Ergonomics

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/terg20

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To cite this article: Dayna F. Easton, Charlotte C. Gupta, Grace E. Vincent, Corneel Vandelanotte, Mitch J. Duncan, Phillip Tucker, Lee Di Milia & Sally A. Ferguson (31 Dec 2024): The relationship between circadian type and physical activity as predictors of sleepiness and fatigue during simulated nightshifts: a randomised controlled trial, Ergonomics, DOI: 10.1080/00140139.2024.2430369

To link to this article: https://doi.org/10.1080/00140139.2024.2430369

Published online: 31 Dec 2024.

ERGONOMICS
https://doi.org/10.1080/00140139.2024.2430369

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RESEARCH ARTICLE

The relationship between circadian type and physical activity as predictors of sleepiness and fatigue during simulated nightshifts: a randomised controlled trial

Dayna F. Easton[a], Charlotte C. Gupta[a], Grace E. Vincent[a], Corneel Vandelanotte[a], Mitch J. Duncan[b,c], Phillip Tucker[d,e], Lee Di Milia[f] and Sally A. Ferguson[a]

[a]Appleton Institute, Central Queensland University, Wayville, SA, Australia; [b]School of Medicine & Public Health, The University of Newcastle, Callaghan, NSW, Australia; [c]Active Living Research Program, Hunter Medical Research Institute, New Lambton Heights, NSW, Australia; [d]School of Psychology, Swansea University, Swansea, United Kingdom; [e]Department of Psychology, Psychobiology and Epidemiology Division, Stockholm University, Stockholm, Sweden; [f]School of Business and Law, Central Queensland University, Rockhampton, QLD, Australia

ABSTRACT

Breaks involving physical activity may provide on-shift recovery from sleepiness and fatigue during nightshifts, with effects potentially influenced by circadian type. Thirty-three adults (M±SD age: 24.6±4.8y; 55% female) participated in five laboratory nightshifts (2200–0600h) and were randomised to sedentary (SIT; *n*=14) or 'breaking-up' sitting (BREAK; *n*=19). Participants completed the Circadian Type Inventory, categorising as rigid (*n*=12) or flexible (*n*=11); and languid (*n*=11) or vigorous (*n*=13). BREAK participants walked 3-minutes every 30-minutes at 3.2 km/h; all completed fatigue and sleepiness scales. Linear mixed models showed a 3-way interaction between nightshift (N1–N5), condition (SIT, BREAK), and rigidity-flexibility for fatigue (*p*<.001) and sleepiness (*p*<.001). Fatigue and sleepiness were greatest on N1 for SIT-Flexible and BREAK-Rigid, with SIT-Rigid experiencing the greatest levels overall. BREAK-Flexible showed no reduction. No 2-way interactions between nightshift and languidity-vigour were found. Breaking up sitting attenuated fatigue and sleepiness for rigid types only. On-shift recovery needs may differ for circadian types.

PRACTITIONER SUMMARY: Work breaks involving physical activity may provide on-shift recovery from sleepiness and fatigue during nightshifts, with effects potentially influenced by circadian type. This RCT investigated active work breaks and circadian type on fatigue and sleepiness during five simulated nightshifts. Findings underscore the importance of individualised approaches to managing shiftworker fatigue.

ARTICLE HISTORY
Received 19 August 2024
Accepted 11 November 2024

KEYWORDS
Shift work; night shift; cognitive performance; fatigue countermeasure; physical activity; individual difference; circadian type

Shift work is essential to keep 24/7 services operating, and employs between 15-17% of the Australian, American and the UK workforce (Australian Bureau of Statistics 2022; Office for National Statistics 2021; United States Bureau of Labor Statistics 2019). Shift work has many detrimental impacts due to the requirement for wakefulness and sleep to be misaligned with other circadian rhythms. When the timing of sleep and wake is mismatched with the external environment and intrinsic circadian rhythms, circadian misalignment arises (Moreno et al. 2019). This misalignment can be worsened by the type of shift work required, such as consecutive night work (Ferguson et al. 2012; Garde et al. 2020). Circadian misalignment and sleep disruption have significant impacts for long-term health, such as increased cardiometabolic risk factors (Barger et al. 2009; Ganesan et al. 2019; Gupta et al. 2022; Kecklund and Axelsson 2016), and acute impacts on sleepiness, fatigue, and performance (Folkard and Tucker 2003).

Reduced cognitive functions increase the risk of serious occupational health and safety incidents (Ayas et al. 2006; Barger et al. 2009; Garde et al. 2020; Gupta et al. 2022; Moreno et al. 2019; Wagstaff and Sigstad Lie 2011). Sleepiness can be objectively measured using physiological assessments, like electroencephalography (Hultman et al. 2021), and subjective self-assessments (Leso et al. 2021; Van Dongen 2006), while fatigue is a more complex construct assessed indirectly through performance tests (Ferris et al.

CONTACT Dayna F. Easton d.f.easton@cqu.edu.au Appleton Institute, Central Queensland University, School of Health, Medical and Applied Sciences, Adelaide, Australia

2021), pupillometry (McGarrigle et al. 2017; McIntire et al. 2014; McLaughlin et al. 2023), or self-reports (Mendonca et al. 2020; Tucker 2003). In shift work, where both can impair functioning, understanding their distinctions is essential for developing effective countermeasures to enhance safety and performance. Objective cognitive performance measures, such as reaction time tests, are an important way of assessing peaks in fatigue and sleepiness associated with night shifts (Sunde et al. 2020). However, these measures are often not a feasible method of detecting real-time fatigue and sleepiness in the field (Qiang, Lan, and Looney 2006). Instead, workers rely on subjective self-assessments to gauge when to make adjustments and implement fatigue countermeasures to improve safety performance (Karim et al. 2024). Despite objective performance offering more reliable indicators of worker performance, subjective self-assessments are important and complementary in detecting fatigue and sleepiness during night work (Kaida et al. 2007; Koradecka et al. 2010).

Work breaks are a well-known countermeasure to reduce fatigue at work (Albulescu et al. 2022; Caldwell et al. 2019; Kim, Park, and Headrick 2018; Kim, Park, and Niu 2017; Mijović et al. 2015; Tucker 2003; Vieten et al. 2023; Wendsche, Paridon, and Blasche 2022; Wennberg et al. 2016). Work breaks within a shift provide acute physical and cognitive recovery from fatigue and mental load, thereby helping to sustain performance over the course of the shift. The frequency, duration and type of activity during the break all contribute to reducing fatigue within a shift (Kim, Park, and Headrick 2018; Tucker 2003). For instance, frequent informal micro-breaks of less than 10 minutes within a shift are effective at providing recovery and conserving employee energy reserves (Albulescu et al. 2022; Chandrasekaran et al. 2021; Mijović et al. 2015; Wendsche, Paridon, and Blasche 2022).

Micro-break activities can include physical and mental rest, socialisation, nutrition, and prayer (Kim, Park, and Niu 2017; Vieten et al. 2023). Incorporating physical activity within these breaks has been found to improve worker productivity and cognitive functions when compared to sedentary micro-breaks in day workers (Benatti and Ried-Larsen 2015; Chandrasekaran et al. 2021; Henning et al. 2009). Using light-intensity physical activity to break up prolonged sitting at work has resulted in improvements in cardiometabolic outcomes (Thorp et al. 2014; Wennberg et al. 2016), fatigue and sleepiness (Albulescu et al. 2022; Thorp et al. 2014; Vincent et al. 2018), and cognitive performance (Chandrasekaran et al. 2021; Mijović et al. 2015; Tuckwell et al. 2023; Tuckwell et al. 2022; Wendsche, Paridon, and Blasche 2022). However, it is unknown whether these findings extend to night working populations with the additional challenge of circadian misalignment resulting from consecutive night shifts (Vincent et al. 2017). In some industries, night staff can be engaging in less physically demanding work than day staff (Chappel et al. 2017; Hulsegge et al. 2017), providing additional reason to investigate the efficacy of breaking up sitting in night workers. Further, using self-assessments of fatigue and sleepiness will provide insight into the specific needs of shift workers, helping to determine whether specific activities, such as breaking up sitting, are beneficial for physical and mental recovery during consecutive night work. Breaking up sitting is a simple countermeasure that could be implemented informally throughout a night shift in most industries. Understanding whether breaking up sitting overnight is an effective countermeasure for shift workers has important implications for developing tailored fatigue management strategies.

Research highlights that the cognitive response to sleep restriction is person specific, and certain trait-like characteristics in personality and circadian typology may be protective factors that reduce the impact of sleepiness and fatigue overnight (Degenfellner and Schernhammer 2021; Saksvik et al. 2011; Van Dongen 2006). Circadian typology, or the individual differences in circadian rhythms, can include measures of chronotype and circadian type. Studies of chronotype (i.e. morningness-eveningness) have dominated the sleep and shift work literature (Colelli et al. 2023; Fischer, Roenneberg, and Vetter 2021; Harfmann et al. 2020; Lack et al. 2009; Taillard et al. 2003; Vetter et al. 2015), and suggest that intrinsic individual differences exist among shift workers that could influence responses to fatigue countermeasures. For instance, one study found that nurses with an evening preference had greater improvement in subjective fatigue, sleepiness and mood in response to a field-based lighting intervention (Olson et al. 2020).

The revised Circadian Type Inventory (rCTI; Di Milia, Smith, and Folkard 2005) is another measure of intrinsic individual difference but is under researched to date. Circadian rhythms can be assessed in terms of the rhythm's phase, amplitude and the stability of the circadian rhythm. Whereas measures of phase are common within the sleep literature, the rCTI was developed to assess rhythm amplitude and stability. The rCTI is comprised of two factors. The first factor, rigid-flexible (FR), assesses rhythm stability and classifies individuals via the flexibility/rigidity of sleep and wake behaviours. Those who can adjust and tolerate irregular sleep-wake routines are classified as flexible types. The second factor, languid-vigour (LV), assesses rhythm amplitude via the languid/vigour dimension and denotes one's ability to overcome drowsiness and fatigue, particularly following sleep restriction (Di Milia, Smith, and Folkard 2005). A systematic review examining the relationship between individual differences and shiftwork tolerance found that flexibility and vigour were associated with greater subjective alertness on the night shift, while scoring high on languidity was not (Saksvik et al. 2011). A recent qualitative review of this literature also found flexibility was associated with greater shift work tolerance while languidity was not (Degenfellner and Schernhammer 2021). Similarly, flexible types were found to be less susceptible to alertness deficits during hours when sleep pressure typically increases, while vigorous types reported lower sleep need and subjective alertness across the day (Di Milia, Smith, and Folkard 2005). Taken together, these studies suggest a relationship exists between circadian type and shift work tolerance. The addition of an alerting countermeasure may further amplify any innate tolerance relating to circadian type overnight. However, no current studies have examined the rCTI in the context of fatigue countermeasures such as breaking up sitting, and night work.

Shift workers are impacted by night work, resulting in reduced alertness and safety performance, which is worsened by consecutive night shifts (Folkard and Tucker 2003; Ganesan et al. 2019; Kecklund and Axelsson 2016; Palancı et al. 2021; Vila, Morrison, and Kenney 2002; Wagstaff and Sigstad Lie 2011). Breaking up sitting has been shown to be an effective fatigue countermeasure in day workers (Benatti and Ried-Larsen 2015; Chandrasekaran et al. 2021; Henning et al. 2009), though its efficacy in night workers is unknown. It is also crucial to assess whether a countermeasure (e.g. breaking up prolonged sitting) is differentially beneficial for shift workers with differing circadian characteristics. This understanding will allow for the implementation of individualised strategies over multiple night shifts. Taken together, it is essential to know whether breaking up prolonged sitting with light-intensity physical activity overnight differentially impacts subjective reporting of fatigue and sleepiness for different circadian types.

Research questions

1a. does having either a flexible or rigid circadian type differentially impact subjective fatigue and sleepiness over five night shifts?

1b. does breaking up sitting differentially impact flexible and rigid circadian types, with respect to subjective fatigue and sleepiness over five night shifts?

2a. does having either a languid or vigorous circadian type differentially impact subjective fatigue and sleepiness over five night shifts?

2b. does breaking up sitting differentially impact languid or vigorous circadian types, with respect to subjective fatigue and sleepiness over five night shifts?

Method

Study design

The present study was part of a broader in-laboratory, randomised controlled trial investigating the impact of simultaneous exposure to prolonged sitting, sleep restriction and circadian disruption in both day shift and night shift conditions, and the effects of breaking up sitting on these relationships. Primary outcomes of the principal study included cognitive performance and cardiometabolic outcomes. The complete protocol for the principal study is published separately (Vincent et al. 2020). The principal study occurred at the Appleton Institute Sleep Laboratory, CQUniversity Adelaide, was registered with the Australian New Zealand Clinical Trials Registry (12619001516178) and approved by the Central Queensland University Human Research Ethics Committee (0000021914). In the context of the larger study (Vincent et al. 2020), the present study will explore subjective assessments of fatigue and sleepiness while other primary outcomes, such as cognitive performance and cardiometabolic outcomes, will be reported elsewhere to answer different research questions. The present study investigated whether breaking up sitting impacted subjective assessments of fatigue and sleepiness differently for circadian types across consecutive night shifts.

Participants

The night shift sample consisted of 52 healthy participants, 41 of whom completed the protocol (age M ± SD: 24.4 ± 4.6 years; 21 females; 23.4 ± 3.0 kg/m^2). Healthy, non-shift working individuals aged between 18 and 35 years were recruited from Adelaide, South Australia via online advertisements, flyers and word of mouth. The circadian type of participants was determined using the 25th and 75th percentile scores on the FR and LV scales. Only 33 participants (age 24.6 ± 4.8 years; 19 females; 23.3 ± 3.1 kg/m^2) were included for analysis in the present study. The remaining participants could not be classified into either flexible, rigid, languid or vigour based on these cut-off scores. Prior to study onset, participants provided electronic consent and were reimbursed (AUD$780) following study completion. Eligibility was determined via a battery of standardised and validated questionnaires. Inclusion criteria examples were: body mass index (BMI) between 18 and 30 kg/m^2, non-smokers, low physical activity levels (sitting ≥5 hours/day; ≤150 minutes/week of moderate-intensity exercise for >3 months, as screened by the International Physical Activity Questionnaire), and habitual bed (22:00–00:00h), no transmeridian travel within the past three months, no current shift work, no diagnosed psychiatric or sleep disorders or history of contraindications to physical activity, and wake times (06:00–08:00h) (Vincent et al. 2020). The full eligibility criteria were also reported within the study protocol (Vincent et al. 2020). Participant demographics by condition are reported below (Table 1).

Study conditions

Participants were randomly allocated into either the sedentary (SIT; $n = 20$) or breaking up sitting condition (BREAK; $n = 21$) prior to study admission. A block randomisation strategy was conducted with a block size of 6 (the number of individual bedroom suites in the Appleton Sleep Laboratory) to ensure participants were randomly allocated to either physical activity condition: Breaking up Sitting (3 participants) or Sedentary (3 participants). After the first 6 participants in the study, all subsequent participants were stratified by sex (to ensure equal number of males and females in the physical activity conditions) and BMI (to ensure no statistical difference in mean BMI of each physical activity condition). Randomisation was conducted by the research team and participants were not blinded to study condition.

Table 1. Participant demographics according to circadian type categorisation (Flexible, Rigid, Languid, Vigorous).

Condition	*N*	Sex	Age (years)	BMI (kg/m^2)	Height (m)
Flexible	4	Female	23.8 ± 4.3	20.7 ± 1.6	1.64 ± 0.08
	7	Male	22.3 ± 4.2	24.4 ± 1.6	1.82 ± 0.08
Rigid	6	Female	23.8 ± 4.0	21.1 ± 3.1	1.64 ± 0.08
	6	Male	25.2 ± 6.3	23.7 ± 3.6	1.78 ± 0.06
Languid	6	Female	25.0 ± 3.7	23.0 ± 4.2	1.61 ± 0.10
	5	Male	22.0 ± 4.7	25.6 ± 2.8	1.73 ± 0.10
Vigorous	7	Female	26.1 ± 5.2	22.8 ± 3.2	1.65 ± 0.06
	6	Male	26.0 ± 5.8	23.2 ± 3.0	1.85 ± 0.09
Total	33		24.2 ± 4.7	23.4 ± 3.2	1.71 ± 0.12

Note. Participants who are categorised as more than one circadian type are only included once in the reported total. Data are presented as mean ± standard deviation.

Participants completed the two-factor 11-item revised Circadian Type Inventory (factor 1: flexible/rigid; factor 2: languid/vigorous). After applying the 25th and 75th percentiles (Di Milia, Smith, and Folkard 2004, 2005) to the respective factors we created the following groups; flexible ($n = 11$), rigid ($n = 12$), languid ($n = 11$), and vigorous ($n = 13$) (Figures 1 and 2). Uneven participant numbers in the languid subgroup (SIT = 2, BREAK = 9) meant that analyses could not be completed for participants in the SIT condition. Instead, languid BREAK and vigorous BREAK were compared for final analysis.

Laboratory setting

Participants lived at the Appleton Institute Sleep Laboratory in Adelaide (Australia) for the 7-day protocol. The facility has six sound-attenuated and temperature-controlled (21 °C + 2 °C) bedrooms with a king-single bed and personal ensuite, and two living/kitchen areas. Light levels were maintained at >300 lux during wake periods and were negligible (<0.3 lux) during sleep periods.

Protocol

This protocol consisted of one Arrival Evening (AR), one Adaptation Day (AD) and five simulated Nightshifts (E1–E5). A final sleep opportunity following the completion of E5 served as a recovery sleep (Figures 1 and 2). Participants arrived at 17:00 on the Arrival Evening and were briefed on protocol and procedures. An overnight sleep opportunity occurred at 22:00 to 07:00 on Arrival Evening to facilitate adjustment to the laboratory environment. On Adaptation Day, participants were familiarised with the cognitive and self-perceived capacity battery, which included the subjective sleepiness and fatigue measures. The rCTI was administered at 18:00 on Adaptation Day as part of a comprehensive once-off questionnaire battery. A nap opportunity was provided prior to commencing the first nightshift (E1) and occurred from 15:00 to 17:00.

From E1 to E5, participants performed simulated 8-hour nightshifts between 22:00 and 06:00. All Nightshifts involved 9-h diurnal sleep opportunities, from 08:00 to 17:00. Participants remained within their designated laboratory bedroom for the entire duration of the study, unless moving to their respective ensuite, the communal kitchen for meals, or engaging in the physical activity intervention. During the simulated shifts, all participants engaged in sedentary activities (e.g. reading, watching television) and the designated cognitive and self-perceived capacity testing batteries.

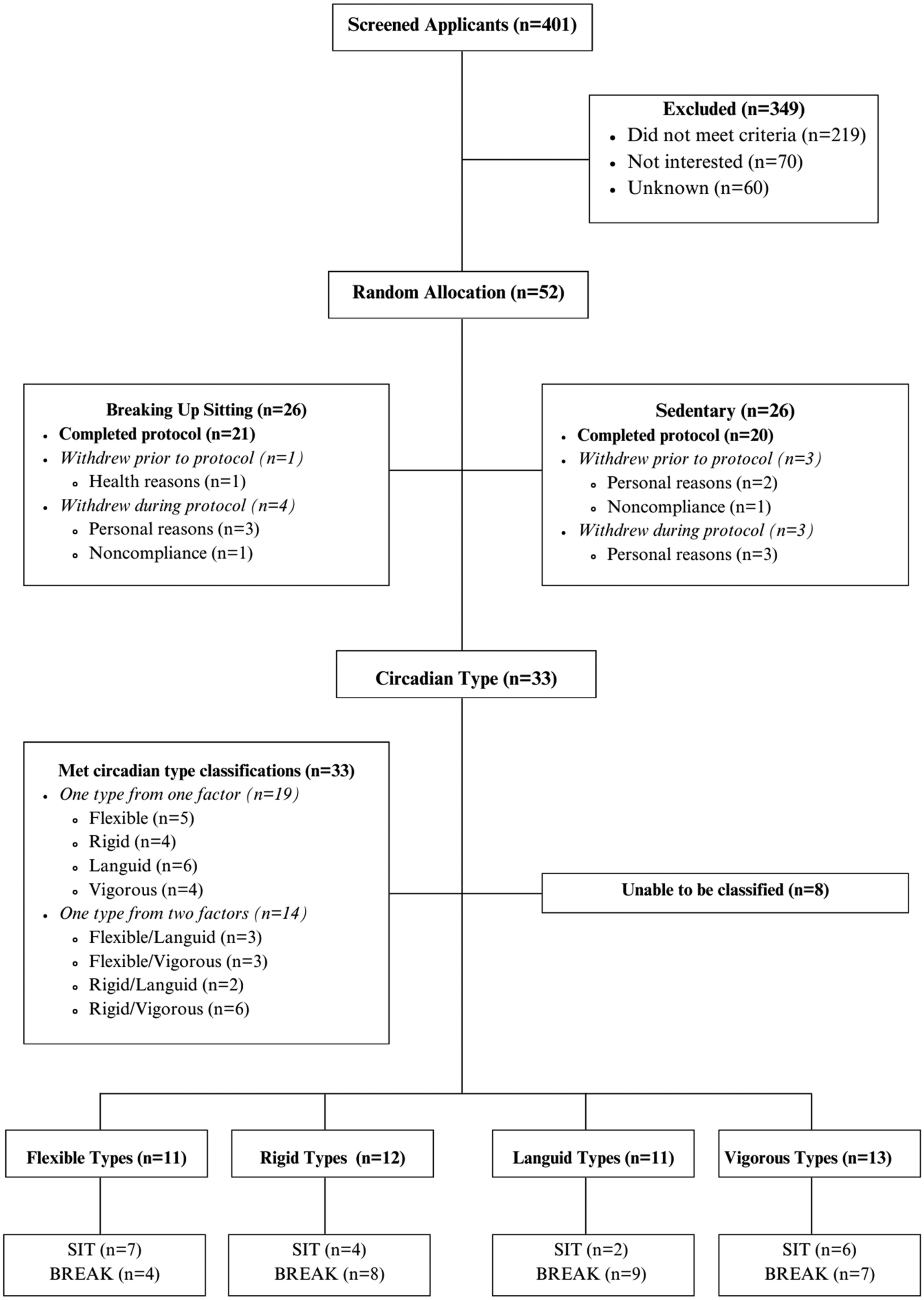

Figure 1. Consort diagram. SIT: sedentary; BREAK: breaking up sitting.

Those allocated to BREAK were required to undergo 3 minutes of light-intensity physical activity every 30 minutes during their simulated shift. The physical activity involved walking at a light pace of 3.2 km/h on a motorised treadmill (Healthrider H95T; Icon Health & Fitness Inc., Utah, USA) at a 0% gradient. All treadmill

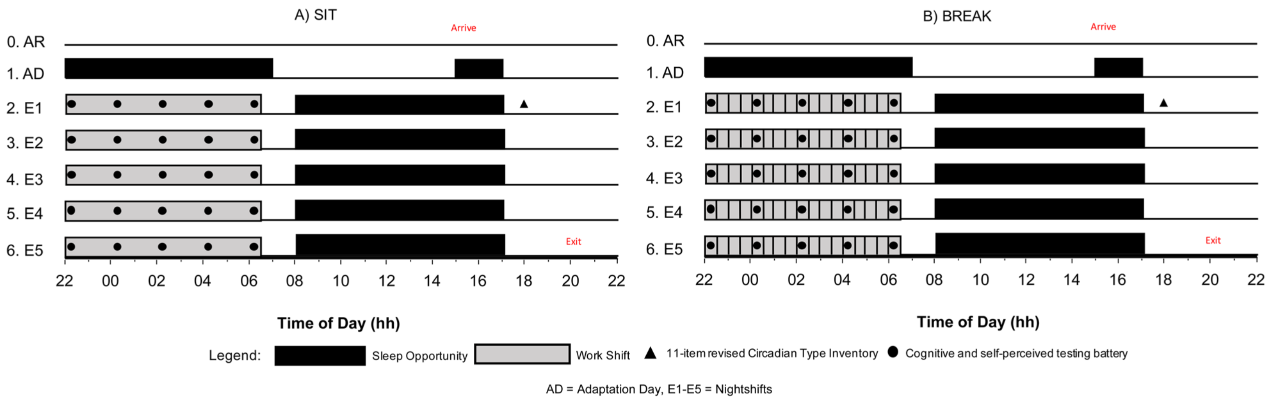

Figure 2. Protocol diagram displaying the sleep periods, activity periods across time (x-axis) and Nightshifts (y-axis). Panel A shows the protocol for sitting (SIT), and panel B shows the protocol for breaking up sitting (BREAK). AR: arrival evening; AD: adaptation day; E1 to E5: Nightshifts.

parameters aligned with the current literature regarding light-intensity exercise as a strategy to improve health and cognitive outcomes (Bailey and Locke 2015). BREAK occurred from the beginning of the night shift (22:00), with the final walk coinciding with the end of the shift (06:00). In total, participants in the BREAK condition performed 17 bouts of breaking up sitting per night. Outside of designated intervention times, participants in BREAK condition remained sedentary. Participants allocated to the SIT condition remained sedentary throughout the study. Compliance with study protocols overnight was monitored by the research team through direct observation or camera surveillance. Each night shift (E1–E5), the subjective fatigue and sleepiness of participants were measured during the five cognitive and self-perceived capacity batteries, every 2 hours (22:00, 00:00, 02:00, 04:00, 06:00), following the designated walk at that time. Testing was completed on an Apple iPad (Apple Inc, Cupertino, California, USA) using an online survey platform (Qualtrics, Provo, Utah, USA).

Measures

Manipulation check

Physical activity

To ensure compliance with intervention requirements (i.e. sedentary or breaking up sitting), triaxial accelerometers were worn by all participants. The activPal monitors (PAL Technologies, Glasgow, Scotland) are approximately 24 × 43 × 5 mm in size and weigh 9 g. The devices were encased in a nitrile sleeve and positioned on the anterior midline of the right thigh by a waterproof adhesive dressing. Manipulation checks were conducted between groups to confirm that step counts differed where designed (i.e. between breaking up sitting and sedentary), and remained consistent within groups where no difference was intended (i.e. within breaking up sitting and sedentary). In line with the existing literature, data was measured at 40 Hz (Stanton et al. 2014).

Control measures

Objective sleep

Objective sleep was assessed using polysomnography (PSG) and standard electroencephalography (EEG) via the Compumedics Grael PSG/EEG system (Compumedics Grael; Melbourne, Victoria, Australia). A derivation of electrodes (i.e. F4-M1, C3-M2 and O2-M1) was used concurrently with two electrooculograms (placed on the left and right outer canthi) and three electromyograms (one placed in the middle of the mandible, and two placed 2 cm below the inferior edge of the mandible). Sleep records were blinded, recorded in 30-s epochs, and scored by the same technician according to AASM scoring criteria (Iber et al. 2007). The following variables were calculated following each sleep period: (i) total sleep time (TST), (ii) wake after sleep onset (WASO), (iii) sleep efficiency (SE), (iv) sleep onset latency (SOL), (v) and the time spent in Stages N1, N2, N3 and rapid eye movement (REM).

Main variables

Circadian type

Circadian type was measured via the 11-item revised Circadian Type Inventory (rCTI). The rCTI assesses the ease in which individuals can alter their sleeping behaviours and daily preferences (Di Milia, Smith, and Folkard 2005). The rCTI has good psychometric properties. Corrected item–total correlation for the five item FR scale ranged from 0.51 to 0.68, and from 0.36 to 0.50 for the LV scale. Cronbach alpha for the FR scale was 0.80, and 0.68 for the LV scale. Test-retest reliability ($n=178$) after 3 months was 0.75 for the FR scale and 0.72 for the LV scale. Using structural equation modelling the factor structure was confirmed in a working sample (Di Milia, Smith, and Folkard 2005), and in a random population sample (Di Milia and Folkard 2021). A sample item from the FR scale is: 'Do you find it as easy to work late at night as earlier in the day?' and from the LV scale: 'Do you find it difficult to "wake-up" properly if you are awoken at an unusual time?' (Di Milia, Smith, and Folkard 2005). Each item is rated on a 5-point Likert scale; 1= almost never, 2=seldom, 3=sometimes, 4=usually, 5=almost always.

Subjective fatigue

The Samn-Perelli Fatigue Scale is a well-validated measure and was used to assess fatigue overnight (Samn and Perelli 1982). This 7-point scale requires participants to select which item best represents their current level of fatigue. The scale ranges from: 1 = fully alert, wide awake, 2 = very lively, responsive, but not at peak, 3 = okay, somewhat fresh, 4 = a little tired, less than fresh, 5 = moderately tired, let down, 6 = extremely tired, very difficult to concentrate, 7 = completely exhausted, unable to function effectively, ready to drop.

Subjective sleepiness

Subjective levels of sleepiness were measured via the well-validated Karolinska Sleepiness Scale (KSS) (Akerstedt and Gillberg 1990). This item requires participants to rate their current level of sleepiness on a 9-point scale. The scale ranges from: 1 = extremely alert, 2 = very alert, 3 = alert, 4 = rather alert, 5 = neither alert nor sleepy, 6 = some signs of sleepiness, 7 = sleepy, no effort to stay awake, 8 = sleepy, some effort to stay awake, 9 = very sleepy, great effort to keep awake, fighting sleep.

Statistical analyses

Data were analysed via Jamovi 2.3.18.0 (2023). For the LV factor, there was a limited number of participants in the SIT languid subgroup (SIT; $n=2$, BREAK; $n=9$). As such, participants in the SIT condition could not be compared between groups for any control or outcome analyses. Only participants in languid and vigour BREAK were included in final analyses. Time-of-day testing was incorporated as a fixed effect in linear mixed models to account for variance over time. However, the main effects and interactions related to this factor are not reported, as the research questions focus on changes in outcomes across each night shift. All data are reported as Mean ± Standard error of the mean unless specified and statistical significance set at $p=0.05$. Residuals were checked for normality.

Manipulation check and control variables (sex, BMI, steps, sleep)

Analyses were conducted to verify that randomisation stratified by sex and BMI had achieved equal distributions of these variables between the two conditions. We compared the numbers of men and women in the two conditions by conducting two separate McNemar tests to compare the FR comparison and LV groups (Pembury Smith and Ruxton 2020). No significant differences were found for either comparison, and so sex was not included as a covariate in the outcome models. To compare BMI values in the two conditions, two separate independent *t*-test were conducted for the FR comparison and for the LV comparison. No significant differences were found for either comparison and so BMI was not included as a covariate in the outcome models.

An independent *t*-test was conducted for all participants in the SIT and BREAK groups to ensure the daily step counts were significantly different between conditions as a manipulation check of the break intervention. To ensure that total daily step count was not significantly different between condition for the FR comparison, a linear mixed model was fitted. Circadian type (F, R), condition (SIT, BREAK) and their interactions were included as fixed factors. No significant effects were observed and so step count was not included as a covariate in outcome models. For the LV comparison, a *t*-test was conducted to ensure that total daily step count did not differ between conditions. A significant difference was observed and so total daily step count for the LV comparison was included as a covariate in all performance outcome models.

To examine differences in polysomnographic sleep data for the FR comparison, a series of separate linear mixed models were fitted for each sleep variable. Circadian type (F, R), condition (SIT, BREAK) and their interactions were included as fixed factors. No significant effects were observed for the FR comparison and so sleep variables were not included as covariates. For the LV comparison, a *t*-test revealed significant differences between conditions for TST, WASO, SE and Stage N2. Based on these significant differences, TST, WASO, SE and Stage N2 were also included as covariates in the LV BREAK outcome analyses.

Outcome variables

Flexible-rigid comparison

For the FR factor, separate linear mixed models were fitted for the Samn-Perelli Fatigue Scale and the

Karolinska Sleepiness Scale. Circadian type (F, R), condition (SIT, BREAK) and Nightshifts (E1–E5) and their interactions were included as fixed factors. Nightshifts were entered as a categorical variable to capture the distinct effects associated with each specific shift. Participant ID was included as a random effect to account for repeated measures on individuals.

Languid-vigour comparison

For the LV factor, separate linear mixed models were fitted for the Samn-Perelli Fatigue Scale and the Karolinska Sleepiness Scale. Circadian type (L, V), and Nightshifts (E1–E5) and their interactions were included as fixed factors. Nightshifts were entered as a categorical variable to capture the distinct effects associated with each specific shift Participant ID was included as a random effect to account for repeated measures on individuals. Step count, TST, WASO, SE and Stage N2 were included as covariates in all performance outcome analyses.

Results

Physical activity

Daily average step count was significantly different between the SIT (1078 ± 46.9) and BREAK groups (6464 ± 60.2), $t(144) = 64.6$, $p = <.001$. No significant two-way interaction between circadian type × condition for step count was observed, $F(1,18.0) = 2.79$, $p = 0.112$. However, a significant difference was observed between languid (6724 ± 84.5) and vigorous types (6151 ± 77.1), $t(77) = 4.85$, $p = <.001$. *Post hoc* analysis indicated the step differences were explained by mean height in the groups. Languid participants were significantly shorter (166 ± 1.71) than vigorous participants, (178 ± 1.83), $t(78.0) = -4.87$, $p = <.001$. Step length (cm) was then calculated as a function of height to determine if this was contributing to differences in total daily step count between languid and vigorous participants. Step length was significantly different between languid (56.17 ± 0.71) and vigorous types (59.87 ± 0.96), $t(76.0) = 3.14$, $p = .002$.

Objective sleep

EEG measured sleep variables of interest were not significantly different between flexible and rigid types in either BREAK or SIT (Table 2). Significant differences in TST ($p = <.001$), WASO ($p = <.001$), SE ($p = <.001$), N2 ($p = .011$) were found for the languid and vigour comparison. All other sleep variables of interest were not significantly different between languid and vigour types (Table 2).

Main variables: flexible-rigid

Subjective fatigue

Samn-Perelli Fatigue Scale. The 2-way interaction between circadian type × nightshifts on subjective fatigue was not significant, $F(4, 450.1) = 1.89$, $p = .054$ (Figure 3(A)).

There was a significant 3-way interaction between condition × nightshifts × circadian type, $F(4, 450.1) = 10.50$, $p = <.001$ (Figure 3(C)). Fatigue was lowest for flexible BREAK participants on E1 compared to all groups. Rigid BREAK participants had significantly lower fatigue on nights E3 to E5 as compared to flexible BREAK participants. Flexible SIT had significantly less fatigue than rigid SIT across all nights. For all significant post-hoc differences see Table 3. Significant main effects were found for nightshifts, $F(4, 450.1) = 17.63$, $p = <.001$, such that fatigue was reduced from E1(3.72 ± 0.15) to E5 (2.88 ± 0.15). Significant main effects were also found for circadian type $F(1, 20.3) = 8.96$, $p = .007$, with flexible types reporting less fatigue (2.85 ± 0.20) compared to rigid

Table 2. All sleep variables for: the two-way interaction between physical activity condition (SIT, BREAK) by circadian type (F, R); and the mean difference between languid and vigour.

Sleep Variable	Flexible		Rigid					Languid	Vigour			
	Sit	Break	Sit	Break	*f*	*df*	*p*	Break	Break	*t*	*df*	*p*
TST (min)	481.00 ± 56.68	468.00 ± 24.80	440.00 ± 18.4	428.00 ± 17.70	5.854	1, 18.6	0.981	464.00 ± 7.36	413.00 ± 9.92	4.040	68.0	<.001
WASO (min)	47.30 ± 15.6	65.70 ± 24.70	91.0 ± 18.10	106.4 ± 17.5	0.005	1, 18.8	0.939	69.3 ± 6.60	122.00 ± 10.0	−4.317	68.0	<.001
SE (%)	90.10 ± 3.00	86.70 ± 4.73	81.50 ± 3.49	79.20 ± 9.08	0.023	1, 18.8	0.880	85.90 ± 1.36	76.50 ± 1.84	4.042	68.0	<.001
SOL (min)	5.79 ± 1.29	6.07 ± .95	5.43 ± 1.50	5.60 ± 1.40	0.001	1, 17.9	0.972	7.06 ± 1.47	4.94 ± 0.71	1.319	68.0	0.192
N1 (min)	28.50 ± 5.20	30.33 ± 7.21	22.20 ± 5.20	21.70 ± 5.11	0.040	1, 18.8	0.843	22.80 ± 1.67	24.30 ± 1.60	−0.630	68.0	0.531
N2 (min)	223.00 ± 13.4	203.00 ± 21.20	211.00 ± 15.6	172.00 ± 15.1	0.339	1, 18.1	0.685	197.00 ± 7.76	166.00 ± 8.58	2.612	68.0	0.011
N3 (min)	119.00 ± 10.90	124.00 ± 17.5	109.00 ± 12.70	129.00 ± 12.40	0.341	1, 18.4	0.566	142.00 ± 6.58	130.00 ± 4.62	1.610	68.0	0.112
REM (min)	109.90 ± 19.30	111.00 ± 13.22	98.00 ± 9.79	109.90 ± 9.39	0.080	1, 18.3	0.780	102.00 ± 4.45	93.20 ± 4.48	1.374	68.0	0.174

Note. TST: total sleep time; WASO: wake after sleep onset; SE: sleep efficiency; SOL: sleep onset latency; N1, stage 1; N2, stage 2; N3, stage 3; REM: rapid eye movement. Data are presented as mean ± SE in minutes (with the exception of sleep efficiency presented as a percentage). Statistical significance set at $p = .05$.

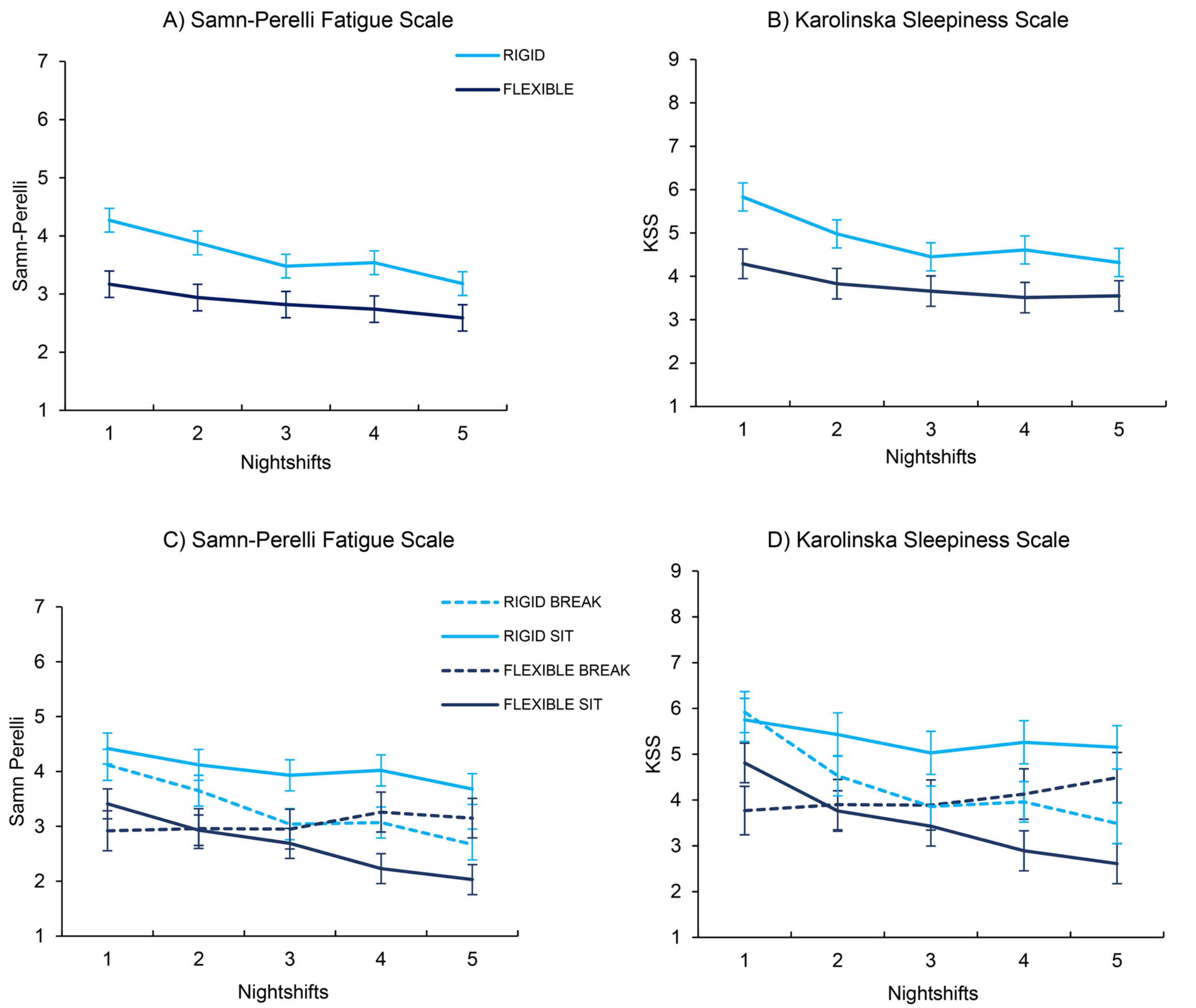

Figure 3. (A) Fatigue scores across five consecutive nightshifts for flexible-rigid types; (B) Sleepiness scores across five consecutive night shifts for flexible-rigid types; (C) Fatigue scores across five consecutive night shifts for flexible-rigid types by activity condition (SIT, BREAK); (D) Sleepiness scores across five consecutive night shifts for flexible-rigid types, by activity condition (SIT, BREAK). Error bars presented as standard error.

types (3.67 ± 0.18). No significant main effects of condition were found $F(1, 20.3) = 0.38$, $p = .547$ on fatigue between SIT (3.35 ± 0.18) BREAK (3.18 ± 0.20) participants.

Subjective sleepiness

Karolinska Sleepiness Scale. The 2-way interaction between circadian type × nightshifts on subjective fatigue was not significant, $F(4, 449.4) = 2.09$, $p = .081$ (Figure 3(B)).

There was a significant 3-way interaction between condition × nightshifts × circadian type, $F(4, 449.4) = 16.71$, $p = <.001$ (Figure 3(D)). Sleepiness was lowest for flexible BREAK participants on E1 compared to rigid BREAK and SIT participants. Flexible SIT participants had significantly less sleepiness than rigid SIT types from E1 to E5, and flexible BREAK participants on E5. Rigid BREAK participants had significantly lower sleepiness on night E5 as compared to rigid SIT types. For significant post-hoc analyses, see Table 4. Significant main effects were found for nightshift, $F(4, 449.5) = 17.62$, $p = <.001$, such that sleepiness was reduced from E1(5.04 ± 0.25) to E5 (3.99 ± 0.25). Significant main effects were also found for circadian type $F(1, 24.8) = 6.48$, $p = .017$, with flexible types reporting less sleepiness (3.77 ± 0.32) compared to rigid types (4.84 ± 0.29). No significant main effects of condition were found $F(1, 20.2) = 0.24$, $p = .632$ on sleepiness between SIT (4.41 ± 0.29) and BREAK (4.19 ± 0.33) participants.

Table 3. Significant group differences in Samn-Perelli Fatigue scores between conditions (Flexible SIT, Rigid SIT, Flexible BREAK, Rigid BREAK) for each Nightshift (E1–E5).

Conditions	*p*
E1	
Flexible SIT < Rigid SIT	.017
Flexible BREAK < Rigid BREAK	.014
Flexible BREAK < Rigid SIT	.003
E2	
Flexible SIT < Rigid SIT	.007
Flexible BREAK < Rigid SIT	.019
E3	
Flexible SIT < Rigid SIT	.004
Flexible BREAK < Rigid BREAK	.044
Rigid BREAK < Rigid SIT	.036
E4	
Flexible SIT < Rigid SIT	<.001
Flexible SIT < Rigid BREAK	.027
Flexible BREAK > Flexible SIT	.031
Rigid BREAK < Rigid SIT	0.18
E5	
Flexible SIT < Rigid SIT	<.001
Flexible BREAK > Flexible SIT	.019
Rigid BREAK < Rigid SIT	.018

Note. The symbol < between condition labels indicates lower fatigue scores, while > indicates higher fatigue scores. Significance is set at ≤.05.

Table 4. Significant group differences in Karolinska Sleepiness Scale scores between conditions (Flexible SIT, Rigid SIT, Flexible BREAK, Rigid BREAK) for each Nightshift (E1–E5).

Conditions	*p*
E1	
Flexible BREAK < Rigid BREAK	.002
Flexible BREAK < Rigid SIT	.009
E2	
Flexible BREAK < Rigid SIT	.043
E3	
Flexible SIT < Rigid SIT	.019
E4	
Flexible SIT < Rigid SIT	<.001
E5	
Flexible SIT < Rigid SIT	<.001
Flexible BREAK > Flexible SIT	.011
Rigid BREAK < Rigid SIT	.016

Note. The symbol < between condition labels indicates lower fatigue scores, while > indicates higher fatigue scores. Significance is set at ≤.05.

Main variables: Languid-vigorous

Subjective fatigue

Samn-Perelli Fatigue Scale. After controlling for sleep and step count as covariates, no significant 2-way interaction was observed between circadian type × nightshifts, $F(4, 272.2) = 2.13$, $p = .77$ (Figure 4(a)). Significant main effects were found for nightshifts, $F(4, 277.3) = 12.99$, $p = <.001$, such that fatigue was reduced from E1(3.86 ± 0.17) to E5 (2.72 ± 0.19). No significant main effects of circadian type were found $F(1, 13.4) = 0.63$, $p = .439$ between languid (3.38 ± 0.21) and vigorous (3.13 ± 0.22) types.

Subjective sleepiness

Karolinska Sleepiness Scale. After controlling for covariates, no significant 2-way interaction existed between circadian type × nightshifts, $F(16, 272.8) = 0.97$, $p = .42$ (Figure 4(B)). Significant main effects were found for nightshifts, $F(4, 277.8) = 12.71$, $p = <.001$, such that sleepiness was reduced from E1(5.30 ± 0.25) to E5 (3.48 ± 0.29). No significant main effects of circadian type were found $F(1, 13.5) = 0.31$, $p = .586$ on sleepiness between languid (4.38 ± 0.31) and vigour (4.11 ± 0.32) types.

Discussion

This study was the first to investigate the relationship between circadian type and breaking up sitting on subjective reports of fatigue and sleepiness over five consecutive simulated night shifts. Flexible and rigid types did not report different levels of fatigue or sleepiness over five nights (research question 1a). Further, breaking up sitting resulted in reduced fatigue and sleepiness scores for rigid types but not for flexible types (research question 1b). Sedentary flexible types reported the lowest fatigue and sleepiness of all conditions over five consecutive nights, while sedentary rigid types reported the highest fatigue and sleepiness. Languid and vigorous types did not report different levels of fatigue and sleepiness.

All participants reported higher fatigue and sleepiness on the first night shift compared to subsequent nights with the exception of the flexible breaking up sitting group. High fatigue and sleepiness on the first night are to be expected given the extended wake (22h) prior to beginning night shifts, which was broken only by a short nap. Flexible types in breaking up sitting had lower fatigue than sedentary rigid types on this night. This finding indicates that circadian differences exist following one night of extended wake and supports previous evidence that flexible types are better able to tolerate irregular work hours (Di Milia and Folkard 2021; Di Milia, Smith, and Folkard 2004, 2005; Saksvik et al. 2011; Wu et al. 2022). Also, flexible breaking up sitting reported significantly lower fatigue on this night, compared to both the rigid breaking up sitting and sedentary conditions, suggesting that breaking up sitting further improved flexible types' fatigue in response to extended wake. We also found that flexible breaking up sitting reported significantly less sleepiness than rigid breaking up sitting and sedentary types on this night. Both these findings suggest that breaking up sitting was an effective alerting factor after extended wake for flexible types, and despite doing the same intervention we did not see the same improvement in rigid breaking up sitting types. Theoretically, one might expect that breaking up sitting is beneficial for everyone, but that there would be a greater benefit from an alerting intervention for rigid types who are posited to have lower tolerance for

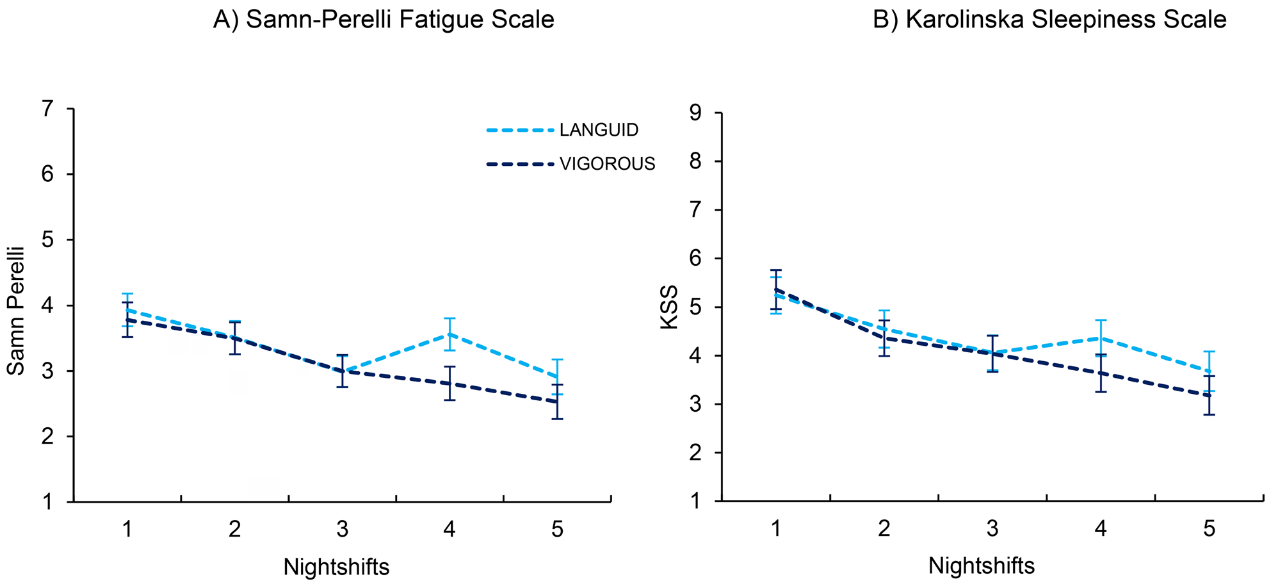

Figure 4. (A) Fatigue scores across five consecutive night shifts for languid-vigour; (B) sleepiness scores across five consecutive nightshifts for languid-vigour. Error bars presented as standard error.

misalignment (Degenfellner and Schernhammer 2021; Di Milia, Smith, and Folkard 2005; Saksvik et al. 2011; Saksvik-Lehouillier et al. 2015). Breaking up sitting might not have been as beneficial for rigid types on the first night due to the innate tolerance flexible types have for irregular work hours, which was then further enhanced by the physical activity intervention.

Flexible breaking up sitting types had the lowest fatigue and sleepiness on the first night compared to all groups, but this was not maintained across night shifts. Flexible breaking up sitting types had low levels of fatigue and sleepiness on the first night, meaning that subsequent improvement across days was unlikely (Kwok et al. 2011). Comparatively, the introduction of breaking up sitting in rigid types produced a greater decline in subjective fatigue over the block of night shifts, compared to sedentary. The higher fatigue reported by the rigid sitting types on the first night meant significant potential for improvement over subsequent nights. We saw a similar trend for sleepiness in rigid breaking up sitting types, though this did not reach significance. These data suggest breaking up sitting may be useful for rigid types over consecutive night shifts. Our findings might be related to the idiosyncratic recovery needs of flexible and rigid types. Much of the research indicates that autonomy over break characteristics, such as choosing break timing to coincide with peaks in fatigue as well as the type of activity, is more effective at regulating the effects of fatigue and performance (Boucsein and Thum 1997; Kim, Park, and Headrick 2018; Tucker 2003). For instance, the preferred timing, and make up, of activity breaks to align with peaks in fatigue and sleepiness may be different for flexible types and rigid types. While these constructs were not assessed in the current study, future studies should consider whether different on-shift recovery needs exist between flexible and rigid circadian types, such as whether intervention timing preferences exist.

Our results for research question 2a highlighted that having a languid or vigorous circadian type did not differentially impact fatigue and sleepiness over five nights after controlling for covariates. The differences in sleep characteristics between groups may have contributed to our findings. On average, languid types obtained 7.7h sleep, relative to the 6.8h sleep for vigorous types. The languid-vigour factor relates to the ability to overcome drowsiness when faced with sleep restriction, with languid types less resilient to the effects of sleep loss (Di Milia, Smith, and Folkard 2005; Jafari Roodbandi, Choobineh, and Daneshvar 2015). Given languid types in our study were not sleep restricted, this might have contributed the lack of observed difference in subjective sleepiness and fatigue. The role of the breaking up sitting intervention could not be determined and research question 2b could not be answered as screening for circadian type to ensure equal numbers were not possible, resulting in low numbers in the sedentary condition for languid types. However, our findings provide interesting data for sleep characteristic differences between languid and vigorous types that should be extended.

Our study was the first to explore circadian type and breaking up sitting with light-intensity physical activity on subjective assessments of fatigue and sleepiness. A study strength lies in the randomised experimental design and highly controlled protocol. However, limitations do exist. The broader project was powered for the main cardiometabolic outcomes, and as such this secondary analysis did not include allocation to physical activity conditions based on circadian type. This meant a smaller sample size and unequal groups. Flexible types had lower subjective fatigue and sleepiness scores than rigid types after five consecutive night shifts but the difference was not significant. Either there is no difference and the lower fatigue and sleepiness scores in flexible types occurred by chance (Hewitt, Mitchell, and Torgerson 2008), or our study is underpowered. Only through additional research with laboratory studies and real shift workers could we conclude either without bias. As such, our findings should be interpreted with relative caution. Additionally, a mismatch between the objective performance and subjective assessments of our participants may exist (Van Dongen 2006). Our participants may have self-reported during heightened states of fatigue and sleepiness, may have been underestimating or overestimating. Future directions include exploring the degree of accuracy between objective outcomes and subjective reports. Though we found different effects of breaking up sitting in flexible and rigid types, we did not make adjustments for multiple comparisons due to the conservative nature of these corrections (Nakagawa 2004), and there may be a chance for Type I error (Armstrong 2014). Our study is the first to examine breaking up sitting with light-intensity physical activity during night shifts; however, our sample of healthy, non-shift workers may limit the generalisability of these findings to shift workers experiencing greater cognitive demand overnight, alongside chronic circadian misalignment and sleep restriction. Future research should explore this intervention with more realistic work tasks, such as simulations, to better replicate the demands faced by shift workers.

Conclusion

Circadian type alone was not associated with a difference in subjective fatigue and sleepiness over five nights. Breaking up prolonged sitting with light-intensity physical activity was most beneficial for rigid circadian types. Subjective assessments of fatigue and sleepiness were not different between languid and vigorous types over five consecutive night shifts. Our results indicate that there may be differences in on-shift recovery needs between flexible and rigid types.

Author contributions

Dayna F. Easton: Methodology, conceptualisation, data curation, visualisation, writing – original draft. **Charlotte C. Gupta**: Methodology, data curation, investigation, writing – review & editing, supervision. **Grace E. Vincent**: Methodology, investigation, writing – review & editing, supervision. **Corneel Vandelanotte**: Methodology, writing – review & editing. **Mitch J. Duncan**: Methodology, writing – review & editing. **Philip Tucker**: Methodology, writing – review & editing. **Lee Di Milia**: Methodology, writing – review & editing. **Sally A. Ferguson**: Methodology, writing – review & editing, supervision.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This work was supported by the Australian Research Council [IA0802].

ORCID

Dayna F. Easton http://orcid.org/0000-0003-4024-4336
Charlotte C. Gupta http://orcid.org/0000-0003-2436-3327
Grace E. Vincent http://orcid.org/0000-0002-7036-7823
Corneel Vandelanotte http://orcid.org/0000-0002-4445-8094
Mitch J. Duncan http://orcid.org/0000-0002-9166-6195
Phillip Tucker http://orcid.org/0000-0002-8105-0901
Lee Di Milia http://orcid.org/0000-0001-7681-5589

Data availability statement

Data will be made available on request.

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