ("put on", 1), ("played out", 1)]),
 ("seconds", 1, [("moments", 1), ("second", 1), ("beats", 1), ("ticks", 1), ("instants", 1), ("jiffies", 1), ("blinks", 1), ("flashes", 1), ("heartbeats", 1), ("breaths", 1), ("bits", 1)]),
 ("emma", 4, [("emma's", 4)]),
 ("recognises", 1, [("identifies", 1), ("recognise", 1), ("recognised", 1), ("notices", 1), ("discerns", 1), ("detects", 1), ("observes", 1), ("acknowledges", 1), ("understands", 1), ("realizes", 1), ("perceives", 1), ("grasps", 1)]),

("calls", 1, [("rings", 1), ("called", 1), ("contacted", 1), ("contacts", 1), ("call", 1), ("phones", 1), ("dials", 1), ("contacts", 1), ("communicates", 1), ("gets in touch", 1), ("reaches out", 1), ("connects", 1), ("makes a call", 1), ("buzzes", 1)]),

("immediately", 1, [("instantly", 1), ("straightaway", 1), ("promptly", 1), ("right away", 1), ("directly", 1), ("at once", 1), ("without delay", 1), ("instantaneously", 1), ("swiftly", 1), ("speedily", 1)]),

("surprisingly", 1, [("unexpectedly", 1), ("surprises", 1), ("surprise", 1), ("surprised", 1), ("astonishingly", 1), ("amazingly", 1), ("startlingly", 1), ("shockingly", 1), ("staggeringly", 1), ("unbelievably", 1), ("incredibly", 1), ("remarkably", 1), ("unpredictably", 1)]),

("connected", 1, [("linked", 1), ("connecting", 1), ("connect", 1), ("connects", 1), ("joined", 1), ("attached", 1), ("coupled", 1), ("tied", 1), ("united", 1), ("bonded", 1), ("associated", 1), ("affiliated", 1), ("engaged", 1)]),

("straight", 1, [("direct", 1), ("right", 1), ("immediately", 1), ("uninterrupted", 1), ("nonstop", 1), ("straightaway", 1), ("without stopping", 1), ("constantly", 1), ("continually", 1), ("without deviation", 1)]),

("away", 1, [("immediately", 1), ("directly", 1), ("right off", 1), ("straight off", 1), ("without delay", 1), ("at once", 1), ("instantaneously", 1), ("promptly", 1), ("instantly", 1), ("swiftly", 1)]),

("answers", 1, [("picks up", 1), ("answer", 1), ("answered", 1), ("picked up", 1), ("connected", 1), ("responds", 1), ("reacts", 1)]),

("correct", 1, [("right", 1), ("correctly", 1), ("accurate", 1), ("true", 1), ("valid", 1), ("exact", 1), ("precise", 1), ("proper", 1), ("appropriate", 1), ("factual", 1), ("spot-on", 1)]),

("congratulates", 2, [("praises", 1), ("congratulate", 1), ("congratulated", 1), ("commends", 1), ("lauds", 1), ("applauds", 1), ("celebrates", 1), ("salutes", 1), ("hails", 1), ("honours", 1), ("extols", 1), ("acclaims", 1), ("pleased", 1)]),

("won", 1, [("secured", 1), ("winning", 1), ("win", 1), ("gained", 1), ("achieved", 1), ("scored", 1), ("attained", 1), ("acquired", 1), ("received", 1), ("triumphed", 1), ("prevailed", 1), ("procured", 1)]),

("biggest", 1, [("largest", 1), ("greatest", 1), ("vastest", 1), ("broadest", 1), ("grandest", 1), ("heaviest", 1), ("major", 1), ("main", 1), ("paramount", 1), ("supreme", 1), ("best", 1)]),

("prize", 3, [("reward", 3), ("award", 3), ("bounty", 3), ("gift", 3), ("bonus", 3), ("trophy", 3), ("honour", 3), ("recognition", 3), ("benefit", 3), ("gain", 3)]),

("ever", 1, [("ever", 1)]),

("given", 1, [("awarded", 1), ("giveaway", 1), ("gave", 1), ("give", 1), ("present", 1),
 ("provide", 1), ("bestow", 1), ("grant", 1), ("endow", 1), ("furnish", 1), ("supply", 1),
 ("supplied", 1), ("confer", 1), ("deliver", 1)]),
 ("away", 1, [("out", 1), ("off", 1), ("forth", 1)]),
 ("huge", 1, [("large", 1), ("massive", 1), ("gigantic", 1), ("enormous", 1), ("immense",
 1), ("vast", 1), ("great", 1), ("grand", 1), ("substantial", 1), ("colossal", 1)]),
 ("cash", 1, [("money", 1), ("currency", 1), ("funds", 1), ("capital", 1), ("finances", 1),
 ("banknotes", 1), ("greenbacks", 1), ("dough", 1), ("lucre", 1), ("bread", 1)]),
 ("luxury", 1, [("lavish", 1), ("opulent", 1), ("deluxe", 1), ("extravagant", 1), ("plush",
 1), ("grand", 1), ("posh", 1), ("high-end", 1), ("sumptuous", 1), ("affluent", 1)]),
 ("holiday", 1, [("vacation", 1), ("break", 1), ("leave", 1), ("recess", 1), ("getaway", 1),
 ("retreat", 1), ("time off", 1), ("respite", 1), ("trip", 1), ("sabbatical", 1)]),
 ("bali", 1, [("bali", 1)]),
 ("thrilled", 1, [("excited", 1), ("happy", 1), ("chuffed", 1), ("elated", 1), ("overjoyed",
 1), ("ecstatic", 1), ("delighted", 1), ("exhilarated", 1), ("enthused", 1), ("tickled", 1), ("over
 the moon", 1), ("jubilant", 1)]),
 ("starts", 1, [("begins", 1), ("initiates", 1), ("commences", 1), ("embarks", 1),
 ("launches", 1), ("kicks off", 1), ("sets off", 1), ("gets going", 1), ("opens", 1), ("undertakes",
 1)]),
 ("crying", 1, [("weeping", 1), ("cry", 1), ("cried", 1), ("sobbing", 1), ("shedding tears",
 1), ("tearful", 1), ("wailing", 1), ("lamenting", 1), ("snivelling", 1), ("bawling", 1),
 ("blubbering", 1), ("moaning", 1)]),
 ("thanks", 1, [("appreciates", 1), ("thanked", 1), ("thank", 1), ("thanking", 1),
 ("expresses gratitude", 1), ("acknowledges", 1), ("praises", 1), ("credits", 1), ("shows
 appreciation", 1), ("gives thanks", 1), ("commends", 1), ("recognizes", 1), ("salutes", 1)]),
 ("host", 3, [("presenter", 3), ("hosts", 3), ("host's", 3), ("announcer", 3), ("broadcaster",
 3), ("disc jockey", 3), ("dj", 3), ("showrunner", 3), ("speaker", 3), ("interviewer", 3),
 ("commentator", 3), ("narrator", 3)]),
 ("spend", 1, [("use", 1), ("spent", 1), ("allocate", 1), ("expend", 1), ("invest", 1), ("pay
 out", 1), ("disburse", 1), ("apply", 1), ("devote", 1), ("lay out", 1), ("squander", 1)]),
 ("money", 1, [("cash", 1), ("funds", 1), ("capital", 1), ("currency", 1), ("resources", 1),
 ("finances", 1), ("wealth", 1), ("dough", 1), ("assets", 1), ("bankroll", 1)]),
 ("new", 1, [("brand-new", 1), ("fresh", 1), ("recent", 1), ("modern", 1), ("up-to-date",
 1), ("latest", 1), ("current", 1), ("novel", 1), ("contemporary", 1), ("unprecedented", 1)]),

("car", 1, [("vehicle", 1), ("automobile", 1), ("motorcar", 1), ("machine", 1), ("wheels", 1), ("auto", 1), ("motor", 1), ("ride", 1), ("transport", 1), ("motor vehicle", 1)]),

("kitchen", 1, [("cooking area", 1), ("cook room", 1), ("galley", 1), ("cuisine", 1), ("pantry", 1), ("scullery", 1), ("canteen", 1), ("cookhouse", 1), ("culinary area", 1), ("kitchenette", 1)]),

("save", 1, [("reserve", 1), ("savings", 1), ("saves", 1), ("saved", 1), ("keep", 1), ("hold back", 1), ("set aside", 1), ("store", 1), ("stash", 1), ("accumulate", 1), ("preserve", 1), ("hoard", 1), ("retain", 1)]),

("rest", 1, [("remainder", 1), ("balance", 1), ("residue", 1), ("surplus", 1), ("leftovers", 1), ("remnant", 1), ("surplusage", 1), ("residuum", 1), ("remaining", 1), ("excess", 1)]),

("again", 1, [("once more", 1), ("repeatedly", 1), ("anew", 1), ("another time", 1), ("a second time", 1), ("afresh", 1), ("over again", 1), ("once again", 1)]),

("gives", 1, [("provides", 1), ("tells", 1), ("offers", 1), ("supplies", 1), ("presents", 1), ("grants", 1), ("furnishes", 1), ("bestows", 1), ("delivers", 1), ("hands over", 1), ("endows", 1)]),

("instructions", 1, [("directions", 1), ("instructs", 1), ("instructed", 1), ("instruction", 1), ("guidelines", 1), ("orders", 1), ("commands", 1), ("indications", 1), ("steps", 1), ("rules", 1), ("requirements", 1), ("procedures", 1), ("protocols", 1)]),

("how", 1, [("method", 1), ("way", 1), ("process", 1), ("procedure", 1), ("technique", 1), ("strategy", 1), ("approach", 1), ("manner", 1), ("style", 1), ("mode", 1)]),

("collect", 1, [("gather", 1), ("get", 1), ("obtain", 1), ("receive", 1), ("accumulate", 1), ("procure", 1), ("acquire", 1), ("pick up", 1), ("secure", 1), ("retrieve", 1), ("access", 1), ("amass", 1)]))

last_sentence_words = [("emma", 1, [("emma's", 1)]),

("calls", 1, [("rings", 1), ("called", 1), ("ring", 1), ("rang", 1), ("phone", 1), ("phones", 1), ("dials", 1), ("contacts", 1), ("reaches out", 1), ("gets in touch", 1), ("communicates", 1), ("connects", 1), ("makes a call", 1), ("buzzes", 1)]),

("tell", 1, [("tells", 1), ("gave", 1), ("give", 1), ("told", 1), ("telling", 1), ("inform", 1), ("informs", 1), ("informed", 1)]),

("husband", 1, [("spouse", 1), ("partner", 1), ("mate", 1), ("other half", 1), ("consort", 1), ("hubby", 1), ("life partner", 1), ("significant other", 1)]),

```
    ("news", 1, [("update", 1), ("information", 1), ("report", 1), ("announcement", 1),  
    ("disclosure", 1), ("message", 1), ("communique", 1), ("notification", 1), ("bulletin", 1),  
    ("tidings", 1)]))
```

```
# Convert list of words to formatted string
```

```
first_sentence_words_str = []  
for word_info in first_sentence_words:  
    word = word_info[0]  
    max_count = word_info[1]  
    synonyms = ','.join([syn[0] for syn in word_info[2]])  
    first_sentence_words_str.append(f'{word}\t{synonyms}\t{max_count}')
```

```
main_body_words_str = []  
for word_info in main_body_words:  
    word = word_info[0]  
    max_count = word_info[1]  
    synonyms = ','.join([syn[0] for syn in word_info[2]])  
    main_body_words_str.append(f'{word}\t{synonyms}\t{max_count}')
```

```
last_sentence_words_str = []  
for word_info in last_sentence_words:  
    word = word_info[0]  
    max_count = word_info[1]  
    synonyms = ','.join([syn[0] for syn in word_info[2]])  
    last_sentence_words_str.append(f'{word}\t{synonyms}\t{max_count}')
```

```
first_sentence_words_str = '\n'.join(first_sentence_words_str)  
main_body_words_str = '\n'.join(main_body_words_str)  
last_sentence_words_str = '\n'.join(last_sentence_words_str)
```

```
# Create input widgets
```

```
first_sentence_input = widgets.Textarea(value="", description='First sentence:')
```

```

first_sentence_word_input = widgets.Textarea(value=first_sentence_words_str,
description='Target words:')
main_body_input = widgets.Textarea(value="", description='Main body:')
main_body_word_input = widgets.Textarea(value=main_body_words_str,
description='Target words:')
last_sentence_input = widgets.Textarea(value="", description='Last sentence:')
last_sentence_word_input = widgets.Textarea(value=last_sentence_words_str,
description='Target words:')
display(first_sentence_input, first_sentence_word_input, main_body_input,
main_body_word_input, last_sentence_input, last_sentence_word_input)

```

Widget Button

```

button = widgets.Button(description='Analyze')
output = widgets.Output()
display(button, output)

```

```
def analyze_text(b):
```

```
    output.clear_output()
```

```
    total_count = [0, 0, 0]
```

```
    with output:
```

```
        text_inputs = [first_sentence_input.value.lower(), main_body_input.value.lower(),
last_sentence_input.value.lower()]

```

```
        word_inputs = [first_sentence_word_input.value.split('\n'),
main_body_word_input.value.split('\n'), last_sentence_word_input.value.split('\n')]

```

```
        for i, (text_input, word_input) in enumerate(zip(text_inputs, word_inputs)):
```

```
            current_text = text_input
```

```
            set1 = []
```

```
            for line in word_input:
```

```
                word_parts = line.split('\t')
```

```
                if len(word_parts) == 3:
```

```
                    word = word_parts[0].strip()

```

```

        if not word: # skip if word is an empty string
            continue
        max_count = int(word_parts[2].strip())
        synonyms = [(syn, 1) for syn in word_parts[1].split(',') if syn] # Make sure
synonym is not an empty string
        set1.append((word, max_count, synonyms))

set1_count = 0
counted_words = defaultdict(int)
counted_synonyms = set()

for word_info in set1:
    current_word = word_info[0]
    max_count = word_info[1]
    count_word = len(re.findall(f'\\b{current_word}\\b', current_text))
    count_word = min(count_word, max_count)
    if count_word > 0:
        counted_words[current_word] = count_word
        set1_count += count_word
        current_text = re.sub(f'\\b{current_word}\\b', '\\033[31m' + current_word +
'\\033[0m', current_text)

    if current_word not in counted_synonyms:
        for synonym, _ in word_info[2]:
            count_syn = len(re.findall(f'\\b{synonym.strip()}\\b', current_text))
            count_syn = min(count_syn, max_count - count_word)
            if count_syn > 0:
                counted_words[synonym.strip()] = count_syn
                counted_synonyms.add(current_word)
                set1_count += count_syn
                current_text = re.sub(f'\\b{synonym.strip()}\\b', '\\033[31m' +
synonym.strip() + '\\033[0m', current_text)
            break

```

```

print(current_text)
print("Set 1 Count: " + str(set1_count))
total_count[i] += set1_count # Add to total count
for word, count in counted_words.items():
    print(f'Word/Synonym "{word}" (from "{next(w[0] for w in set1 if word in [w[0]]
+ [syn[0] for syn in w[2]])}") was found {count} time(s)')

print(f'First sentence total count: {total_count[0]}')
print(f'Main body total count: {total_count[1]}')
print(f'Last sentence total count: {total_count[2]}')

button.on_click(analyze_text)

```

The Return

```
from collections import defaultdict
import re
from IPython.display import display
from ipywidgets import widgets

# Target Words + Synonyms in sets

first_sentence_words = [("fiona", 1, [("fiona's")]),
    ("getting", 1, [("preparing", 1), ("arranging", 1), ("becoming", 1), ("became", 1), ("got",
1), ("gets", 1)]),
    ("ready", 1, [("prepared", 1), ("set", 1), ("primed", 1), ("equipped", 1), ("organized", 1),
("arranged", 1), ("poised", 1), ("geared", 1), ("prepped", 1), ("slated", 1)]),
    ("go", 1, [("proceed", 1), ("travel", 1), ("move", 1), ("depart", 1), ("head", 1),
("journey", 1), ("drive", 1), ("traverse", 1), ("voyage", 1), ("navigate", 1), ("goes", 1),
("going", 1)]),
    ("town", 1, []),
    ("rainy", 1, [("wet", 1), ("drizzly", 1), ("showery", 1), ("stormy", 1), ("damp", 1), ("rain-
filled", 1), ("misty", 1), ("soggy", 1), ("drizzling", 1), ("raining", 1), ("rains", 1)]),
    ("afternoon", 1, [("noon", 1)])])

main_body_words = [("needed", 1, [("required", 1), ("necessary", 1), ("essential", 1),
("desired", 1), ("mandated", 1), ("obligatory", 1), ("compulsory", 1), ("demanded", 1),
("called for", 1), ("requisite", 1), ("needs", 1), ("needing", 1)]),
    ("return", 1, [("send back", 1), ("restore", 1), ("revert", 1), ("refund", 1), ("resend", 1),
("take back", 1), ("replace", 1), ("reciprocate", 1), ("remit", 1), ("repay", 1), ("returning", 1),
("returns", 1)]),
    ("winter", 1, [("cold", 1), ("frosty", 1), ("icy", 1), ("snowy", 1), ("wintry", 1), ("chilly",
1), ("frigid", 1), ("arctic", 1), ("boreal", 1), ("nippy", 1)]),
    ("clothes", 1, [("garments", 1), ("attire", 1), ("apparel", 1), ("outfits", 1), ("wardrobe",
1), ("clothing", 1)]),
    ("gardening", 1, [("horticultural", 1), ("planting", 1), ("cultivating", 1), ("garden", 1),
("floricultural", 1), ("cultivation", 1), ("gardens", 1)]),
    ("tools", 1, [("instruments", 1), ("implements", 1), ("devices", 1), ("utensils", 1),
("gear", 1), ("equipment", 1), ("appliances", 1), ("machinery", 1), ("apparatus", 1),
("hardware", 1), ("tool", 1), ("utensil", 1)]),
    ("bought", 1, [("purchased", 1), ("acquired", 1), ("procured", 1), ("obtained", 1),
("gotten", 1), ("secured", 1), ("invested in", 1), ("picked up", 1), ("took", 1), ("paid for", 1),
("buy", 1), ("buys", 1), ("paid for", 1)]),
    ("online", 1, [("internet", 1), ("web", 1), ("net", 1), ("computer", 1)]),
    ("friday", 1, []),
```

("week", 1, []),
 ("prior", 1, [("earlier", 1), ("preceding", 1), ("before", 1), ("former", 1), ("previous", 1),
 ("antecedent", 1), ("pre-existent", 1)]),
 ("laid", 1, [("placed", 1), ("set", 1), ("positioned", 1), ("put", 1), ("arranged", 1),
 ("located", 1), ("spread", 1), ("allocated", 1), ("rested", 1), ("deposited", 1), ("places", 1),
 ("place", 1), ("puts", 1), ("lay", 1), ("lays", 1)]),
 ("items", 3, [("articles", 1), ("objects", 1), ("pieces", 1), ("units", 1), ("things", 1),
 ("goods", 1), ("products", 1), ("materials", 1), ("stuff", 1), ("commodities", 1), ("item", 1)]),
 ("living", 1, [("main", 1), ("sitting", 1)]),
 ("room", 1, [("space", 1), ("area", 1)]),
 ("floor", 1, [("ground", 1), ("base", 1), ("bottom", 1)]),
 ("ready", 1, [("prepared", 1), ("set", 1), ("poised", 1), ("equipped", 1), ("primed", 1),
 ("geared", 1), ("all set", 1), ("prepped", 1)]),
 ("package", 1, [("wrap", 1), ("box", 1), ("pack", 1), ("parcel", 1), ("bundle", 1),
 ("encase", 1), ("crate", 1), ("bag", 1), ("containerise", 1), ("enclose", 1), ("packaged", 1),
 ("packages", 1), ("packaging", 1)]),
 ("fiona", 1, []),
 ("noticed", 1, [("saw", 1), ("observed", 1), ("detected", 1), ("discerned", 1),
 ("recognised", 1), ("spotted", 1), ("identified", 1), ("noted", 1), ("perceived", 1),
 ("discovered", 1), ("notices", 1), ("noticed", 1), ("spots", 1), ("spot", 1), ("sees", 1), ("see",
 1)]),
 ("thread", 2, [("strand", 1), ("yarn", 1), ("string", 1), ("fiber", 1), ("filament", 1), ("cord",
 1), ("line", 1), ("twine", 1), ("wire", 1), ("tread", 1), ("threads", 1)]),
 ("carpet", 1, [("rug", 1), ("mat", 1), ("runner", 1), ("flooring", 1), ("covering", 1),
 ("underlay", 1), ("textile", 1), ("floor covering", 1)]),
 ("loose", 1, [("unfixed", 1), ("unattached", 1), ("detached", 1), ("unsecured", 1), ("free",
 1), ("unbound", 1), ("slack", 1), ("unfettered", 1), ("unfastened", 1), ("lax", 1)]),
 ("created", 1, [("made", 1), ("makes", 1), ("make", 1), ("making", 1), ("forms", 1),
 ("forming", 1), ("formed", 1), ("producing", 1), ("produces", 1), ("produced", 1),
 ("generated", 1), ("developed", 1), ("fashioned", 1), ("crafted", 1), ("designed", 1),
 ("established", 1), ("constructed", 1), ("creates", 1), ("create", 1), ("creating", 1)]),
 ("loop", 1, [("circle", 1), ("ring", 1), ("curl", 1), ("coil", 1), ("spiral", 1), ("round", 1),
 ("twirl", 1), ("whorl", 1), ("curve", 1), ("gyre", 1), ("loops", 1), ("looping", 1), ("looped", 1)]),
 ("stuck", 1, [("fixed", 1), ("attached", 1), ("adhered", 1), ("clung", 1), ("secured", 1),
 ("fastened", 1), ("embedded", 1), ("set", 1), ("glued", 1), ("lodged", 1), ("sticks", 1), ("stick",
 1), ("sticking", 1)]),
 ("took", 1, [("acquired", 1), ("obtained", 1), ("got", 1), ("grasped", 1), ("seized", 1),
 ("received", 1), ("held", 1), ("captured", 1), ("snatched", 1), ("collected", 1), ("take", 1),
 ("takes", 1), ("taking", 1)]),
 ("scissors", 1, [("shears", 1), ("cutters", 1), ("clippers", 1), ("blade", 1), ("snips", 1),
 ("trimmer", 1), ("cutting tool", 1), ("snippers", 1), ("cutting instrument", 1), ("scissor", 1)]),
 ("cut", 1, [("slice", 1), ("trim", 1), ("chop", 1), ("carve", 1), ("clip", 1), ("sever", 1),
 ("prune", 1), ("slash", 1), ("shear", 1), ("shave", 1), ("cuts", 1), ("cutting", 1), ("cutter", 1),
 ("slices", 1), ("trims", 1), ("chops", 1), ("chopping", 1), ("slicing", 1)]),

("put", 1, [("placed", 1), ("positioned", 1), ("set", 1), ("laid", 1), ("installed", 1),
 ("arranged", 1), ("deposited", 1), ("stored", 1), ("located", 1), ("stowed", 1), ("puts", 1)]),
 ("plastic", 1, [("synthetic", 1), ("polymer", 1), ("PVC", 1), ("polyethylene", 1), ("vinyl",
 1), ("acrylic", 1), ("polypropylene", 1)]),
 ("parcel", 1, [("package", 1), ("packet", 1), ("bundle", 1), ("pack", 1), ("box", 1),
 ("container", 1), ("wrapping", 1), ("bag", 1), ("case", 1), ("envelope", 1), ("parcels", 1)]),
 ("bags", 1, [("sacks", 1), ("pouches", 1), ("containers", 1), ("satchels", 1), ("packets", 1),
 ("bundles", 1), ("packs", 1), ("carriers", 1), ("cases", 1), ("totes", 1), ("bag", 1)]),
 ("taped", 1, [("sealed", 1), ("bound", 1), ("fastened", 1), ("secured", 1), ("tied", 1),
 ("stuck", 1), ("adhered", 1), ("attached", 1), ("wrapped", 1), ("encased", 1), ("tapes", 1),
 ("taped", 1), ("taping", 1), ("sealing", 1), ("seals", 1)]),
 ("closed", 1, [("sealed", 1), ("shut", 1), ("enclosed", 1), ("locked", 1), ("fastened", 1),
 ("secured", 1), ("concluded", 1), ("terminated", 1), ("ended", 1), ("finished", 1), ("closing", 1),
 ("closes", 1)]),
 ("pen", 1, [("marker", 1), ("quill", 1), ("stylus", 1), ("pencil", 1), ("ballpoint", 1),
 ("writing instrument", 1), ("ink pen", 1), ("felt-tip", 1), ("biro", 1), ("fountain pen", 1)]),
 ("find", 2, [("locate", 1), ("discover", 1), ("detect", 1), ("uncover", 1), ("identify", 1),
 ("spot", 1), ("notice", 1), ("recognize", 1), ("unearth", 1), ("discern", 1), ("finds", 1),
 ("finding", 1), ("finder", 1)]),
 ("write", 1, [("pen", 1), ("compose", 1), ("record", 1), ("script", 1), ("draft", 1),
 ("scribe", 1), ("inscribe", 1), ("jot", 1), ("scribble", 1), ("note", 1)]),
 ("addresses", 1, [("locations", 1), ("destinations", 1), ("sites", 1), ("places", 1), ("spots",
 1), ("points", 1), ("locales", 1), ("coordinates", 1), ("directions", 1), ("positions", 1),
 ("address", 1)]),
 ("large", 1, [("big", 1), ("huge", 1), ("vast", 1), ("giant", 1), ("extensive", 1),
 ("enormous", 1), ("massive", 1), ("substantial", 1), ("great", 1), ("sizeable", 1), ("great", 1)]),
 ("marker", 1, [("pen", 1), ("highlighter", 1), ("indicator", 1), ("signal", 1), ("sign", 1),
 ("symbol", 1), ("pointer", 1), ("mark", 1), ("emblem", 1), ("signpost", 1)]),
 ("packaged", 1, [("wrapped", 1), ("enclosed", 1), ("boxed", 1), ("packed", 1),
 ("parcelled", 1), ("bundled", 1), ("bagged", 1), ("enveloped", 1), ("sealed", 1), ("contained",
 1), ("packages", 1), ("package", 1)]),
 ("searched", 1, [("looked for", 1), ("hunted", 1), ("sought", 1), ("scoured", 1),
 ("explored", 1), ("examined", 1), ("inspected", 1), ("investigated", 1), ("probed", 1),
 ("checked", 1), ("looking for", 1), ("looks for", 1), ("look for", 1)]),
 ("car", 1, [("vehicle", 1), ("automobile", 1), ("motor", 1), ("machine", 1), ("wheels", 1),
 ("ride", 1), ("auto", 1), ("motorcar", 1)]),
 ("keys", 1, [("key", 1)]),
 ("nowhere", 1, [("absent", 1), ("missing", 1), ("vanished", 1), ("gone", 1), ("invisible",
 1), ("non-existent", 1), ("unavailable", 1), ("unseen", 1), ("not present", 1), ("not there", 1)]),
 ("sight", 1, [("view", 1), ("vision", 1), ("glimpse", 1), ("glance", 1), ("look", 1), ("peep",
 1), ("eyeshot", 1), ("observation", 1), ("apparition", 1), ("perception", 1)]),
 ("lifted", 1, [("raised", 1), ("elevated", 1), ("hoisted", 1), ("uplifted", 1), ("moved up", 1),
 ("boosted", 1), ("upturned", 1), ("upraised", 1), ("uprooted", 1), ("ascended", 1), ("lifts", 1),
 ("lifter", 1), ("lift", 1), ("lifting", 1)]),


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("sofa", 1, [("couch", 1), ("settee", 1), ("divan", 1), ("loveseat", 1), ("davenport", 1),
("lounge", 1), ("lounger", 1), ("daybed", 1), ("chaise", 1), ("canapé", 1), ("sofas", 1)]),
("cushions", 1, [("pillows", 1), ("pads", 1), ("cushioning", 1), ("comforters", 1),
("cushion", 1)]),
("check", 1, [("inspect", 1), ("examine", 1), ("look over", 1), ("scan", 1), ("review", 1),
("survey", 1), ("study", 1), ("probe", 1), ("investigate", 1), ("search", 1), ("checking", 1),
("checks", 1), ("checked", 1)]),
("underneath", 1, [("below", 1), ("beneath", 1), ("under", 1), ("lower", 1), ("nether", 1),
("inferior", 1), ("sub", 1), ("bottom", 1), ("underfoot", 1), ("downstairs", 1)]),
("suddenly", 1, [("abruptly", 1), ("instantly", 1), ("immediately", 1), ("swiftly", 1),
("promptly", 1), ("quickly", 1), ("hastily", 1), ("speedily", 1), ("rapidly", 1), ("all of a
sudden", 1), ("sudden", 1)]),
("remembered", 1, [("recalled", 1), ("recollected", 1), ("reminisced", 1), ("thought of",
1), ("brought to mind", 1), ("memorized", 1), ("kept in mind", 1), ("thought back to", 1),
("called to mind", 1), ("retained", 1), ("remembers", 1), ("remembering", 1), ("recall", 1)]),
("left", 1, [("departed", 1), ("exited", 1), ("went", 1), ("quit", 1), ("abandoned", 1),
("deserted", 1), ("forsaken", 1), ("left behind", 1), ("vacated", 1), ("withdraw", 1), ("leave",
1), ("leaves", 1)]),
("fruit", 1, []),
("bowl", 1, [("dish", 1), ("container", 1), ("basin", 1), ("pot", 1), ("vessel", 1), ("jar", 1)]),
("kitchen", 1, [])

```

```

last_sentence_words = [("fiona", 1, [("fiona's")]),
("coat", 1, [("jacket", 1), ("overcoat", 1), ("cloak", 1), ("wrap", 1), ("raincoat", 1),
("trench", 1), ("mantle", 1), ("parka", 1), ("poncho", 1), ("garment", 1)]),
("loaded", 1, [("packed", 1), ("filled", 1), ("stuffed", 1), ("loaded up", 1), ("brimmed",
1), ("charged", 1), ("laded", 1), ("crammed", 1), ("heaped", 1), ("freighted", 1)]),
("packages", 1, [("parcels", 1), ("bundles", 1), ("boxes", 1), ("containers", 1),
("wrappings", 1), ("packets", 1), ("bags", 1), ("wraps", 1), ("cases", 1), ("loads", 1)]),
("car", 1, [("vehicle", 1), ("automobile", 1), ("motor", 1), ("machine", 1), ("wheels", 1),
("transport", 1), ("ride", 1), ("auto", 1), ("motorcar", 1), ("machine", 1)])]

```

Convert list of words to formatted string

```

first_sentence_words_str = []
for word_info in first_sentence_words:
    word = word_info[0]
    max_count = word_info[1]
    synonyms = ','.join([syn[0] for syn in word_info[2]])
    first_sentence_words_str.append(f'{word}\t{synonyms}\t{max_count}')

```

```

main_body_words_str = []
for word_info in main_body_words:
    word = word_info[0]

```

```

max_count = word_info[1]
synonyms = ','.join([syn[0] for syn in word_info[2]])
main_body_words_str.append(f'{word}\t{synonyms}\t{max_count}')

last_sentence_words_str = []
for word_info in last_sentence_words:
    word = word_info[0]
    max_count = word_info[1]
    synonyms = ','.join([syn[0] for syn in word_info[2]])
    last_sentence_words_str.append(f'{word}\t{synonyms}\t{max_count}')

first_sentence_words_str = '\n'.join(first_sentence_words_str)
main_body_words_str = '\n'.join(main_body_words_str)
last_sentence_words_str = '\n'.join(last_sentence_words_str)

# Create input widgets
first_sentence_input = widgets.Textarea(value="", description='First sentence:')
first_sentence_word_input = widgets.Textarea(value=first_sentence_words_str,
description='Target words:')
main_body_input = widgets.Textarea(value="", description='Main body:')
main_body_word_input = widgets.Textarea(value=main_body_words_str,
description='Target words:')
last_sentence_input = widgets.Textarea(value="", description='Last sentence:')
last_sentence_word_input = widgets.Textarea(value=last_sentence_words_str,
description='Target words:')
display(first_sentence_input, first_sentence_word_input, main_body_input,
main_body_word_input, last_sentence_input, last_sentence_word_input)

# Widget Button

button = widgets.Button(description='Analyze')
output = widgets.Output()
display(button, output)

def analyze_text(b):
    output.clear_output()
    total_count = [0, 0, 0]
    with output:

        text_inputs = [first_sentence_input.value.lower(), main_body_input.value.lower(),
last_sentence_input.value.lower()]
        word_inputs = [first_sentence_word_input.value.split('\n'),
main_body_word_input.value.split('\n'), last_sentence_word_input.value.split('\n')]

```

```

for i, (text_input, word_input) in enumerate(zip(text_inputs, word_inputs)):
    current_text = text_input
    set1 = []
    for line in word_input:
        word_parts = line.split('\t')
        if len(word_parts) == 3:
            word = word_parts[0].strip()
            if not word: # skip if word is an empty string
                continue
            max_count = int(word_parts[2].strip())
            synonyms = [(syn, 1) for syn in word_parts[1].split(',') if syn] # Make sure
synonym is not an empty string
            set1.append((word, max_count, synonyms))

    set1_count = 0
    counted_words = defaultdict(int)
    counted_synonyms = set()

    for word_info in set1:
        current_word = word_info[0]
        max_count = word_info[1]
        count_word = len(re.findall(f'\\b{current_word}\\b', current_text))
        count_word = min(count_word, max_count)
        if count_word > 0:
            counted_words[current_word] = count_word
            set1_count += count_word
            current_text = re.sub(f'\\b{current_word}\\b', '\033[31m' + current_word +
'\033[0m', current_text)

            if current_word not in counted_synonyms:
                for synonym, _ in word_info[2]:
                    count_syn = len(re.findall(f'\\b{synonym.strip()}\\b', current_text))
                    count_syn = min(count_syn, max_count - count_word)
                    if count_syn > 0:
                        counted_words[synonym.strip()] = count_syn
                        counted_synonyms.add(current_word)
                        set1_count += count_syn
                        current_text = re.sub(f'\\b{synonym.strip()}\\b', '\033[31m' +
synonym.strip() + '\033[0m', current_text)
                        break

    print(current_text)
    print("Set 1 Count: " + str(set1_count))
    total_count[i] += set1_count # Add to total count

```

```

        for word, count in counted_words.items():
            print(f'Word/Synonym "{word}" (from "{next(w[0] for w in set1 if word in [w[0]]
+ [syn[0] for syn in w[2]])}" was found {count} time(s)')

        print(f'First sentence total count: {total_count[0]}')
        print(f'Main body total count: {total_count[1]}')
        print(f'Last sentence total count: {total_count[2]}')

button.on_click(analyze_text)

```

The Skateboard Race

```
from collections import defaultdict
import re
from IPython.display import display
from ipywidgets import widgets

# Pre-defined target words for each section
first_sentence_words = [
    ("josh", 1, [("josh", 0)]),
    ("decides", 1, [("chooses", 1), ("resolves", 1), ("determines", 1), ("opts", 1), ("elects", 1),
    ("concludes", 1), ("picks", 1), ("settles on", 1), ("finalizes", 1), ("makes up his mind", 1)]),
    ("meet", 1, [("encounter", 1), ("gather", 1), ("unite", 1), ("converge", 1), ("assemble", 1),
    ("connect", 1), ("get together", 1), ("join", 1), ("convene", 1), ("rendezvous", 1)]),
    ("friends", 1, [("buddies", 1), ("comrades", 1), ("mates", 1), ("pals", 1), ("companions", 1),
    ("chums", 1), ("colleagues", 1), ("associates", 1), ("peers", 1), ("cohorts", 1)]),
    ("park", 1, [("playground", 1), ("greenspace", 1), ("common", 1), ("public garden", 1),
    ("recreational area", 1), ("greenbelt", 1), ("nature reserve", 1), ("open space", 1), ("recreation
    ground", 1), ("square", 1)])

main_body_words = [
    ("friend", 1, [("pal", 1), ("companion", 1), ("ally", 1), ("mate", 1), ("buddy", 1),
    ("comrade", 1), ("cohort", 1), ("acquaintance", 1), ("colleague", 1), ("confidant", 1)]),
    ("billy", 3, []),
    ("invites", 1, [("encourages", 1), ("challenges", 1), ("asks", 1), ("challenge", 1), ("requests",
    1), ("calls", 1), ("summons", 1), ("beckons", 1), ("proposes", 1), ("persuades", 1), ("tempts",
    1), ("ushers", 1)]),
    ("race", 1, [("sprint", 1), ("dash", 1), ("run", 1), ("gallop", 1), ("rush", 1), ("speed", 1),
    ("compete", 1), ("dart", 1), ("scamper", 1), ("hustle", 1)]),
    ("down", 1, [("descend", 1), ("lower", 1), ("drop", 1), ("decline", 1), ("fall", 1),
    ("deteriorate", 1), ("decrease", 1), ("diminish", 1), ("lessen", 1), ("reduce", 1)]),
    ("steep", 1, [("sharp", 1), ("precipitous", 1), ("acute", 1), ("abrupt", 1), ("sheer", 1),
    ("brisk", 1), ("incline", 1), ("steeply inclined", 1), ("extreme", 1), ("high", 1)]),
    ("hill", 1, [("mound", 1), ("knoll", 1), ("rise", 1), ("height", 1), ("tumulus", 1),
    ("prominence", 1), ("embankment", 1), ("hillock", 1), ("knob", 1), ("butte", 1)]),
    ("skateboards", 1, [("boards", 1), ("skateboard", 1), ("board", 1), ("decks", 1),
    ("longboards", 1), ("shortboards", 1), ("scooters", 1), ("cruisers", 1), ("freestyle boards", 1),
    ("street boards", 1), ("vert boards", 1), ("penny boards", 1)]),
    ("josh", 5, [("josh", 0)]),
    ("makes", 1, [("forms", 1), ("creates", 1), ("produces", 1), ("constructs", 1), ("prepares", 1),
    ("designs", 1), ("fashions", 1), ("builds", 1), ("composes", 1), ("crafts", 1)]),
    ("quick", 1, [("rapid", 1), ("swift", 1), ("speedy", 1), ("hasty", 1), ("fast", 1), ("prompt", 1),
    ("immediate", 1), ("instantaneous", 1), ("accelerated", 1), ("expedited", 1)])
```

("start", 1, [("begin", 1), ("initiate", 1), ("commence", 1), ("embark", 1), ("launch", 1),
 ("kick off", 1), ("set out", 1), ("set off", 1), ("undertake", 1), ("proceed", 1)]),
 ("lead", 1, [("front", 1), ("ahead", 1), ("forefront", 1), ("head", 1), ("front-run", 1),
 ("outstrip", 1), ("outrun", 1), ("precede", 1), ("pioneer", 1), ("command", 1)]),
 ("faster", 1, [("quicker", 1), ("speedier", 1), ("swifter", 1), ("rapidly", 1), ("hastier", 1),
 ("briskly", 1), ("accelerated", 1), ("hurried", 1), ("advanced", 1), ("zippier", 1)]),
 ("board", 1, [("deck", 1), ("plank", 1), ("panel", 1), ("slab", 1), ("skateboard", 1), ("flat
 surface", 1), ("piece", 1), ("timber", 1), ("lumber", 1), ("mat", 1)]),
 ("starts", 1, [("begins", 1), ("initiates", 1), ("commences", 1), ("embarks", 1), ("launches",
 1), ("kicks off", 1), ("sets off", 1), ("sparks off", 1), ("sets in motion", 1), ("starts off", 1)]),
 ("wobbling", 1, [("shaking", 1), ("wobbles", 1), ("shakes", 1), ("teetering", 1), ("tottering",
 1), ("shuddering", 1), ("trembling", 1), ("rocking", 1), ("swaying", 1), ("quivering", 1),
 ("wiggling", 1), ("juddering", 1)]),
 ("suddenly", 1, [("abruptly", 1), ("unexpectedly", 1), ("instantly", 1), ("swiftly", 1),
 ("rapidly", 1), ("surprisingly", 1), ("all of a sudden", 1), ("out of the blue", 1), ("without
 warning", 1), ("immediately", 1)]),
 ("slips", 1, [("slides", 1), ("skids", 1), ("glides", 1), ("tumbles", 1), ("falls", 1), ("loses
 footing", 1), ("stumbles", 1), ("drops", 1), ("trips", 1), ("swoops", 1)]),
 ("underneath", 1, [("below", 1), ("under", 1), ("beneath", 1), ("down", 1), ("lower", 1),
 ("base", 1), ("nether", 1), ("bottom", 1), ("underbelly", 1), ("subterranean", 1)]),
 ("crashes", 1, [("collides", 1), ("smashes", 1), ("impacts", 1), ("slams", 1), ("hits", 1),
 ("bumps", 1), ("strikes", 1), ("collapses", 1), ("plummets", 1), ("tumbles", 1)]),
 ("ground", 1, [("floor", 1), ("earth", 1), ("surface", 1), ("terrain", 1), ("soil", 1), ("land", 1),
 ("turf", 1), ("groundwork", 1), ("ground level", 1), ("pavement", 1)]),
 ("painfully", 1, [("sorely", 1), ("agonisingly", 1), ("distressingly", 1), ("excruciatingly", 1),
 ("harshly", 1), ("severely", 1), ("acutely", 1), ("tormentingly", 1), ("unbearably", 1),
 ("intensely", 1)]),
 ("slides", 1, [("glides", 1), ("sliding", 1), ("slipping", 1), ("skidding", 1), ("skid", 1), ("slip",
 1), ("slips", 1), ("skids", 1), ("moves", 1), ("sweeps", 1), ("skates", 1), ("shifts", 1), ("coasts",
 1), ("drifts", 1), ("slithers", 1)]),
 ("concrete", 1, [("cement", 1), ("hard", 1), ("solid", 1), ("material", 1), ("paved", 1),
 ("tarmac", 1), ("asphalt", 1), ("stone", 1), ("pavement", 1), ("roadway", 1)]),
 ("shredding", 1, [("tearing", 1), ("rips", 1), ("rip", 1), ("scraping", 1), ("ripping", 1),
 ("fraying", 1), ("slicing", 1), ("cutting", 1), ("dismantling", 1), ("splitting", 1), ("fracturing",
 1), ("pulping", 1), ("trashing", 1)]),
 ("jeans", 2, [("denims", 2), ("pants", 2), ("trousers", 2), ("dungarees", 2), ("levi's", 2),
 ("blue jeans", 2), ("slacks", 2), ("overalls", 2), ("bottoms", 2), ("breeches", 2)]),
 ("coming", 2, [("arriving", 2), ("approaching", 2), ("drawing near", 2), ("advancing", 2),
 ("nearing", 2), ("progressing", 2), ("reaching", 2), ("turning up", 2), ("showing up", 2),
 ("coming up", 2)]),
 ("stop", 1, [("halt", 1), ("cease", 1), ("pause", 1), ("arrest", 1), ("check", 1), ("block", 1),
 ("end", 1), ("interrupt", 1), ("stay", 1), ("terminate", 1)]),
 ("feels", 1, [("senses", 1), ("experiences", 1), ("perceives", 1), ("detects", 1), ("suffers", 1),
 ("endures", 1), ("undergoes", 1), ("encounters", 1), ("recognizes", 1), ("notices", 1)]),

("strong", 1, [("powerful", 1), ("intense", 1), ("potent", 1), ("sturdy", 1), ("robust", 1),
 ("vigorous", 1), ("forceful", 1), ("firm", 1), ("hard", 1), ("stout", 1)]),
 ("jolt", 1, [("shock", 1), ("startle", 1), ("jar", 1), ("thrust", 1), ("bump", 1), ("lurch", 1),
 ("jounce", 1), ("shake", 1), ("surprise", 1), ("impact", 1)]),
 ("pain", 1, [("discomfort", 1), ("ache", 1), ("soreness", 1), ("throbbing", 1), ("agony", 1),
 ("hurt", 1), ("stinging", 1), ("sting", 1), ("suffering", 1), ("distress", 1)]),
 ("leg", 1, [("limb", 1), ("leg", 1), ("appendage", 1), ("lower extremity", 1), ("shanks", 1),
 ("stems", 1), ("pins", 1), ("stump", 1), ("thigh", 1), ("leg", 1), ("foot", 1)]),
 ("covered", 2, [("coated", 2), ("blanketed", 2), ("cloaked", 2), ("shrouded", 2), ("veiled", 2),
 ("clad", 2), ("enveloped", 2), ("encased", 2), ("shielded", 2), ("masked", 2)]),
 ("blood", 3, [("plasma", 3), ("bloodied", 3), ("haemoglobin", 3), ("gore", 3), ("life fluid",
 3), ("claret", 3), ("sanguine fluid", 3), ("vital fluid", 3), ("red cells", 3), ("bloodstream", 3),
 ("corpuscles", 3)]),
 ("wipe", 1, [("clean", 1), ("wipes", 1), ("cleans", 1), ("rubs", 1), ("brushes", 1), ("rub", 1),
 ("clear", 1), ("brush", 1), ("swab", 1), ("mop", 1), ("wash", 1), ("sweep", 1), ("buff", 1),
 ("scrub", 1)]),
 ("away", 1, [("apart", 1), ("distant", 1), ("off", 1), ("aside", 1), ("removed", 1), ("out", 1),
 ("elsewhere", 1), ("far", 1), ("afield", 1), ("astray", 1)]),
 ("notices", 1, [("observes", 1), ("seeing", 1), ("sees", 1), ("detects", 1), ("recognizes", 1),
 ("discerns", 1), ("spots", 1), ("identifies", 1), ("discovers", 1), ("finds", 1)]),
 ("large", 1, [("big", 1), ("huge", 1), ("substantial", 1), ("extensive", 1), ("vast", 1),
 ("enormous", 1), ("gigantic", 1), ("immense", 1), ("grand", 1), ("sizeable", 1)]),
 ("white", 1, [("pale", 1), ("colourless", 1), ("bleached", 1), ("snowy", 1), ("pearly", 1),
 ("alabaster", 1), ("ivory", 1), ("milk-like", 1), ("fair", 1), ("clear", 1)]),
 ("lump", 1, [("mass", 1), ("bulge", 1), ("bump", 1), ("swelling", 1), ("nodule", 1), ("clump",
 1), ("growth", 1), ("tumour", 1), ("protuberance", 1), ("hump", 1)]),
 ("middle", 1, [("centre", 1), ("core", 1), ("midst", 1), ("heart", 1), ("median", 1),
 ("midpoint", 1), ("central point", 1), ("midsection", 1), ("interior", 1), ("hub", 1)]),
 ("shin", 1, [("leg", 1), ("lower leg", 1), ("calf", 1), ("crus", 1), ("tibia", 1), ("foreleg", 1),
 ("stalk", 1), ("limb", 1), ("drumstick", 1), ("shinbone", 1)]),
 ("screams", 1, [("shrieks", 1), ("yells", 1), ("cries", 1), ("howls", 1), ("screeches", 1),
 ("hoots", 1), ("hollers", 1), ("yelps", 1), ("squalls", 1), ("bawls", 1)]),
 ("realises", 1, [("understands", 1), ("recognizes", 1), ("acknowledges", 1), ("discerns", 1),
 ("perceives", 1), ("grasps", 1), ("comprehends", 1), ("sees", 1), ("discovers", 1),
 ("apprehends", 1)]),
 ("bone", 1, [("skeletal", 1), ("calcified tissue", 1), ("bony structure", 1), ("skeletal
 structure", 1)]),
 ("poking", 1, [("prodding", 1), ("jabbing", 1), ("stabbing", 1), ("thrusting", 1), ("pushing",
 1), ("sticking", 1), ("nudging", 1), ("prod", 1), ("jut", 1), ("dig", 1)]),
 ("calls", 1, [("shouts", 1), ("cries", 1), ("yells", 1), ("hails", 1), ("exclaims", 1), ("rings", 1),
 ("contacts", 1), ("phones", 1), ("signals", 1), ("alerts", 1)]),
 ("rushes", 1, [("hurries", 1), ("sprints", 1), ("dashes", 1), ("races", 1), ("scampers", 1),
 ("hastes", 1), ("bolts", 1), ("scuttles", 1), ("runs", 1), ("charges", 1)]),

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    ("gasps", 1, [("panting", 1), ("wheezes", 1), ("gulp", 1), ("sighs", 1), ("huff", 1), ("puffs",
1), ("breathes", 1), ("inhales", 1), ("chokes", 1), ("gasp", 1)]),
    ("sight", 1, [("view", 1), ("vision", 1), ("glimpse", 1), ("scene", 1), ("look", 1), ("prospect",
1), ("outlook", 1), ("picture", 1), ("appearance", 1)]),
    ("broken", 1, [("fractured", 1), ("shattered", 1), ("cracked", 1), ("splintered", 1),
("snapped", 1), ("busted", 1), ("crushed", 1), ("smashed", 1), ("damaged", 1), ("broken
down", 1)]),
    ("bloody", 1, [("bleeding", 1), ("bloodied", 1), ("bloodstained", 1), ("blood-soaked", 1),
("sanguinary", 1), ("bloodied", 1), ("gore-spattered", 1), ("sanguine", 1), ("blood-spattered",
1), ("blood-covered", 1), ("crimson", 1)]),
    ("leg", 1, [("limb", 1), ("shank", 1), ("appendage", 1), ("lower extremity", 1), ("thigh", 1),
("calf", 1), ("crus", 1), ("leg", 1), ("foot", 1), ("hock", 1)]),
    ("frantically", 1, [("desperately", 1), ("hysterically", 1), ("wildly", 1), ("frenziedly", 1),
("madly", 1), ("frantic", 1), ("panicked", 1), ("manically", 1), ("agitatedly", 1), ("rabidly",
1)]),
    ("calls", 1, [("signals", 1), ("calling", 1), ("contacts", 1), ("alerts", 1), ("rings", 1),
("phones", 1), ("hails", 1), ("shouts", 1), ("yells", 1), ("cries", 1), ("communicates", 1)]),
    ("ambulance", 1, [("emergency vehicle", 1), ("medic van", 1), ("rescue vehicle", 1),
("paramedic vehicle", 1), ("ems vehicle", 1), ("medical transport", 1), ("emergency transport",
1), ("aid car", 1), ("first aid vehicle", 1), ("emergency van", 1)]),
    ("keep", 1, [("maintain", 1), ("preserve", 1), ("sustain", 1), ("retain", 1), ("hold", 1),
("save", 1), ("reserve", 1), ("guard", 1), ("protect", 1)]),
    ("calm", 1, [("tranquil", 1), ("composed", 1), ("serene", 1), ("peaceful", 1), ("unruffled", 1),
("soothe", 1), ("relaxed", 1), ("placid", 1), ("quiet", 1)])
]

```

```

last_sentence_words = [
    ("billy", 1, [("billy", 1)]),
    ("silent", 1, [("quiet", 1), ("silently", 1), ("quietly", 1), ("mute", 1), ("hushed", 1), ("still",
1), ("soundless", 1), ("unvoiced", 1), ("taciturn", 1), ("muted", 1), ("noiseless", 1)]),
    ("waits", 1, [("bides", 1), ("lingers", 1), ("holds", 1), ("pauses", 1), ("awaits", 1), ("delays",
1), ("hangs", 1), ("stays", 1), ("abides", 1)]),
    ("patiently", 1, [("calmly", 1), ("paitent", 1), ("calm", 1), ("tolerantly", 1), ("enduringly",
1), ("forbearingly", 1), ("steadily", 1), ("submissively", 1), ("quietly", 1), ("composedly", 1),
("stoically", 1), ("perseveringly", 1)]),
    ("josh", 1, [("comrade", 1), ("pal", 1), ("mate", 1), ("buddy", 1), ("friend", 1), ("chum", 1),
("cohort", 1), ("companion", 1), ("associate", 1), ("partner", 1)])
]

```

```

# Convert list of words to formatted string
first_sentence_words_str = []
for word_info in first_sentence_words:

```



```

word = word_info[0]
max_count = word_info[1]
synonyms = ','.join([syn[0] for syn in word_info[2]])
first_sentence_words_str.append(f'{word}\t{synonyms}\t{max_count}')

main_body_words_str = []
for word_info in main_body_words:
    word = word_info[0]
    max_count = word_info[1]
    synonyms = ','.join([syn[0] for syn in word_info[2]])
    main_body_words_str.append(f'{word}\t{synonyms}\t{max_count}')

last_sentence_words_str = []
for word_info in last_sentence_words:
    word = word_info[0]
    max_count = word_info[1]
    synonyms = ','.join([syn[0] for syn in word_info[2]])
    last_sentence_words_str.append(f'{word}\t{synonyms}\t{max_count}')

first_sentence_words_str = '\n'.join(first_sentence_words_str)
main_body_words_str = '\n'.join(main_body_words_str)
last_sentence_words_str = '\n'.join(last_sentence_words_str)

# Create input widgets
first_sentence_input = widgets.Textarea(value="", description='First sentence:')
first_sentence_word_input = widgets.Textarea(value=first_sentence_words_str,
description='Target words:')
main_body_input = widgets.Textarea(value="", description='Main body:')
main_body_word_input = widgets.Textarea(value=main_body_words_str,
description='Target words:')
last_sentence_input = widgets.Textarea(value="", description='Last sentence:')
last_sentence_word_input = widgets.Textarea(value=last_sentence_words_str,
description='Target words:')
display(first_sentence_input, first_sentence_word_input, main_body_input,
main_body_word_input, last_sentence_input, last_sentence_word_input)

# Define a button to run the analysis
button = widgets.Button(description='Analyze')
output = widgets.Output()
display(button, output)

def analyze_text(b):
    output.clear_output() # Clear the output before each run
    total_count = [0, 0, 0] # Count for first_sentence, main_body, last_sentence

```

```

with output:
    # Get input values
    text_inputs = [first_sentence_input.value.lower(), main_body_input.value.lower(),
last_sentence_input.value.lower()]
    word_inputs = [first_sentence_word_input.value.split('\n'),
main_body_word_input.value.split('\n'), last_sentence_word_input.value.split('\n')]

    for i, (text_input, word_input) in enumerate(zip(text_inputs, word_inputs)):
        current_text = text_input
        # Parse target words and synonyms from input
        set1 = []
        for line in word_input:
            word_parts = line.split('\t')
            if len(word_parts) == 3:
                word = word_parts[0].strip()
                if not word: # skip if word is an empty string
                    continue
                max_count = int(word_parts[2].strip())
                synonyms = [(syn, 1) for syn in word_parts[1].split(',') if syn] # ensure synonym
is not an empty string
                set1.append((word, max_count, synonyms))

        set1_count = 0
        counted_words = defaultdict(int)
        counted_synonyms = set()

        for word_info in set1:
            current_word = word_info[0]
            max_count = word_info[1]
            count_word = len(re.findall(f'\\b{current_word}\\b', current_text))
            count_word = min(count_word, max_count)
            if count_word > 0:
                counted_words[current_word] = count_word
                set1_count += count_word
                current_text = re.sub(f'\\b{current_word}\\b', '\033[31m' + current_word +
'\033[0m', current_text)

            if current_word not in counted_synonyms:
                for synonym, _ in word_info[2]:
                    count_syn = len(re.findall(f'\\b{synonym.strip()}\\b', current_text))
                    count_syn = min(count_syn, max_count - count_word)
                    if count_syn > 0:
                        counted_words[synonym.strip()] = count_syn
                        counted_synonyms.add(current_word)

```

```

        set1_count += count_syn
        current_text = re.sub(f'\\b{synonym.strip()}\\b', '\033[31m' +
synonym.strip() + '\033[0m', current_text)
        break

    print(current_text)
    print("Set 1 Count: " + str(set1_count))
    total_count[i] += set1_count # Add to total count
    for word, count in counted_words.items():
        print(f'Word/Synonym "{word}" (from "{next(w[0] for w in set1 if word in [w[0]]
+ [syn[0] for syn in w[2]])}" was found {count} time(s)')

    print(f'First sentence total count: {total_count[0]}')
    print(f'Main body total count: {total_count[1]}')
    print(f'Last sentence total count: {total_count[2]}')

button.on_click(analyze_text)

```

The Work Meeting

```
from collections import defaultdict
import re
from IPython.display import display
from ipywidgets import widgets

# Pre-defined target words for each section
first_sentence_words = [("sarah", 1, [("sarah's", 1)]),
    ("marketing", 1, [("promote", 1), ("promoter", 1), ("advertise", 1), ("advertiser", 1),
    ("sales", 1), ("brand", 1), ("publicizing", 1), ("merchand", 1)]),
    ("assistant", 1, [("aide", 1), ("help", 1), ("helper", 1), ("deputy", 1), ("adjutant", 1),
    ("subordinate", 1), ("apprentice", 1), ("junior", 1), ("associate", 1), ("colleague", 1),
    ("worker", 1)]),
    ("large", 1, [("big", 1), ("sizeable", 1), ("massive", 1), ("extensive", 1), ("substantial",
    1), ("grand", 1), ("vast", 1), ("enormous", 1), ("huge", 1), ("immense", 1)]),
    ("graphic", 1, [("visual", 1), ("pictorial", 1), ("illustrate", 1), ("illustrator", 1),
    ("depictive", 1), ("", 1), ("draw", 1), ("art", 1)]),
    ("design", 1, [("blueprint", 1), ("designs", 1), ("layout", 1), ("plan", 1), ("sketch", 1),
    ("draft", 1), ("diagram", 1), ("outline", 1), ("pattern", 1), ("template", 1)]),
    ("firm", 1, [("business", 1), ("corporation", 1), ("agency", 1), ("establishment", 1),
    ("enterprise", 1), ("institution", 1), ("organisation", 1), ("office", 1), ("bureau", 1),
    ("company", 1)])])

main_body_words = [("company", 2, [("corporation", 2), ("business", 2), ("enterprise", 2),
    ("firm", 2), ("establishment", 2), ("organization", 2), ("entity", 2), ("concern", 2),
    ("operation", 2), ("institution", 2), ("agency", 2), ("office", 2)]),
    ("usually", 1, [("normally", 1), ("normal", 1), ("typical", 1), ("typically", 1),
    ("common", 1), ("commonly", 1), ("generally", 1), ("routinely", 1), ("regularly", 1),
    ("habitually", 1), ("traditionally", 1), ("mostly", 1), ("often", 1)]),
    ("holds", 1, [("conducts", 1), ("carries out", 1), ("organizes", 1), ("hosts", 1), ("handle",
    1), ("manage", 1), ("arrange", 1), ("direct", 1), ("administers", 1), ("oversee", 1), ("have", 1)]),
    ("group", 1, [("team", 1), ("teams", 1), ("crew", 1), ("assembly", 1), ("collective", 1),
    ("gathering", 1), ("congregation", 1), ("cluster", 1), ("squad", 1), ("band", 1), ("committee",
    1), ("employee", 1), ("worker", 1), ("work", 1)]),
    ("meetings", 1, [("gathering", 1), ("meeting", 1), ("session", 1), ("conferences", 1),
    ("conventions", 1), ("assemblies", 1), ("assembly", 1), ("summit", 1), ("symposium", 1),
    ("forum", 1), ("get togethers", 1), ("roundtable", 1)]),
    ("monday's", 1, [("monday", 1), ("start of the week", 1)]),
    ("9am", 1, [("9 am", 1)]),
    ("instead", 1, [("alternatively", 1), ("rather", 1), ("in lieu", 1), ("as a substitute", 1),
    ("conversely", 1), ("in place of", 1), ("on the contrary", 1), ("in contrast", 1), ("as an
    alternative", 1), ("in preference to", 1), ("however", 1), ("but", 1)])]
```

("head", 1, [("leader", 1), ("boss's", 1), ("boss", 1), ("director", 1), ("executive", 1),
 ("supervisor", 1), ("principal", 1), ("manager", 1), ("superintendent", 1), ("CEO", 1)]),
 ("jack", 4, [("jack's", 4)]),
 ("asks", 2, [("request", 2), ("asked", 2), ("ask", 2), ("inquire", 2), ("enquires", 2),
 ("queries", 2), ("query", 2), ("interrogate", 2), ("question", 2), ("probe", 2), ("seek", 2),
 ("demand", 2), ("calls for", 2), ("invite", 2), ("call", 2)]),
 ("meet", 1, [("convene", 1), ("see", 1), ("sees", 1), ("meets", 1), ("encounter", 1),
 ("confer", 1), ("consult", 1), ("interact", 1), ("connect", 1), ("join", 1), ("gather", 1),
 ("discuss", 1), ("engage with", 1), ("talk", 1), ("catch up", 1)]),
 ("alone", 1, [("solo", 1), ("singularly", 1), ("independently", 1), ("individually", 1),
 ("separately", 1), ("exclusively", 1), ("privately", 1), ("one on one", 1), ("one-on-one", 1),
 ("personally", 1), ("unaccompanied", 1), ("on her own", 1)]),
 ("sarah", 5, [("sarah's", 5)]),
 ("worries", 2, [("fear", 2), ("worried", 1), ("fears", 2), ("worry", 2), ("stresses", 2),
 ("stress", 2), ("dread", 2), ("anxieties", 2), ("anxious", 2), ("concern", 2), ("apprehension", 2),
 ("nervousness", 2), ("unease", 2), ("agitation", 2), ("tension", 2), ("nervous", 2), ("tense", 2)]),
 ("knows", 1, [("understand", 1), ("know", 1), ("realises", 1), ("recognises", 1),
 ("comprehends", 1), ("acknowledge", 1), ("perceive", 1), ("discerns", 1), ("is aware of", 1),
 ("is cognisant of", 1), ("appreciate", 1), ("think", 1)]),
 ("not", 3, [("isn't", 3), ("isnt", 3)]),
 ("performing", 1, [("functioning", 1), ("performance", 1), ("working", 1), ("acting", 1),
 ("operating", 1), ("executing", 1), ("behaving", 1), ("carrying out", 1), ("doing", 1),
 ("conducting", 1), ("handling", 1), ("function", 1), ("work", 1), ("act", 1), ("operate", 1),
 ("behave", 1)]),
 ("well", 1, [("adequate", 1), ("satisfactorily", 1), ("suitably", 1), ("properly", 1),
 ("correct", 1), ("efficient", 1), ("effective", 1), ("competent", 1), ("excellent", 1), ("capably",
 1), ("good", 1)]),
 ("walks", 1, [("stroll", 1), ("leads", 1), ("lead", 1), ("walk", 1), ("walked", 1), ("tread",
 1), ("march", 1), ("amble", 1), ("step", 1), ("pace", 1), ("saunter", 1), ("stride", 1), ("roam", 1),
 ("wanders", 1), ("goes", 1)]),
 ("office", 1, [("workspace", 1), ("workplace", 1), ("bureau", 1), ("room", 1), ("suite", 1),
 ("studio", 1), ("cubicle", 1), ("workstation", 1), ("desk", 1), ("study", 1)]),
 ("puts", 1, [("places", 1), ("put", 1), ("placed", 1), ("set", 1), ("position", 1), ("arranges",
 1), ("deposit", 1), ("establishes", 1), ("install", 1), ("lay", 1), ("situates", 1), ("parks", 1)]),
 ("employee", 1, [("staff", 1), ("personal", 1), ("work", 1), ("worker", 1), ("personnel",
 1), ("member", 1), ("associate", 1), ("colleague", 1), ("subordinate", 1), ("workman", 1),
 ("workforce", 1), ("operative", 1)]),
 ("file", 2, [("document", 2), ("details", 2), ("record", 2), ("dossier", 2), ("report", 2),
 ("paperwork", 2), ("portfolio", 2), ("profile", 2), ("case", 2), ("archive", 2), ("folder", 2)]),
 ("glass", 1, [("crystal", 1), ("transparent", 1), ("clear", 1), ("glazed", 1), ("pane", 1),
 ("porthole", 1), ("window", 1), ("see through", 1), ("seethrough", 1), ("see-through", 1),
 ("laminated", 1), ("plexiglas", 1)]),
 ("table", 1, [("desk", 1), ("counter", 1), ("stand", 1), ("bench", 1), ("board", 1),
 ("surface", 1), ("console", 1), ("workstation", 1), ("worktable", 1), ("platform", 1)]),

("pulls", 1, [("extract", 1), ("draw", 1), ("yank", 1), ("drag", 1), ("retrieve", 1), ("tug", 1), ("pluck", 1), ("grab", 1), ("wrest", 1), ("jerk", 1), ("take", 1), ("takes out", 1)]),
 ("record", 1, [("documentation", 1), ("records", 1), ("archive", 1), ("register", 1), ("log", 1), ("report", 1), ("data", 1), ("profile", 1), ("history", 1), ("chronicle", 1), ("transcript", 1), ("review", 1)]),
 ("says", 1, [("state", 1), ("say", 1), ("tells", 1), ("declare", 1), ("affirm", 1), ("announce", 1), ("proclaim", 1), ("voice", 1), ("express", 1), ("utter", 1), ("mention", 1), ("remark", 1), ("tell", 1), ("speak", 1)]),
 ("met", 1, [("achieve", 1), ("missed", 1), ("reaching", 1), ("hit", 1), ("achieved", 1), ("reach", 1), ("reached", 1), ("attain", 1), ("fulfil", 1), ("realise", 1), ("satisfied", 1), ("satisfy", 1), ("match", 1), ("complete", 1), ("complied with", 1), ("accomplish", 1)]),
 ("target", 1, [("goal", 1), ("targets", 1), ("objective", 1), ("aim", 1), ("end", 1), ("benchmark", 1), ("standard", 1), ("quota", 1), ("criterion", 1), ("mark", 1), ("milestone", 1)]),
 ("last", 2, [("previous", 2), ("final", 2), ("past", 2), ("latest", 2), ("recent", 2), ("ending", 2), ("latter", 2), ("terminal", 2), ("concluding", 2), ("prior", 2)]),
 ("months", 1, [("period", 1), ("interval", 1), ("time", 1), ("duration", 1), ("stretch", 1), ("season", 1), ("term", 1), ("phase", 1), ("cycle", 1), ("span", 1)]),
 ("fills", 1, [("saturates", 1), ("fill", 1), ("filled", 1), ("flood", 1), ("engulf", 1), ("overwhelm", 1), ("overflow", 1), ("brim", 1), ("steeps", 1)]),
 ("tears", 1, [("cries", 1), ("upset", 1), ("crying", 1), ("cried", 1), ("wept", 1), ("weep", 1), ("sob", 1), ("lamentations", 1), ("tearfulness", 1), ("grief", 1), ("wailing", 1), ("sorrow", 1), ("distress", 1), ("bawling", 1), ("cry", 1), ("sadness", 1), ("sad", 1)]),
 ("angrily", 1, [("irritably", 1), ("irritable", 1), ("furious", 1), ("fury", 1), ("resentfully", 1), ("resentful", 1), ("bitterly", 1), ("bitter", 1), ("aggressively", 1), ("aggressive", 1), ("angry", 1), ("angrily", 1), ("vehemently", 1), ("irately", 1), ("indignantly", 1), ("hotly", 1), ("irate", 1)]),
 ("why", 1, [("questions", 1), ("question", 1)]),
 ("should", 1, [("must", 1), ("should've", 1), ("ought to", 1), ("are to", 1), ("have to", 1), ("need to", 1), ("are supposed to", 1), ("are expected to", 1), ("are required to", 1), ("are obliged to", 1), ("would", 1)]),
 ("deserve", 1, [("merit", 1), ("allows", 1), ("deserves", 1), ("deserved", 1), ("warrant", 1), ("earn", 1), ("justify", 1), ("qualify for", 1), ("be entitled to", 1), ("be worthy of", 1), ("be deserving of", 1), ("be due", 1), ("rate", 1), ("qualify", 1)]),
 ("chance", 1, [("opportunity", 1), ("chances", 1), ("possibility", 1), ("occasion", 1), ("shot", 1), ("option", 1), ("opening", 1), ("break", 1), ("prospect", 1), ("scope", 1), ("window", 1)]),
 ("sympathy", 1, [("compassion", 1), ("empathy", 1), ("pity", 1), ("understanding", 1), ("tenderness", 1), ("sensitivity", 1), ("kindness", 1), ("humanity", 1), ("sorrow", 1), ("commiseration", 1)]),
 ("tells", 1, [("inform", 1), ("informs", 1), ("tell", 1), ("advise", 1), ("notifies", 1), ("brief", 1), ("discloses", 1), ("relays", 1), ("impart", 1), ("convey", 1), ("divulge", 1), ("reveal", 1), ("notes", 1)]),

("improved", 1, [("enhance", 1), ("improve", 1), ("improved", 1), ("better", 1),
 ("advance", 1), ("progress", 1), ("elevate", 1), ("upgrade", 1), ("boost", 1), ("augment", 1),
 ("strengthen", 1), ("refine", 1), ("change", 1)]),
 ("warning", 1, [("caution", 1), ("warn", 1), ("warned", 1), ("alert", 1), ("notice", 1),
 ("alarm", 1), ("indication", 1), ("signal", 1), ("advisory", 1), ("forewarning", 1), ("heads-up",
 1), ("red flag", 1)]),
 ("fired", 1, [("dismiss", 1), ("firing", 1), ("fire", 1), ("sacked", 1), ("sacks", 1), ("fires",
 1), ("sack", 1), ("terminate", 1), ("let go", 1), ("release", 1), ("laid off", 1), ("discharge", 1),
 ("axe", 1), ("expel", 1), ("ousted", 1)]),
 ("immediately", 1, [("instant", 1), ("right away", 1), ("prompt", 1), ("promptly", 1),
 ("direct", 1), ("swift", 1), ("instantaneous", 1), ("straight away", 1), ("speedily", 1), ("without
 delay", 1), ("pronto", 1)]),
 ("feels", 1, [("experience", 1), ("feel", 1), ("sense", 1), ("perceive", 1), ("undergoes", 1),
 ("suffer", 1), ("endure", 1)]),
 ("sick", 1, [("unwell", 1), ("ill", 1), ("ailing", 1), ("poorly", 1), ("unhealthy", 1),
 ("infirm", 1), ("afflicted", 1), ("indisposed", 1), ("malaise", 1), ("nauseous", 1)]),
 ("paying", 1, [("remitting", 1), ("pay", 1), ("settling", 1), ("disbursing", 1),
 ("compensating", 1), ("satisfying", 1), ("meeting", 1), ("defraying", 1), ("reimbursing", 1),
 ("clearing", 1), ("pay", 1)]),
 ("rent", 1, [("lease", 1), ("rental", 1), ("tenancy", 1), ("hire", 1), ("let", 1), ("leasehold",
 1), ("sublet", 1), ("rental agreement", 1), ("occupancy", 1), ("lodging", 1)]),
 ("firmly", 1, [("decisively", 1), ("resolutely", 1), ("steadfastly", 1), ("staunchly", 1),
 ("determinedly", 1), ("sturdily", 1), ("solidly", 1), ("unwaveringly", 1), ("rigidly", 1),
 ("strongly", 1)]),
 ("instructs", 1, [("directs", 1), ("instructed", 1), ("instruct", 1), ("order", 1),
 ("command", 1), ("tells", 1), ("guide", 1), ("teaches", 1), ("educates", 1)]),
 ("collect", 1, [("gather", 1), ("pack", 1), ("take", 1), ("pick up", 1), ("accumulate", 1),
 ("assemble", 1), ("retrieve", 1), ("round up", 1), ("compile", 1)]),
 ("things", 1, [("belonging", 1), ("belongings", 1), ("items", 1), ("possession", 1),
 ("effects", 1), ("personal effects", 1), ("stuff", 1), ("property", 1), ("goods", 1), ("assets", 1)]),
 ("leave", 1, [("depart", 1), ("leaves", 1), ("left", 1), ("exit", 1), ("vacate", 1), ("retreat",
 1), ("withdraw", 1), ("quit", 1), ("go", 1), ("split", 1), ("make tracks", 1), ("take off", 1)])]

last_sentence_words = [("way", 1, [("route", 1), ("path", 1), ("course", 1), ("direction", 1),
 ("road", 1), ("track", 1), ("passage", 1), ("trail", 1)]),
 ("out", 1, [("outside", 1), ("outdoors", 1), ("outward", 1), ("beyond", 1), ("open", 1),
 ("forth", 1), ("away", 1), ("off", 1)]),
 ("calls", 1, [("contacts", 1), ("phones", 1), ("rings", 1), ("communicates", 1),
 ("connects", 1), ("dials", 1), ("reaches out to", 1), ("buzzes", 1), ("touches base with", 1),
 ("gets in touch with", 1)]),
 ("best", 1, [("closest", 1), ("dearest", 1), ("top", 1), ("ultimate", 1)]),
 ("friend", 1, [("companion", 1), ("ally", 1), ("pal", 1), ("buddy", 1), ("confidant", 1),
 ("mate", 1)])]

```

        ("rosie", 1, [("rosie's", 1)]),
        ("plans", 1, [("arrange", 1), ("arranges", 1), ("organise", 1), ("plans", 1), ("schedule", 1),
("prepare", 1), ("designs", 1), ("organises", 1), ("sets up", 1), ("plots", 1), ("forecasts", 1),
("strategizes", 1), ("outlines", 1)]),
        ("meet", 1, [("gather", 1), ("see", 1), ("convene", 1), ("encounter", 1), ("unite", 1),
("congregate", 1), ("assemble", 1), ("join", 1), ("come together", 1), ("link up", 1), ("connect",
1)]),
        ("local", 1, [("nearby", 1), ("neighbourhood", 1), ("community", 1), ("proximate", 1),
("surrounding", 1), ("close", 1), ("regional", 1)]),
        ("pub", 1, [("tavern", 1), ("bar", 1), ("inn", 1), ("saloon", 1), ("alehouse", 1), ("public
house", 1), ("taproom", 1), ("watering hole", 1), ("brewery", 1), ("bistro", 1)])]

```

```

# Convert list of words to formatted string

```

```

first_sentence_words_str = []
for word_info in first_sentence_words:
    word = word_info[0]
    max_count = word_info[1]
    synonyms = ','.join([syn[0] for syn in word_info[2]])
    first_sentence_words_str.append(f'{word}\t{synonyms}\t{max_count}')

```

```

main_body_words_str = []
for word_info in main_body_words:
    word = word_info[0]
    max_count = word_info[1]
    synonyms = ','.join([syn[0] for syn in word_info[2]])
    main_body_words_str.append(f'{word}\t{synonyms}\t{max_count}')

```

```

last_sentence_words_str = []
for word_info in last_sentence_words:
    word = word_info[0]
    max_count = word_info[1]
    synonyms = ','.join([syn[0] for syn in word_info[2]])
    last_sentence_words_str.append(f'{word}\t{synonyms}\t{max_count}')

```

```

first_sentence_words_str = '\n'.join(first_sentence_words_str)
main_body_words_str = '\n'.join(main_body_words_str)
last_sentence_words_str = '\n'.join(last_sentence_words_str)

```

```

# Create input widgets

```

```

first_sentence_input = widgets.Textarea(value="", description='First sentence:')
first_sentence_word_input = widgets.Textarea(value=first_sentence_words_str,
description='Target words:')
main_body_input = widgets.Textarea(value="", description='Main body:')

```



```

main_body_word_input = widgets.Textarea(value=main_body_words_str,
description='Target words:')
last_sentence_input = widgets.Textarea(value="", description='Last sentence:')
last_sentence_word_input = widgets.Textarea(value=last_sentence_words_str,
description='Target words:')
display(first_sentence_input, first_sentence_word_input, main_body_input,
main_body_word_input, last_sentence_input, last_sentence_word_input)

# Define a button to run the analysis
button = widgets.Button(description='Analyze')
output = widgets.Output()
display(button, output)

def analyze_text(b):
    output.clear_output() # Clear the output before each run
    total_count = [0, 0, 0] # Count for first_sentence, main_body, last_sentence
    with output:
        # Get input values
        text_inputs = [first_sentence_input.value.lower(), main_body_input.value.lower(),
last_sentence_input.value.lower()]
        word_inputs = [first_sentence_word_input.value.split('\n'),
main_body_word_input.value.split('\n'), last_sentence_word_input.value.split('\n')]

        for i, (text_input, word_input) in enumerate(zip(text_inputs, word_inputs)):
            current_text = text_input
            # Parse target words and synonyms from input
            set1 = []
            for line in word_input:
                word_parts = line.split('\t')
                if len(word_parts) == 3:
                    word = word_parts[0].strip()
                    if not word: # skip if word is an empty string
                        continue
                    max_count = int(word_parts[2].strip())
                    synonyms = [(syn, 1) for syn in word_parts[1].split(',') if syn] # ensure synonym
is not an empty string
                    set1.append((word, max_count, synonyms))

            set1_count = 0
            counted_words = defaultdict(int)
            counted_synonyms = set()

            for word_info in set1:
                current_word = word_info[0]

```

```

max_count = word_info[1]
count_word = len(re.findall(f'\\b{current_word}\\b', current_text))
count_word = min(count_word, max_count)
if count_word > 0:
    counted_words[current_word] = count_word
    set1_count += count_word
    current_text = re.sub(f'\\b{current_word}\\b', '\033[31m' + current_word +
'\033[0m', current_text)

    if current_word not in counted_synonyms:
        for synonym, _ in word_info[2]:
            count_syn = len(re.findall(f'\\b{synonym.strip()}\\b', current_text))
            count_syn = min(count_syn, max_count - count_word)
            if count_syn > 0:
                counted_words[synonym.strip()] = count_syn
                counted_synonyms.add(current_word)
                set1_count += count_syn
                current_text = re.sub(f'\\b{synonym.strip()}\\b', '\033[31m' +
synonym.strip() + '\033[0m', current_text)
                break

print(current_text)
print("Set 1 Count: " + str(set1_count))
total_count[i] += set1_count # Add to total count
for word, count in counted_words.items():
    print(f'Word/Synonym "{word}" (from "{next(w[0] for w in set1 if word in [w[0]]
+ [syn[0] for syn in w[2]])}" was found {count} time(s)')

print(f'First sentence total count: {total_count[0]}')
print(f'Main body total count: {total_count[1]}')
print(f'Last sentence total count: {total_count[2]}')

button.on_click(analyze_text)

```

Appendix C

Due to protocol deviations in Chapter 4 (fiction reading study), as some participants did not abstain from reading fiction in the day, I conducted a full analysis on those who completed the protocol precisely (n=16) with the purpose of comparing findings to the combined group (protocol adherence group and protocol deviation group). The results indicated that there were no overall differences in finding between groups. Presented in the thesis is an additional analysis determining if there are differences between groups across all variables, the results showed that there were not. These results should be considered supplementary to provide further evidence that these groups do not differ on outcomes in the study.

Results

Sleep Quality

Descriptive Statistics

Table 65: Descriptive Statistics for Objective and Subjective Sleep Quality and Objective Sleep Variables

Variable	Group HOA (n=6) SCD (n=10)	Time Point		
		Pre-intervention Mean (SD)	Intervention Mean (SD)	Post-Intervention Mean (SD)
Global PSQI Score	HOA	5.75 (1.75)	3.67 (1.17)	3.33 (0.52)
	SCD	6.75 (2.74)	4.40 (1.31)	4.30 (1.89)
Consensus Sleep Diary Sleep Quality	HOA	3.79 (.46)	4.00 (.43)	3.53 (.51)
	SCD	3.22 (.73)	3.33 (.58)	3.27 (.59)
Actigraphy Composite Quality Score	HOA	.61 (2.61)	0.93 (2.12)	.43 (1.91)
	SCD	-.37 (1.97)	-0.31 (1.69)	.39 (1.44)
Objective Total Sleep Time (seconds)	HOA	26576.93 (2495.40)	27636.14 (1252.94)	26024.13 (1955.63)
	SCD	26269.65 (3711.60)	26979.04 (2995.50)	25912.50 (3241.27)
Sleep Latency (seconds)	HOA	1041.29 (982.23)	817.95 (627.37)	870.52 (473.97)
	SCD	680.49 (631.85)	520.23 (262.60)	479.11 (208.19)
Sleep Efficiency (%)	HOA	88.36 (5.08)	88.55 (4.33)	89.32 (2.27)

	SCD	88.36 (4.66)	88.86 (3.75)	89.69 (3.64)
Sleep Fragmentation (SFI index)	HOA	23.91 (6.27)	24.34 (8.49)	24.47 (8.69)
	SCD	30.26 (9.45)	29.03 (8.47)	28.89 (11.45)

Assumption checks for all sleep-related variables				
	Levene's test of Homogeneity (p-value)			Mauchly's test of Sphericity (p-value)
Variable	Pre-intervention	Intervention	Post-Intervention	
Global PSQI scores	.04	1.00	<.001*	.72
Sleep Diary Quality Score	.23	.67	.39	.62
Actigraphic Sleep Quality Score	.76	.99	.68	.09
Objective Total Sleep Time	.28	.10	.25	.33
Objective Sleep Onset Latency	.28	.03	.04	.05*
Objective Sleep Efficiency	.82	.50	.17	<.001*
Sleep Fragmentation	.37	.90	.34	.21

Main Analysis

Variable	Main Effect (p-value, η^2)		
	Study Phase	Group	Interaction (Study Phase x Group)
Global PSQI scores	<.001 (.58)	.28 (.08)	.95 (<.001)
Sleep Diary Quality Score	.02 (.28)*	.06 (.21)	.14 (.018)
Actigraphic Sleep Quality Score	.34 (.08)	.46 (.04)	.01 (.29)*
Objective Total Sleep Time	<.001 (.32)*	.82 (<.001)	.78 (.02)
Objective Sleep Onset Latency	.33 (.08)	.16 (.15)	.90 (<.001)
Objective Sleep Efficiency	.26 (.10)	.91 (<.001)	.89 (<.001)
Sleep Fragmentation	.91 (<.001)	.32 (.08)	.62 (.04)

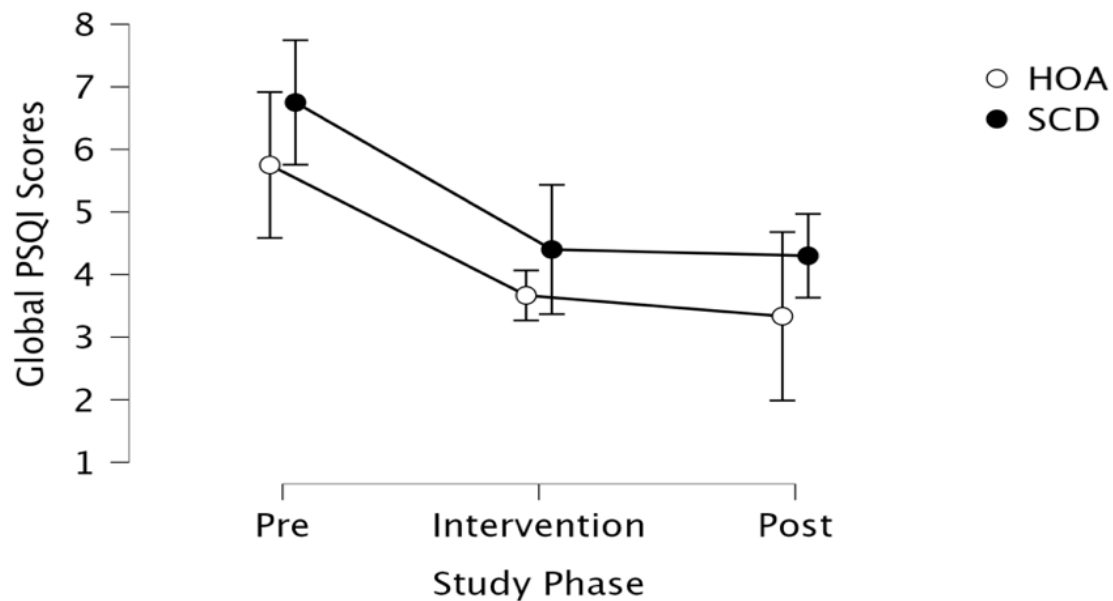
PSQI

There was a significant main effect of study phase on PSQI scores, $F(2, 28) = 12.89$, $p < .001$, $\eta^2 = .58$. The assumption of homogeneity of variances, as assessed by Levene's test, was violated for the post-intervention PSQI scores $F(1,14)=24.72$, $p<.001$ and pre-intervention PSQI scores $F(1,14)=5.32$, $p=0.04$. However, the SCD group, which had the larger sample size, showed greater variance, a factor that would typically inflate the p-value, resulting in greater difficulty to detect a statistically significant effect. However, the presence of a large effect size and a highly significant p-value suggests that the observed differences across the study phases are unlikely to be statistical anomalies.

There was no significant interaction between study phase and group on PSQI scores, $F(2,28) = .06$, $p = .95$, $\eta^2 = <.001$, nor was there a significant main effect of group, $F(1,14) = 1.29$, $p = .28$, $\eta^2 = .08$, suggesting that there was no significant difference in average global PSQI scores across healthy older adults and adults with SCD.

Given the significant main effect of the study phase on global PSQI scores, post-hoc comparisons were conducted to examine pairwise differences between the study phases. Using a Bonferroni adjustment, post-hoc tests revealed that subjective sleep quality improved significantly during the intervention, as PSQI scores were lower during the intervention phase compared to the pre-intervention phase, $t(15) = 5.11$, $p<.001$, $d = 1.22$, with a mean difference of -2.22 ($SE=.43$). Furthermore, post-intervention scores were also significantly lower than pre-intervention scores, $t(15) = 2.43$, $p <.001$, $d = 1.34$, with a mean difference of -2.43 ($SE=.43$). These results suggest that subjective sleep quality as assessed by the PSQI improved over the reading intervention and were sustained after the intervention had ended. Notably, while a global PSQI score of 5 or above indicates a poor sleeper, the group means at baseline were above this threshold ($M=5.75$, $SD=1.75$) and declined significantly below this threshold during the intervention ($M=3.76$, $SD=1.17$) and remained below it post-intervention ($M=3.33$, $SD=.52$), indicating improved sleep perceptions consistent with good sleeper categorisation.

Figure 36: Global PSQI Scores Across 3 Study Phases



Note: 1 Lower scores on the PSQI indicate better sleep. Poor sleep according to the PSQI is classified as ≥ 5 .

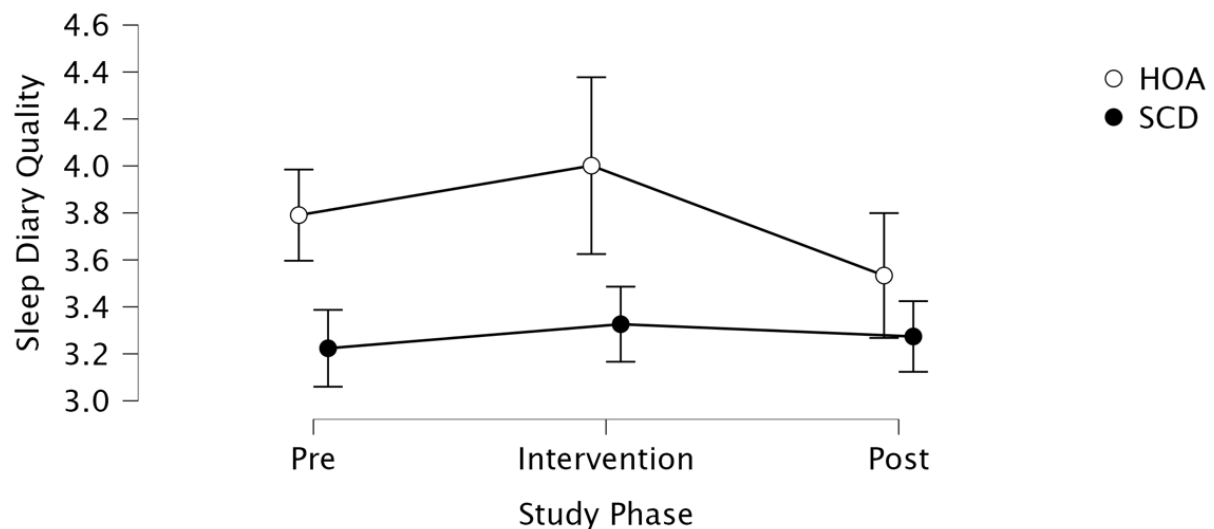
Consensus Sleep Diary

To assess the impact of study phase on subjective sleep quality ratings derived from the consensus sleep diary (where higher scores indicate higher subjective sleep quality). There was a significant main effect of study phase on sleep diary quality ratings $F(2,24)=4.77$, $p=0.02$, $\eta^2=.28$. There was no main effect of groups on sleep diary ratings $F(1,12)=2.56$, $p=.14$, $\eta^2=.18$, nor was there a significant interaction between study phase and group $F(2,24)=3.23$, $p=.06$, $\eta^2=.21$.

Post-hoc pairwise comparisons with a Bonferroni correction examining sleep diary quality ratings across study phases showed only a significant change from intervention to post intervention phases, such as that perceived sleep quality dropped at the post-intervention phase compared to the intervention $t(15)=3.07$, $p=.02$, $d=.44$, with a mean difference of $-.26$ ($SE=.08$). Whilst means increasing in self-reported sleep quality were shown at the

intervention phase compared to baseline for both groups (HOA Mean change=.21, SCD Mean change=.11), these changes were not statistically significant according to post-hoc comparison analysis ($p's > 0.05$). Thus, these results suggest that perceived sleep quality reduced after the intervention.

Figure 37: CSD Sleep Diary Quality Across 3 Study Phases



Note: 2 Higher scores on the Consensus Sleep Diary Indicate better self-reported sleep quality

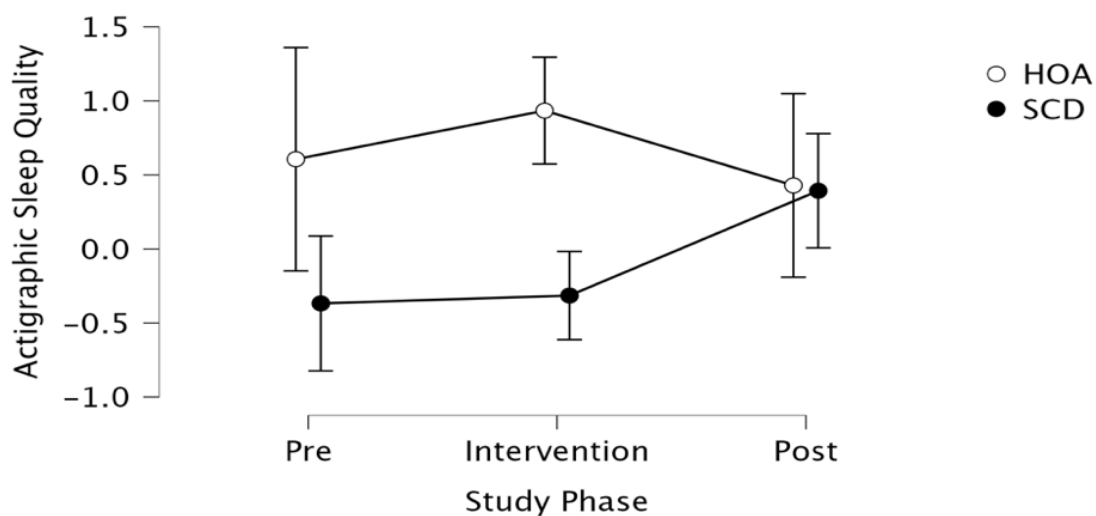
Actigraphy

To determine the effect of study phase on objective sleep quality, derived from a composite value comprising of averages of z-scores $((TST + SE + (SF * -1))$ from actigraphic variables, a 3x2 factorial mixed ANOVA was conducted. Higher scores indicate better objective sleep quality. The assumptions for sphericity and homogeneity of variances were met. The analysis revealed that there was no significant difference in objective sleep quality across the study phases, $F(2,26)=1.13$, $p=.34$, $\eta^2=.29$, nor were there any significant difference across groups $F(1,13)=.58$, $p=.46$, $\eta^2=.04$. However, there was a significant interaction between study phase and group $F(2,26)=5.19$, $p=.01$, $\eta^2=.29$.

A post-hoc analysis examining the interaction between study phase and group using a Tukey correction, revealed that only the comparison between pre-intervention and post-intervention

for the SCD was significant, $t(15)=3.05$, $p=.05$, Cohen's $d=.39$. Specifically, sleep quality improved on the composite sleep quality score as measured by actigraphy by .76 units by the end of the study compared to baseline for this group. Whilst both groups showed improvements from baseline to the reading period (HOA mean difference=.32, SCD mean difference=.06), these increases were not significant ($p's>.05$). Thus, these results suggest that objective sleep quality improved significantly only for the SCD group at the end of the study compared to baseline.

Figure 38: Actigraphic Sleep Quality Composite Score Across 3 Study Phases



Note: Higher actigraphy sleep quality Z scores indicate better quality of sleep. (95% CI)

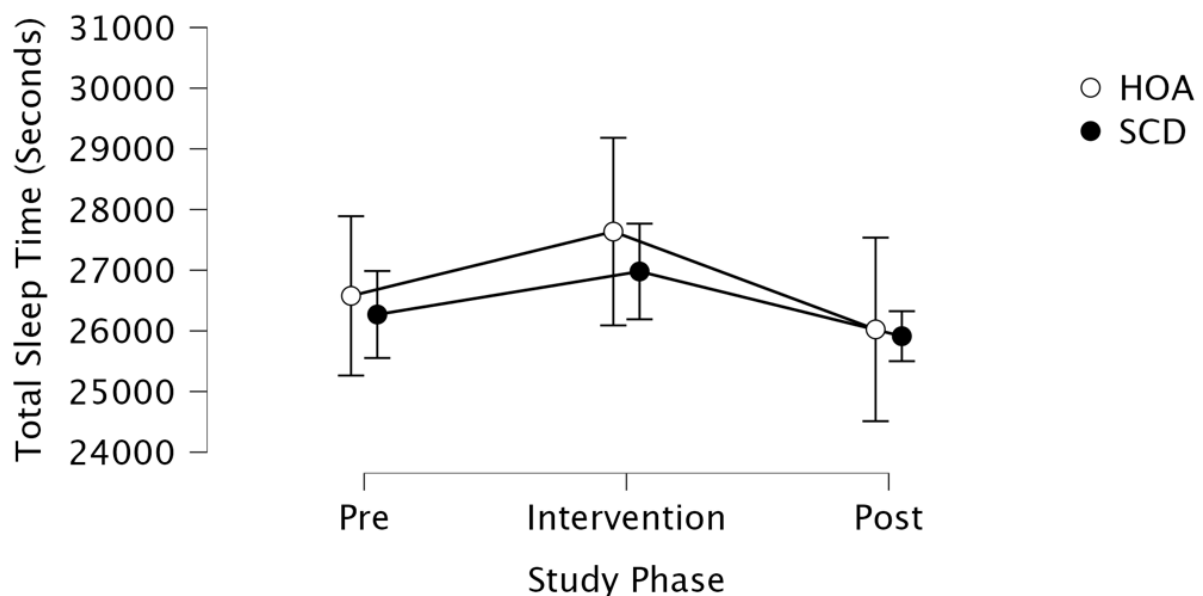
Sleep (Actigraphy variables)

Total Sleep Time (TST)

To examine the effect of the reading intervention on objective TST, a 3x2 mixed repeated measures factorial ANOVA was conducted. The assumptions for homogeneity of variances and sphericity were met. There was a significant main effect of study phase on TST, $F(2,26)=6.10$, $p<0.001$, $\eta^2=.32$. There was no interaction between TST and group, $F(2,26)=.25$, $p=.78$, $\eta^2=.02$, nor was there a difference in TST between groups across study phases $F(1,13)=.05$, $p=.82$, $\eta^2<.001$.

Using post-hoc comparisons with a Bonferroni correction, changes TST sleep times across the study phases were examined. During the intervention phase, mean TST rose compared to pre-intervention levels (mean difference=884.30 seconds). However, this increase was not statistically significant $t(13)=2.27$, $p=.10$, $d=.30$. Comparing pre-intervention and post-intervention phases, no significant difference in TST emerged $t(13)=1.17$, $p=.76$, $d=.15$. However, a drop in mean TST was shown between the intervention and post-intervention phases (mean difference -1339.28 seconds), which was statistically significant $t(13)= 3.43$, $p<.001$, $d=.45$. Taken together, these results suggest at the potential of reading to temporarily boost TST. However, this benefit is not enduring as the cessation of reading is associated with a drop in TST to levels lower than before the intervention began.

Figure 39: Mean Total Sleep Time (Seconds) Across 3 Study Phases



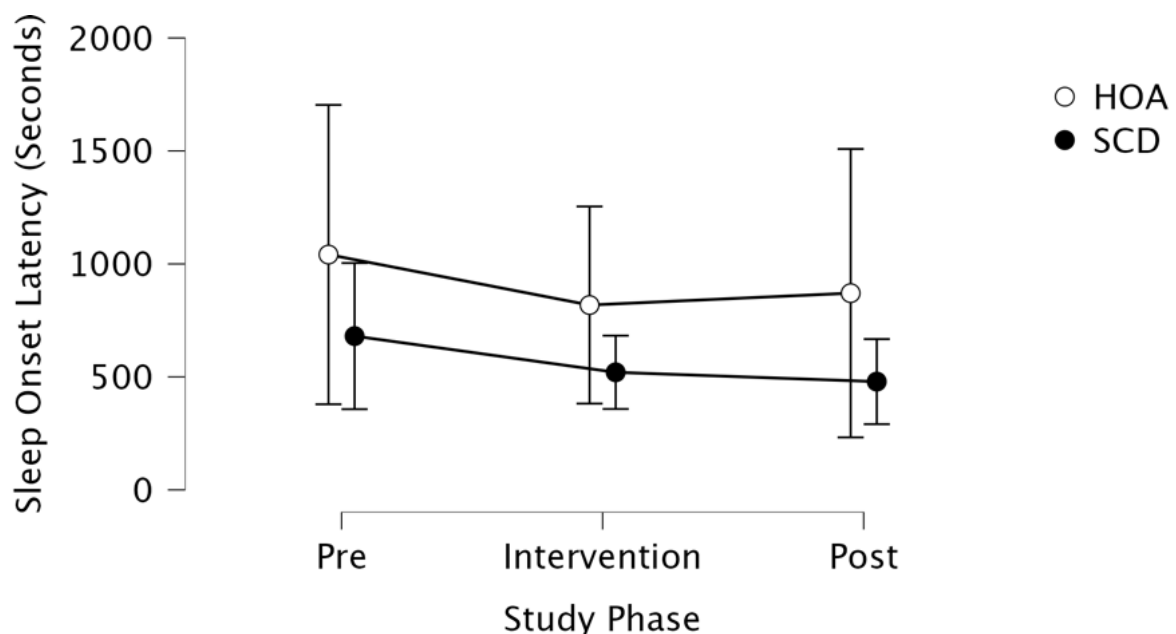
Sleep Onset Latency (SOL)

To determine the effect of the reading intervention on objective Sleep Onset Latency (SOL), a repeated measured mixed 3x2 factorial ANOVA was conducted. Mauchly's test indicated that the assumption of sphericity has been violated $\chi^2(2) = 6.11$, $p= .05$. Therefore, the Greenhouse-Geisser correction was used ($\epsilon = .71$). Results revealed that there was no difference in SOL across the 3 study phases $F(1.43, 18.59)=1.10$, $p=.33$, $\eta p^2=.08$, nor was

there an interaction between SOL and group $F(1.43, 18.59)=.05$, $p=.90$, $\eta^2<.001$, nor a difference between group $F(1,13)=2.21$, $p=.16$, $\eta^2=.15$.

However, the analysis revealed a violation of the assumption of homogeneity of variances, as indicated by a significant Levene's test for Intervention SOL mean $F(1,13)=5.62$, $p=.03$ and Post-Intervention SOL mean $F(1,13)=5.28$, $p=.04$. This assumption is a requirement for a traditional ANOVA, and its violation can potentially impact the trustworthiness of these findings. Specifically, when the assumption is not met, the ANOVA may produce inaccurate probability values. In this case, given the unequal sample sizes and that the group with the larger sample size (SCD) demonstrated smaller variance compared to the smaller HOA group, the p-values could be more conservative than they would be equal variance resulting in a potential type 2 error. Thus, this test might be less likely to detect a true effect, if one exists. However, it's worth noting that while these results may be influenced by this variance inequality, the effect size ($\eta^2=.08$) provides some indication of the magnitude of observed differences. Despite potential challenges with the ANOVA's p-value, the effect size suggests a small to medium impact of the intervention phase on SOL. In light of these considerations, a cautious interpretation of these findings is advised. Future research should consider balanced sample sizes to further clarify these effects.

Figure 40: Mean Sleep Onset Latency (Seconds) Across 3 Study Phases

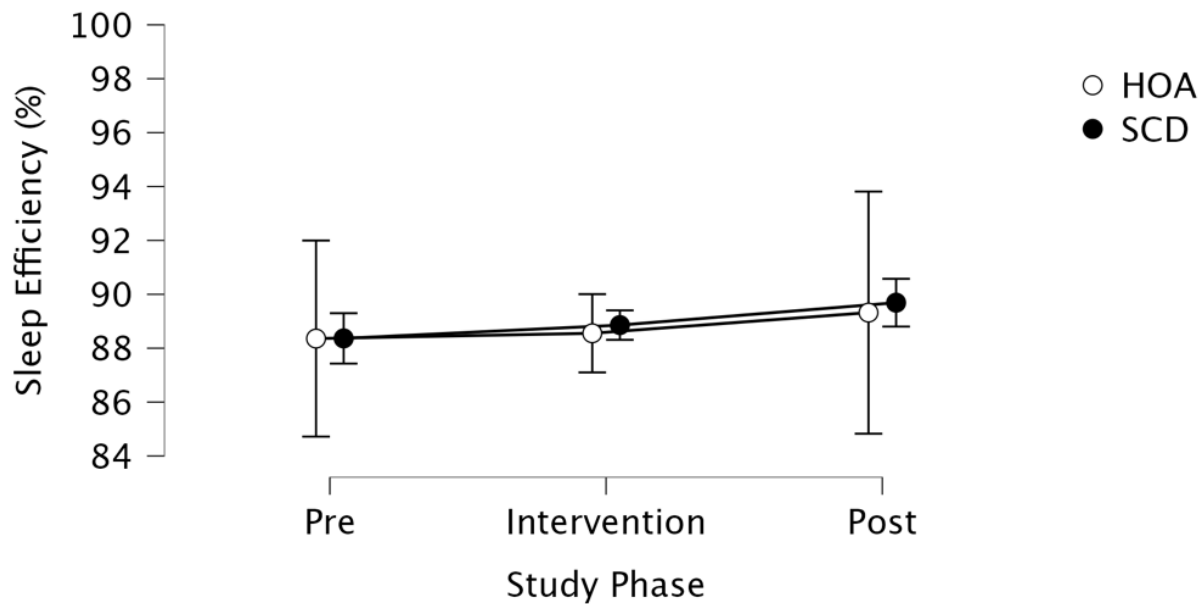


Sleep efficiency

To investigate the influence of reading on Sleep Efficiency (SE) a repeated measures mixed 3x2 factorial ANOVA was performed. Assumption tests indicated that there was no violation of homogeneity of variances, however Mauchly's test indicated that the assumption of sphericity has been violated $\chi^2(2) = 11.20$, $p < .001$. Therefore, the Greenhouse-Geisser correction was used ($\epsilon = .62$). Results indicate that study phase had no effect on SE $F(1.24, 84.41) = 1.41$, $p = .26$, $\eta^2 = .10$, that there was no interaction between SE and group $F(1.24, 16.18) = .04$, $p = .89$, $\eta^2 < .001$ and no difference between group $F(1, 13) = .01$, $p = .91$, $\eta^2 < .001$. This suggests that reading did not have any significant effect on improving SE across the intervention.

However, on examining the descriptive statistics, SE means were generally higher for the SCD group across study phases, implying better sleep quality, compared to the HOA group. Additionally, the means reveal a pattern suggestive of improved SE during the reading period and continual enhancement post-intervention. This could suggest a possible sustained effect of the intervention on SE. However, as the results were not statistically significant, such patterns might be indicative of potential effect that this study, perhaps due to sample size, was not sufficiently powered to detect. Future research with larger sample sizes would be beneficial to further examine these observed trends.

Figure 41: Mean Sleep Efficiency (%) Across 3 Study Phases

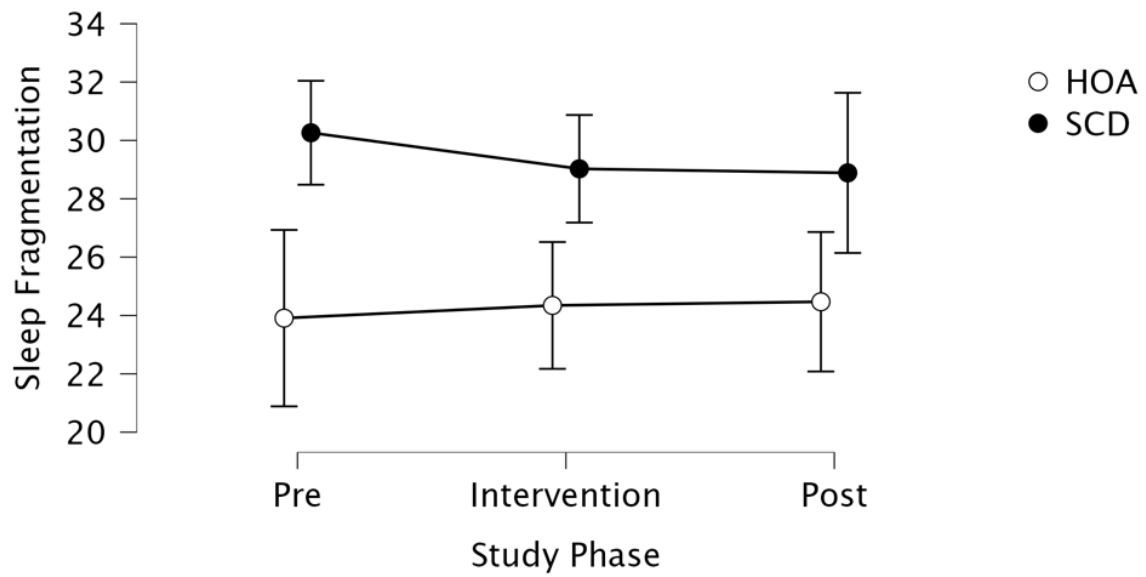


Sleep Fragmentation

To assess the impact of reading on Sleep Fragmentation (SF), a repeated measures mixed 3x2 factorial ANOVA was employed. Both the assumptions of sphericity and homogeneity of variances were satisfied. The analysis revealed no significant difference in SF across the study phases, $F(2,26)=.09$, $p=.91$, $\eta^2<.001$, nor was there an interaction between SF and group, $F(2,26)=.48$, $p=.62$, $\eta^2=.04$, or a difference between groups, $F(1,13)=1.09$, $p=.32$, $\eta^2=.08$.

Though not statistically significant, the means indicate that the SCD group generally had higher SF scores than the HOA group. Both groups showed an improvement during the intervention, with a slight decline post-intervention, but still maintaining scores better than the pre-intervention phase. These trends suggest that while reading may have influenced SF scores, the effects were not statistically significant within this sample.

Figure 42: Mean Sleep Fragmentation Index Scores Across 3 Study Phases



Summary of Sleep Quality Results

Variable	Main Effect (p-value, η^2)		
	Study Phase	Group	Interaction (Study Phase x Group)
Global PSQI scores	<.001 (.58)	.28 (.08)	.95 (<.001)
Sleep Diary Quality Score	.02 (.28)*	.06 (.21)	.14 (.018)
Actigraphic Sleep Quality Score	.34 (.08)	.46 (.04)	.01 (.29)*
Objective Total Sleep Time	<.001 (.32)*	.82 (<.001)	.78 (.02)
Objective Sleep Onset Latency	.33 (.08)	.16 (.15)	.90 (<.001)
Objective Sleep Efficiency	.26 (.10)	.91 (<.001)	.89 (<.001)
Sleep Fragmentation	.91 (<.001)	.32 (.08)	.62 (.04)

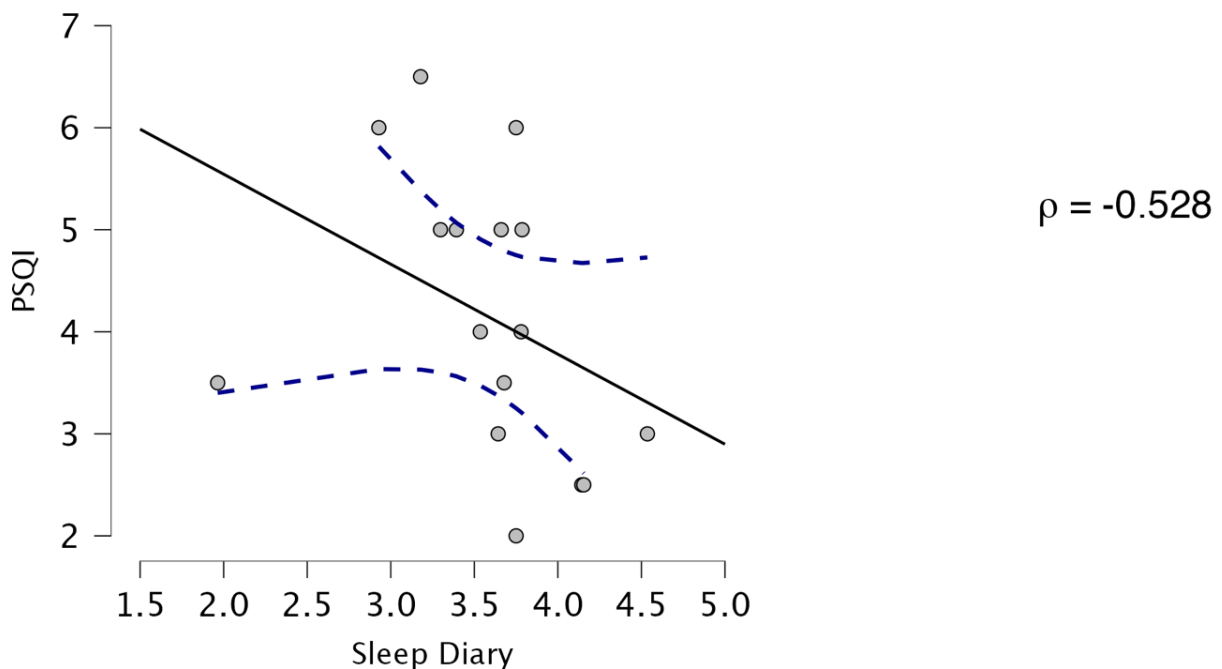
Subjective Versus Objective Measures of sleep

Subjective measures

To determine whether objective and subjective measures are related in this study, a test of association between the PSQI, actigraphy quality composite z-scores and sleep diary quality scores were performed at the intervention phase. Higher scores on the actigraphy and sleep diary indicate better sleep, whereas higher scores on the PSQI indicate poorer sleep.

In light of the data not meeting the assumption of normality as indicated by a significant Shapiro-Wilk test ($W=.78$, $p<.001$) a Spearman's rank-order correlation was conducted. The results showed a moderate statistically significant correlation between sleep diary scores and PSQI scores $p(15)=.53$, $p=.04$, 95% CI $(-.83, -.05)$, suggesting that as people rate poorer sleep on the PSQI, they also rate poorer sleep on the sleep diary.

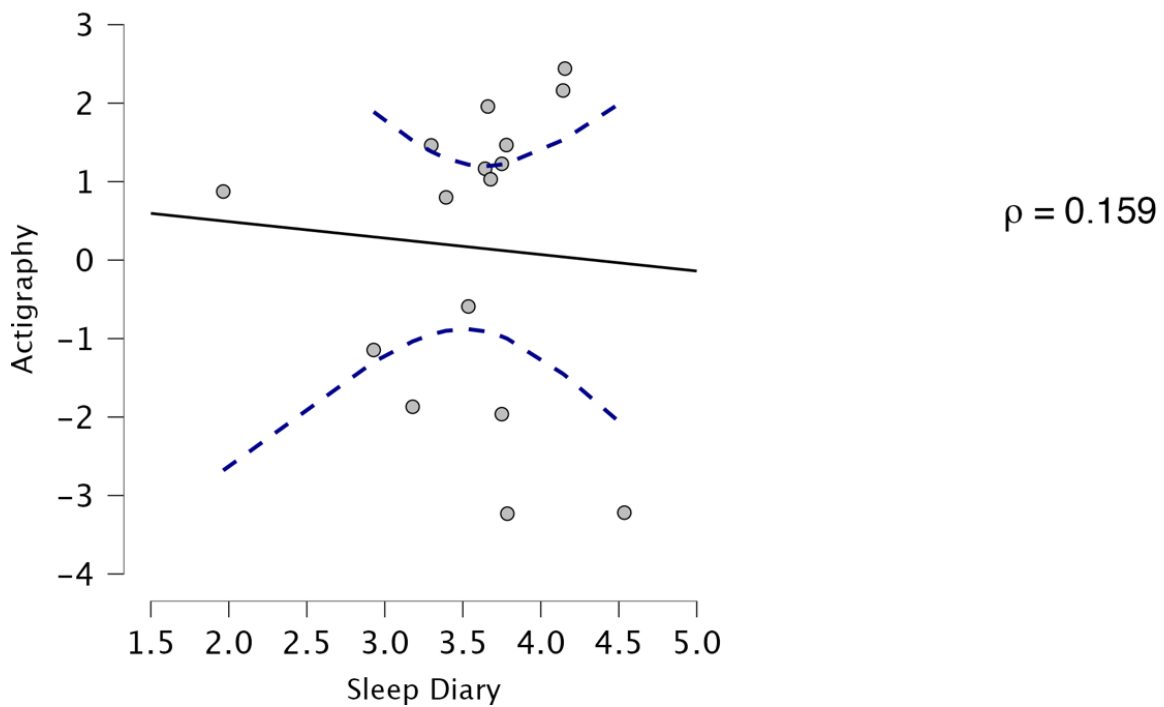
Figure 43: PSQI Sleep Quality Versus CSD Sleep Diary Quality at Intervention Phase



Objective versus subjective measures

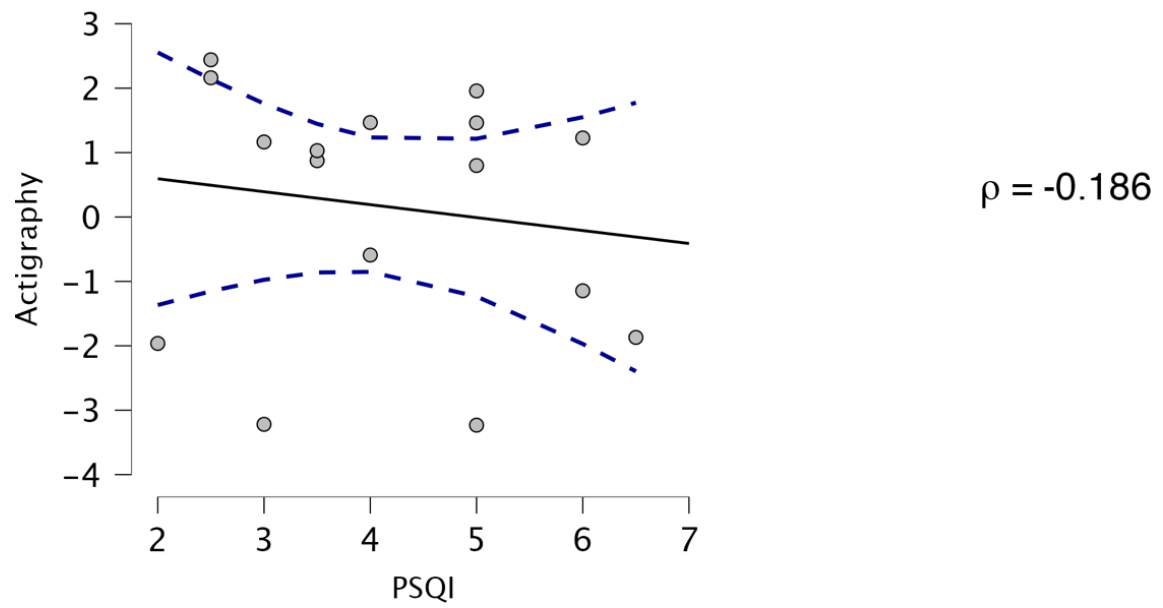
No significant correlation was observed between subjective and objective measures of sleep quality. Specifically, actigraphy and sleep diary quality scores were not significantly correlated, $p(15)=0.19$, $p=.56$, 95% CI $(-.42, .78)$.

Figure 44: Actigraphy Sleep Quality Versus CSD Sleep Quality at Intervention Phase



Similarly actigraphy sleep quality scores were not significantly correlated with PSQI global sleep quality scores $p(15)=-.19$, $p=.49$, 95% CI $(-.74, .37)$.

Figure 45: Actigraphy Sleep Quality Score Versus PSQI Sleep Quality Score at The Intervention Phase



Wellbeing

Table 66: Descriptive Statistics for Wellbeing Variables Across 3 Study Phases

Variable	Group HOA (n=6) SCD (n=10)	Time Point		
		Pre-intervention Mean (SD)	Intervention Mean (SD)	Post-Intervention Mean (SD)
PERMA	HOA	7.55 (1.43)	7.73 (1.97)	7.60 (2.05)
	SCD	8.24 (.86)	8.46 (.89)	8.47 (1.00)
Positive Emotion	HOA	7.42 (1.45)	7.36 (2.04)	7.11 (2.12)
	SCD	7.85 (.50)	8.50 (.77)	8.40 (.91)
Engagement	HOA	7.42 (1.45)	7.36 (2.04)	7.11 (2.12)
	SCD	7.85 (.05)	8.50 (.77)	8.40 (.91)
Relationships	HOA	7.58 (2.32)	8.00 (2.48)	7.11 (1.89)
	SCD	8.52 (1.66)	8.45 (1.64)	8.20 (.71)
Meaning	HOA	7.39 (1.78)	7.72 (2.58)	7.67 (2.60)
	SCD	8.67 (1.39)	8.72 (1.30)	8.53 (1.53)
Achievement	HOA	7.92 (0.93)	8.03 (1.06)	8.11 (1.36)
	SCD	7.83 (.96)	8.40 (.81)	8.47 (1.02)
Negative Emotion	HOA	2.56 (1.01)	2.61 (.74)	2.83 (.55)
	SCD	3.78 (1.94)	2.72 (1.37)	2.43 (1.20)
Loneliness	HOA	2.58 (3.37)	3.08 (4.43)	3.17 (3.82)
	SCD	3.10 (2.75)	1.65 (1.75)	1.10 (.88)