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ORIGINAL ARTICLE

Effects of sleep on positive, negative and neutral valenced story and image memory

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Abstract

During sleep, emotional memories are preferentially strengthened. However, most studies on sleep and emotional memory focus on comparing negative valence with neutral valence stimuli. This study compared the sleep-dependent memory effects for stories and images, each comprising negative, neutral, and positive stimuli. It was hypothesized that a sleep effect would be seen for negatively and positively valenced stimuli. A novel story memory task (comprising three stories), and photographs from the Nencki Affective Picture database were presented for learning to 61 healthy adults (ages 18–25). They were tested for memory on the two tasks immediately, and then again after either a 2-hr nap (n = 31; 17 women, 14 men) or 2-hr wake period (n = 30; 13 women, 17 men). At second testing, the sleep condition had significantly better recall compared to the wake condition on both tasks. There was a relationship with valence only for the story task, with better performance for the sleep condition on the negatively and positively valenced texts, but not on the neutral text. There were no significant relationships between memory measures and sleep-stage duration and EEG power variables. The story memory findings support the hypothesis that memory consolidation prioritizes emotional memory, whether positively or negatively valenced.

KEYWORDS
EEG power, emotional memory, image memory, memory, memory consolidation, N2 sleep, narrative memory, REM sleep, sigma power, Sleep, Slow Wave Sleep, story memory

Practitioner points

- Three new standardized short stories, of positive, negative and neutral emotional valence, and data of their characteristics, are published here.
- The positive and negatively valenced stories were better remembered across a period of sleep in comparison to a period of wakefulness.
- The findings support the hypothesis that sleep-dependent memory consolidation prioritizes emotional memory, whether positively or negatively valenced.

BACKGROUND

There is a solid body of evidence regarding the consolidation effects of sleep on both procedural (Korman et al., 2007) and declarative memories (Ellenbogen et al., 2009). While memory stabilization can also be observed over wakefulness (Brashers-Krug et al., 1996), enhancement in both the declarative (Plihal & Born, 1997; Stickgold & Walker, 2013; Tucker et al., 2006) and procedural domains (Fischer et al., 2002; Stickgold et al., 2000; Walker et al., 2002) appears to be the product of sleep. The impact of sleep on memory is both versatile and enduring. A nap as short as six minutes can bolster memory for declarative information (Lahl et al., 2008) and a 3-hour post-training nap can enhance the retention of materials up to four years later (Wagner et al., 2006). Critically, recently encoded memory traces are *selectively* consolidated during sleep, depending on salience cues and relevance for the future (Born & Wilhelm, 2012; Stickgold & Walker, 2013). For instance, motivational factors, such as reward or emotional valence, may tag memories for consolidation (Diekelmann & Born, 2010; Hu et al., 2006; Payne et al., 2008, 2012). The first aim of the current paper was to address the effects of emotional valence of stimuli on memory consolidation, using stimuli with positive, negative, and neutral valences. The second aim was to address memory for stories, in addition to the more widely studied memory for photos.

Sleep and memory for images

There is a considerable literature on the effects of sleep on memory for images and photos, showing superior recall performance following sleep relative to wakefulness (Sopp et al., 2018). Studies attempting to tease out the relationship of sleep stages to emotional image memory consolidation have utilized various protocols. In a split-night design, sleep across the first half of the night, which is rich in Slow Wave Sleep (SWS), is compared to sleep across the second half of the night, which is rich in Rapid Eye Movement (REM) sleep. Using this design, Groch et al. (2013, 2015) found an enhancement of negative compared to neutral valenced picture recognition across a period of late (REM-rich) sleep, but not across early (SWS-rich) sleep.

Some of the literature demonstrates that REM sleep is critical for tasks involving memory for emotional stimuli, such as the consolidation of fear and safety memories or of the emotionally negative component of complex pictures (Marshall et al., 2014; Payne et al., 2012). Indeed, several studies using emotional memory recognition tasks have found that EEG theta activity (4–8 Hz) during REM sleep correlates with post-sleep improvements in memory performance (Cantero et al., 2003; Nishida et al., 2009; Payne & Kensinger, 2018; Popa et al., 2010). Furthermore, in Sopp et al. (2017), emotional source memory correlated with frontal theta lateralization during REM sleep, whereas neutral item memory correlated with spindle power during NREM sleep. However, there are inconsistencies in the literature. For instance, selective consolidation of the negative emotional components of complex visual memories has been related to N3 delta power during a nap (Payne et al., 2015), but to REM sleep during a whole night (Payne et al., 2012). Furthermore, in Cellini et al. (2016), a daytime nap (with or without REM sleep) was found to facilitate consolidation of memory for photos irrespective of valence, and, in Harrington et al. (2018), sleep rich in either REM or SWS did not interact with photograph memory valence. Also, the finding that recognition for negative picture stimuli was improved compared to neutral stimuli not only across undisturbed sleep but also across REM-deprived sleep (Morgenthaler et al., 2014) suggests that emotional memory consolidation was successfully accomplished within NREM sleep only. A further relationship with NREM sleep was shown by Lehmann et al. (2016), where cueing during NREM sleep significantly improved memory for emotional but not neutral pictures, while no benefit was observed for cuing during REM sleep. Therefore, although an overall sleep effect for memory of photos is in general clear from the literature (although not found by Ashton et al., 2019), relationships with valence and sleep stage are not consistent.

Sleep and story memory

Whereas declarative memory items and word list materials have been commonly used in sleep and memory research, much of memory is narrative based (Mar, 2004), and hence there is a major research question of how narrative memory is affected by sleep. In studies that do not involve sleep, it is known that emotionally toned texts are recalled better than neutral stories. For example, Heuer and Reisberg (1990) developed two stories, which were visually presented using slides. In the neutral version a mother and son visit the father's workplace, he is a mechanic and they watch him repair a car; in the negative version, both visit the work place, the father is a surgeon and struggles to save someone's life. Using these stories, Kazui et al. (2000) and Cahill and McGaugh (1995) showed better recall for emotional rather than neutral content. Groch et al. (2011) similarly used neutral and emotionally negative texts, originally devised by Schürer-Necker (1994), and demonstrated the superior memorability of negative text relative to neutral text at both learning and retrieval.

Sleep has been shown to result in better story memory recall than an equal length period of wake. A one-hour nap, compared to wake, benefits neutral valenced story memory and word pair associates (Lau et al., 2018), and overnight sleep, compared to an equal length period of daytime wakefulness, benefits memory for a negatively valenced story (van Rijn et al., 2017). In Wagner et al. (2006), 3-hr sleep following learning, compared with wakefulness, enhanced memory for negative emotional texts after 4 years, but no enhancement was observed for neutral texts. There is also superior recall of negative compared to neutral texts after a 3-h period of late (REM-rich) night sleep, but not after similar periods of early (SWS-rich) night sleep, where each is compared to a 3-h period of wakefulness (Wagner et al., 2001). However, as late sleep is also rich in (non-REM) sleep stage N2, these effects cannot be attributed conclusively to REM sleep. Indeed, Gilson et al. (2016) found similar performance between neutral and sad stories after short (45 mins) and long naps (90 mins), and no difference in recall of either type of story between these nap conditions, even though the long naps were richer in REM and N2 sleep. The sleep stage and electrophysiological correlates issue is further complicated by Benedict et al.'s (2009) finding that interleukin-6, administered during late night sleep, improved negative emotional but not neutral story memory, while also increasing slow wave activity. Furthermore, the late sleep effects might also be due to the cortisol increase at that time, given that suppression of cortisol from 04:00 by metyrapone suppresses emotional text recall, but not neutral text recall (Rimmele et al., 2015). Contrary to this, though, Wagner et al. (2005) found that cortisol blockade during sleep impairs neutral text memory but enhances emotional memory. Therefore, although there is an overall sleep effect for story memory, with suggestions that this is greater for emotional story memory, as with memory for photographs, there is again a lack of consistency in relationships between emotional story memory and sleep stages and electrophysiology.

Sleep and positive valenced stimuli

To date, the majority of studies on sleep and emotional memory have focused on the comparison of negative valence with neutral valence stimuli, and less attention has been given to positive valence stimuli. The attention to negative emotion is likely driven by the clinical relevance of sleep for adaptation to stress, and the fact that sleep impairment is associated with a range of negative affect symptoms and anxiety disorders (Krystal, 2012). Nevertheless, a growing body of research suggests that the intensity of emotional experience, regardless of valence, determines its processing during sleep. Accordingly, an alternative model, the Reward Activation Model (RAM), posits that the Mesolimbic Dopaminergic (ML-DA) system stimulates re-activation of reward-related memories during sleep (Perogamvros & Schwartz, 2012).

Accruing evidence indicates that structures of the RAM reward processing circuit, including the ventral tegmental area, ventral striatum, hippocampus, amygdala, prefrontal cortex, and anterior cingulate cortex (Kiyatkin & Stein, 1995; Yun et al., 2004), are activated during sleep (Dahan et al., 2007; Nofzinger et al., 2002). Consistent with this model, the promise of a monetary reward leads to a greater improvement in a finger sequence motor task following sleep compared to a period of wake (Fischer & Born, 2009). Finally, perceived value of learned materials predicts recall following sleep, suggesting intrinsic motivation may likewise act as a positive reinforcer (van Rijn et al., 2017). These findings support the hypothesis that activation of emotionally or motivationally relevant information, either positively or negatively valenced, may boost offline learning mechanisms during sleep.

Aims and hypotheses

The two neurocognitive approaches described above diverge on whether it is negative/aversive/stressful memories, or any bi-valent motivational or salient memories, that are prioritized for consolidation during sleep. We therefore aimed to compare the sleep-dependent memory effects for the full range of emotional stimuli—negative, positive, and neutral. To operationalize this, we utilized a bi-valent picture memory task (the Nencki Affective Picture System (NAPS) database; Marchewka et al., 2014), and developed and validated a bi-valent story memory task, which is detailed in the Materials section below. To our knowledge, this is the first study to address the relationship of sleep to bi-valent story memory consolidation.

In line with previous research, we hypothesized that recall on both tasks following a nap would exceed recall after a similar period of wakefulness. We also hypothesized that this effect would be greater for the emotional stimuli. The relative benefit of sleep for positive versus negative emotional stimuli would be used to test between theories that predict that emotionally negative stimuli are preferentially consolidated during sleep, versus that emotional stimuli in general, whether negative or positive, are prioritized over neutral stimuli. We also aimed to explore the relationship of memory change across sleep to measures of sleep electrophysiology, that is, EEG power during sleep of each of the wavebands delta, theta, and sigma, and length of each sleep stage. In view of the inconsistent literature reviewed above regarding relationships of electrophysiology and sleep stage to both types of memory under investigation, these analyses did not have hypotheses and were exploratory.

METHODS

Participants

Sixty-one healthy, non-smoking adults aged between 18 and 25 were recruited. All participants were students at Swansea University, native English speakers, with normal or corrected-to-normal vision and no history of psychiatric, neurological, or sleep-related disorders. Participants were screened to be good sleepers according to their reported sleep quality over the prior month using the Pittsburgh Sleep Quality Index (PSQI; Buysse et al., 1989). This included taking no longer than 30 minutes to get to sleep each night and sleep efficiency no lower than 70%. Participants were instructed to keep a consistent sleep/wake schedule for three days prior to the experiment, including the avoidance of daytime naps, and to refrain from drinking caffeine and alcohol after 15:00 on the day prior to the experiment. Before taking part in the experiment, all participants confirmed that they had adhered to these instructions. All participants gave written informed consent and were paid for their participation. Ethics approval for this study was obtained from the Research Ethics Committee of the School of Psychology, Swansea University.

Participants were randomly allocated to either the sleep (*n* = 31, 17 women, 14 men, mean age = 21.00, *SE* = 0.32) or wake conditions (*n* = 30, 13 women, 17 men, mean age = 21.23, *SE* = 0.32). Two participants, one from the sleep and one from the wake condition, were removed from analyses due to 'severe' scores (rated 22) on the depression subscale of the Depression, Anxiety and Stress Scale-21 (DASS-21; Lovibond & Lovibond, 1995).

Materials

Questionnaires

Participants completed a battery of questionnaires for screening purposes and to ensure equivalence between the sleep and wake conditions on a number of relevant dimensions. These included the PSQI (Buysse et al., 1989) for measures of sleep quality, the short form DASS-21 (Lovibond & Lovibond, 1995) for anxiety and depression, the Napping Behaviour Questionnaire (NBQ; Lovato et al., 2014), Morningness-Eveningness Questionnaire (MEQ short form; Adan & Almirall, 1991) and the Epworth Sleepiness Scale (ESS; Johns, 1991). Subjective state alertness levels were probed using the Stanford Sleepiness Scale (SSS; Hoddes et al., 1973).

Image task

The image task was presented to participants on a 39.6cm Samsung R55 laptop using E-Prime 2.0 (version 2.0.10.353) with responses relayed through a customized button box featuring nine marked buttons along the top edge (representing ratings 1–9) and two central buttons marked 'Old' and 'New'. All instructions were presented in white text, size 36 Courier New font, on a black background. Photos used in the image task were taken from the Nencki Affective Picture System (NAPS) database of emotional imagery (Marchewka et al., 2014). This database was chosen over the older and more commonly used International Affective Picture System (IAPS; Lang et al., 2008) as the NAPS images are comparably (i) more modern in content (taken circa 2006–2012 as opposed to the 1970s–1990s), (ii) of higher quality and resolution, and (iii) organized by category (i.e., people, faces, animals, objects, and landscapes), thus permitting more tightly controlled stimulus construction.

Analogous with the IAPS, NAPS images have standardized data on 1–9 scales of valence (where 1 = very negative to 9 = very positive, with 5 = neutral) and emotional arousal (where 1 = relaxed to 9 = aroused, with 5 = neutral/ambivalent) that use the classic Self-Assessment Manikin (SAM; Bradley & Lang, 1994). Using these standardized valence data two sets of 120 images were created, each set consisting of 40 positive valence photos (both sets, mean standardized valence rating = 7.52, both SEs = .04), 40 neutral valence photos (mean standardized valence ratings = 5.27 and 5.26, both SEs = .05), and 40 negative valence photos (mean standardized valence ratings = 2.53 and 2.56, SDs = .08 and 0.07, respectively). The three valence categories differed significantly from each other, all ts > 43.00, all dfs = 158, all ps < .001: Effect sizes for differences in standardized valence rating between the three valence categories were all very large: positive category > neutral category, Cohen's d = 7.973; neutral category > negative category, d = 6.915; positive category > negative category, d = 13.677. The three valence categories (each *n* = 80) had the following standardized arousal ratings: positive valence category, mean standardized arousal rating = 4.15, *SE* = 0.10; neutral valence category, mean standardized arousal rating = 4.98, *SE* = 0.06; negative valence category, mean standardized arousal rating = 6.72, *SE* = 0.06. The three valence categories differed significantly from each other in standardized arousal, all *t*s > 6.90, all dfs = 158, all *p*s < .001: Effect sizes for differences in standardized arousal rating between the valence categories were all large: negative category > neutral category, d = 3.157; neutral category > positive category, d = 1.093; negative category > positive category, d = 3.344. For testing purposes, each image set was further divided into two subsets (set 1 A/B and set 2 A/B). Valence and arousal thresholds were closely matched between subset versions, and all subsets contained an equal number of people, faces, objects, animals, and landscapes.

Story task

Emotional texts were created for the current investigation so as to address several issues with the widely used Schürer-Necker emotional texts (Schürer-Necker, 1994; Wagner et al., 2001), a classic measure successfully deployed in a number of sleep investigations (e.g., Benedict et al., 2009; Rimmele et al., 2015; Wilhelm et al., 2011). Issues here were that the Schürer-Necker texts (i) consist of only negative and neutral valence, (ii) have markedly different narrative styles, and (iii) have extreme negative valence (namely, a text passage on the rape and murder of a child), which may be problematic for clearing ethics approval in some investigations. The texts featured in the present investigation combine formal elements of the Schürer-Necker task with a short story framework developed by Cahill and McGaugh (1995), who created negative and neutral texts to investigate mood induction and memory retention. These latter two stories, based on a child's hospital visit, start and end identically while the central narrative is either negative (the child is hospitalized from a car accident) or neutral (the child observes a hospital practice drill).

As text valence follows a within-participant manipulation in the present experiment, it was necessary to use stories with different themes, but with each following a format and narrative style similar to the original Cahill and McGaugh (1995) texts. To this end, a positive variant of 'The Hospital Visit' text was generated (the child visits his baby niece in hospital), alongside new neutral and negative texts. The neutral text, 'The Date,' describes the progression of a date between a young woman and a suitor. The negative text, 'The Dental Exam,' describes the disastrous and bloody exam failure of a final year dental student.

Story task texts

> ***The Hospital Visit [positive valence]:*** A mother and her son are leaving home in the morning. She is taking him to visit his father's workplace. The father is a laboratory technician at Victoria Memorial Hospital. They check before crossing a busy road. While walking along, the mother receives a phone call to say her sister had given birth. The mother excitedly told her son that he had a new baby cousin called Sophie. At the hospital the boy rushes to his auntie's bedside so he can hold his baby cousin for the first time. The baby yawned, making cute babbling noises. She looked healthy, happy, and rosy. The ward staff took a photograph of the smiling duo. After, while the boy stayed with his father and auntie, the mother left to phone her other child's pre-school. Feeling elated, she phoned the pre-school to tell them she would soon pick up her child. Heading to pick up her child, she hails a taxi at the number nine bus stop.

> ***The Date [neutral valence]:*** Samantha works hard, and has been planning her day off all week. On Saturday, she got on the train to South Kensington to visit the Natural History Museum. She was planning to meet up with a suitor she met through a dating website. Upon arrival, she saw a tall man talking to some tourists who had asked him to

> take a photo of them. She quickly saw that it was her prospective date, Chris. Chris was wearing a different jacket than she originally saw in his profile photo. They went for coffee where they both talked about politics and who they would vote for in the next election. Later on in the museum gift shop, he bought a book of stamps for some postcards he was planning to write. To top off the day, they walked through the geology exhibit up on the second floor of the museum. Samantha eventually made her excuses and left, catching the 7pm train back home.
>
> ***The Dental Exam [negative valence]:*** Robert was a trainee dentist at the School of Clinical Medicine in Edinburgh. In the last phase of his training, he would undergo a supervised dental operation, his first one ever on a live patient. Robert had been preparing for this for months. In the exam things started to go wrong immediately as his drill slipped and pierced his patient's cheek. To stem the blood he grabbed a towel from a nearby rack but this only served to muffle the woman's desperate screams. She was clearly choking on her own blood. Panicking, Robert tried to extract the drill piece in one smooth motion however this brought with it a chunk of flesh. In tears, he cried for help, and his examiner quickly took over. Not only did Robert fail the exam, he did so in the fastest time ever recorded at the School of Clinical Medicine. He would later tell his friends this story at the pub, not skimping on the details.

All three texts had the same number of emotionally neutral opening (3) and closing (1) sentences, and were closely matched for total number of scored nouns, verbs, and adjectives (~62), overall word count (~162), number of sentences (n = 11), and the ratio of middle (emotional or neutral) content words to opening and closing neutral content words (Table 1). These similarities between the three stories were essential given that strength of initial memory can interact with sleep-dependent memory processes (Schoch et al., 2017). The three texts we devised were shown prior to the study to not differ significantly in number of words recalled.

Memory for the Cahill and McGaugh (1995) texts was originally probed through questions relating to discrete story elements (i.e., sentences). In the present study, we used instead the more fine-grained scoring system from Wagner et al. (2001), based on untimed written free recall, with each recalled noun, verb, and adjective scored as correct, including word transitions (e.g. 'plan' to 'planned') and word synonyms (e.g. 'injured' to 'hurt'), while additional word repetitions were not scored.

Sleep measures

Polysomnographic (PSG) data were collected from all participants (sampling rate 200Hz, high-pass filter 0.1 Hz) using a Trackit™ 18/8 system (version 2.7.7, Lifelines Ltd, UK) with impedance levels set at < 8 kΩ. Electroencephalography (EEG) placement followed the standard 10–20 system with sensors

TABLE 1 Sentence and word counts for the three stories

	The Hospital Visit	The Date	The Dental Exam
Valence	**Positive**	**Neutral**	**Negative**
Total word count	163	161	162
Sentences	11	11	11
Scored neutral initial & final words	27	25	26
Scored middle content words	38	34	38

at F3/4 and M1/2 derivations, a ground electrode placed on the forehead, and a common reference at CPz. Electrooculography (EOG) electrodes were applied above the right outer canthus and below the left outer canthus, with two electromyography (EMG) electrodes placed on the chin to monitor muscle tone. For participants in the wake condition, PSG data were monitored to ensure that they did not fall asleep. For participants in the sleep condition, PSG data were scored using REMLogic (V.2.1, Natus Medical Incorporated) following standard American Academy of Sleep Sciences (ASSM) guidelines (Silber et al., 2007).

Sleep power analyses

Eye movement, body movement, and respiratory artefacts were manually removed from sleep traces, and power analyses were conducted on artefact-free 20-second epochs across the entire nap period using AcqKnowledge Data Analysis Software (V. 4.4, Biopac Systems Incorporated). Sleep traces were analysed for absolute power in delta (0.5–4 Hz), theta (4–8 Hz), and sigma (12–14 Hz) frequency bands. Power analyses were not conducted on the separate sleep stages due to participant variability in sleep stage lengths.

Design and procedure

The experiment followed a mixed-design, with the within-participant variables of valence (positive, neutral, and negative) for each memory task (text and image), and testing session (immediate and delayed), and the between-participant variable of sleep or wake (see Figure 1). The SSS was completed to assess alertness prior to training and after the sleep/wake period. Participants completed the DASS21, MEQ, NBQ, and ESS after the sleep/wake period.

All participants arrived at the sleep laboratory at 10:00 to 10:30 at which point they were randomly allocated to either the sleep or wake conditions prior to being wired up for PSG purposes. Participants were notified prior to training that their memory would later be tested. Training was immediately followed by testing at time point one (T1), with text training and first testing nested between image training and first testing so as to curtail ceiling performance on the latter measure. PSG recordings were then activated and participants entered the bedrooms at 13:00 to 13:30. Participants in the sleep condition were immediately put to bed, whereas participants in the wake condition first sat alone on a chair in the bedroom for 10 minutes with the lights on. This was to provide an equivalent period of potential text/image rehearsal (should it occur) as for participants trying to get to sleep in the nap condition. Following this, participants in the wake condition sat in bed watching a series of factual documentaries of their choosing on a laptop (the documentary series *How Stuff Works* on chocolate, wheat, salt, or beer, the BBC documentary *The Secret Life of Chaos*, or the documentary film *The King of Kong*). After two hours, participants were asked to leave the bedrooms where PSG de-wiring commenced during a 20-minute break. Participants then completed the battery of paper-based measures. Testing at time point two (T2) commenced at approximately 15:30 to 16:00 after which participants were paid and debriefed upon finishing the experiment at 16:30 to 17:00.

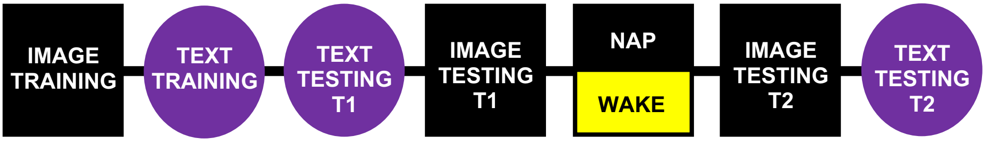

FIGURE 1 Chronological outline of the procedure. T1 and T2 indicate time points 1 and 2

Image training and testing

There was first a short practice session featuring clipart images of varying emotional content, in which six images were randomly presented within a single practice block. Participants were then trained with 120 images. The practice and training trials consisted of, in turn: a 500 ms fixation cross, a 250 ms image, a 500 ms fixation cross, an untimed valence rating, and an untimed arousal rating. Valence and arousal responses were prompted with the onscreen presentation of the appropriate SAM in conjunction with the word ‘EMOTION?’ and ‘AROUSAL?’, respectively. These were scored on 1–9 scales with anchors 1 = negative and 9 = positive, and 1 = not arousing and 9 = highly arousing, with responses provided using the button box.

Testing at T1 and T2 followed an identical format, with 120 images from either Set 1 or Set 2 randomly presented in a single block. Half the items from training (subset 1A/B or 2A/B) were paired with a matched subset of items from the opposing set at each time point, which served as ‘new’ items. Each testing block therefore contained 60 old and 60 new images, with each matched subset (e.g., 1A/2B) containing the same proportion of valenced items (positive, neutral, or negative) and content (animals, objects, people, landscapes, and places). After counterbalancing the presentation order of each subset (T1 or T2), this produced four possible combinations of stimuli for testing, which were pseudo randomly allocated to participants.

Participants were told that they would encounter new images alongside images they had seen previously, for each of which they would have to determine and signal whether it was ‘Old’ or ‘New’ using the button box. As with training, testing was preceded by a short practice phase consisting of a single block of six randomly presented clipart images (3 new, 3 old). A given testing trial consisted of: a 500 ms fixation cross, a 250 ms image, a 500 ms fixation cross, and an untimed Old/New decision.

Story training and testing

In story training, participants were told that they would be reading three short stories and that they would have to memorize them in as much detail as possible. The three stories (The Hospital Visit, The Date and The Dental Exam) were presented to participants typewritten on paper in a randomized order. Participants were given three minutes to read each text, after each of which they rated the text on eleven 7-point (−3 to 3) dimensions (following Wagner et al., 2001): (i) incomprehensible-comprehensible, (ii) uninteresting-interesting, (iii) difficult-easy, (iv) neutral-emotional, (v) unarousing-startling, (vi) unimportant-important, (vii) abstract-concrete, (viii) serious-amusing, (ix) boring-arousing, (x) unfamiliar-familiar, and (xi) negative-positive. For recall, participants were presented with three blank Word document files on a PC and asked to replicate the texts as literally as they could and in as much detail as possible. Participants could write up the texts in any order and this task was untimed. The format of recall testing was identical at T1 and T2.

Data analysis

Statistical analyses were conducted using IBM SPSS Statistics for Windows, version 28.0 (IBM Corp., Armonk, NY, USA). Independent samples t-tests were then used to compare the sleep and wake conditions on the questionnaire metrics (PSQI, DASS21, NBQ, MEQ, ESS, SSS), to ensure equivalency between participants in the two conditions. Validity of the memory measures was tested by a series of ANOVAs on text and image valence ratings to ensure they were being differentially and relatively rated as positive, neutral, or negative valence.

Text rating variables were tested by ANOVA with the within-participant factor of valence (positive, neutral, or negative), and with post-hoc LSD contrasts where the ANOVA was significant for the valence factor. For the two tasks separately, mixed-effects ANOVAs compared memory performance between the groups at baseline, with the within-participant factor of valence. In accordance with previous studies (Cairney et al., 2015; Payne et al., 2008) memory change was then assessed by difference in performance between T1 and T2, using ANOVA, with the within-participant factor of valence and between-subjects factor of group. Planned comparisons between the groups for each valence separately were conducted by t-test. Effect sizes are reported as partial eta squared and Cohen's d. Absolute power in delta, theta, alpha, and sigma frequency bands were correlated using Pearson tests with memory change measures from both the image and text task. Alpha levels for ANOVAs, and post-hoc and planned comparisons were set at $p < .05$. Pearson tests were adjusted for multiple correlations, due to the large number of correlations and lack of specific hypotheses.

RESULTS

Story ratings

Stories were rated by the 59 participants on 11 dimensions during training using a 7-point scale (−3 to +3). A series of 3x2 ANOVAs were conducted on these ratings using the within-participant variable of valence (positive, neutral, or negative) and the between-participant variable of condition (sleep or wake). As the factor of condition revealed no main effects or interactions only the main effects of valence are reported in Table 2. All three texts were found to be equivalent on the dimensions of comprehensibility, difficulty, concreteness, and seriousness. The negative text was rated as more interesting, arousing, important, and less boring than the neutral and positive texts; however, it should be noted that analogous differences were seen in the texts used by Wagner et al. (2001) and should be considered an intrinsic component of valence manipulation. Importantly, the largest and most consistent differences relate to the valence dimension in which the texts were rated appropriately as positive, neutral, and negative. Effect sizes for the main effect of valence and for comparisons between valence categories, where these are significant, are presented in Table S1.

Image ratings

Two participants from the wake condition were removed from the image rating and image memory analyses due to (i) chance (~50%) accuracy performance at test on the image task and (ii) missing data due to an equipment failure at T2 on the image task. Responses from excessively fast (≤ 300msec) and slow (≥3000 msec) trials were trimmed from the dataset (~9% of total responses). This resulted in the removal from the image analyses of one further wake condition participant, who was a high outlier on number of trimmed responses, which led to concerns about robustness and sufficiency of data for this participant across the stimulus categories.

Fifty-six participants thus provided valid data for the image ratings at learning (sleep, $n = 30$; wake, $n = 26$). To determine that images were being appropriately rated as emotionally positive, neutral, or negative in accordance with their pre-experiment designations a 3 × 2 mixed-effects ANOVA was conducted on the image emotion ratings (1–9, negative-positive) during training using the within-participant variable of valence category (negative, neutral, or positive) and the between-participant variable of condition (sleep or wake). The emotion ratings followed the expected order of positive condition ($M = 6.18$, $SE = 0.13$), neutral condition ($M = 4.43$, $SE = 0.10$), and negative condition ($M = 2.79$, $SE = 0.13$): There was here a large main effect of valence category, $F(2,108) = 176.36$, $p < .001$, partial eta sq = .766, with the three valence categories being rated as significantly different from each other on emotion ratings, with all ts > 10.00, dfs = 56, and all *ps* < .001: effect sizes between negative and neutral categories, Cohen's d = 1.331; between negative and positive categories, d = 1.957; and between neutral and positive categories, d = 2.040. There was no main effect of condition, $F(1,54) = 0.282$, $p = .597$, nor an interaction between condition and valence, $F(2,108) = 0.104$, $p = .901$, for these emotion ratings.

TABLE 2 Ratings by 59 participants of story characteristics for the negatively, neutral and positively valenced texts, with main effect of valence and significant comparisons for each characteristic

	Negative text		Neutral text		Positive text				
	M	***SE***	***M***	***SE***	***M***	***SE***	***F* (2,114)**	***p***	**Significant Comparisons**
Comprehensibility	2.34	0.14	2.39	0.12	2.27	0.14	0.368	.693	
Interestingness	2.02	0.11	−0.35	0.23	0.58	0.18	56.234	<.001	neg > pos > neut
Difficulty	2.17	0.14	2.17	0.14	1.77	0.21	3.455	.035	neg > pos
Emotionality	1.66	0.14	−0.64	0.19	1.34	0.11	82.109	<.001	neg > pos > neut
Arousal	1.91	0.14	−1.32	0.16	0.09	0.14	139.763	<.001	neg > pos > neut
Importance	1.16	0.16	−1.24	0.16	0.49	0.13	94.662	<.001	neg > pos > neut
Concreteness	1.08	0.19	0.86	0.18	1.19	0.15	1.353	.263	
Seriousness	−0.37	0.25	−0.29	0.14	−0.04	0.18	0.766	.467	
Boringness	1.63	0.15	−1.35	0.17	0.25	0.20	80.028	<.001	neg > pos > neut
Familiarity	−0.71	0.20	0.22	0.19	0.36	0.18	14.677	<.001	pos & neut > neg
Valence	−1.64	0.14	0.53	0.18	2.18	0.12	165.86	<.001	pos > neut > neg

Note: All ratings were made on a 7-point scale (−3 to +3). F-values represent the main effect of valence. Where comparisons between valences are significant at $p < .05$ on within-subjects contrasts these are indicated. Effect sizes are presented in Table S1.

Group comparisons on background, sleep, and sleepiness measures

A series of independent-samples t-tests were used to compare the sleep and wake conditions on scores from the PSQI, MEQ, the three DASS-21 subscales (depression, anxiety, and stress), Epworth Sleepiness Scale, and the Stanford Sleepiness Scale before learning and after second testing. No significant differences between conditions were found on any of these measures (Table 3, all ts < 1, all *p*s > .44). Global PSQI values (*M* = 4.54, *SE* = 0.27) indicated average scores below the threshold (5) indicative of poor sleep quality (Buysse et al., 1989).

Average DASS-21 metrics from the depression (*M* = 2.98, *SE* = 0.47), anxiety (*M* = 4.07, *SE* = 0.57) and stress (*M* = 7.46, *SE* = 0.75) subscales were well within the suggested 'normal' threshold for these measures (Lovibond & Lovibond, 1995). MEQ scores (*M* = 13.25, *SE* = 0.45) indicated no overall morning or evening type for either condition or differences between the two conditions (Adan & Almirall, 1991). NBQ scores indicated a comparable amount of habitual nappers in the sleep (*n* = 27, 90%) and wake conditions (*n* = 24, 83%; Lovato et al., 2014). Taken together, these results indicate a robust degree of equivalency between the sleep and wake conditions on these measures.

Image task analyses

Image task performance at T1

Two participants in the sleep group slept for less than 30 minutes and were thus excluded from the memory analyses, resulting in analysis of memory data for 54 participants in the image task (sleep group, *n* = 28, mean sleep duration = 65.28 mins, *SE* = 3.88; wake group, *n* = 26). A 3 × 2 mixed effects ANOVA using the within-participant factor of valence (negative, neutral, and positive) and the between-participants factor of condition (sleep vs. wake) was conducted on T1 percentage accuracy to determine performance equivalence prior to the sleep/wake manipulation.

At T1, there was a main effect of valence on memory score, *F*(2, 104) = 4.334, *p* = .016, partial eta sq = .077 (negative images, mean = 87.07, *SE* = 0.99; neutral images, mean = 88.96, *SE* = 0.83; positive images, mean = 86.17, *SE* = 1.02). The only significant pairwise comparison was for neutral versus positive images, *p* = .003, partial eta sq = .160. There was no main effect of condition, *F*(1, 52) = 2.741, *p* = .104 (wake condition, *M* = 88.67, *SE* = 1.10; sleep condition, *M* = 86.14, *SE* = 1.06). There was no significant valence × condition interaction, *F*(2, 104) = 1.621, *p* = .203.

TABLE 3 Scores on sleep quality (assessed by PSQI), Depression, Anxiety and Stress (all assessed by DASS-21), Morningness-Eveningness, Epworth Sleepiness Scale, and Stanford Sleepiness Scale pre-learning and post-final testing, for the sleep and wake groups

	Sleep (*n* = 30)		**Wake (*n* = 29)**	
	M	***SE***	***M***	***SE***
Sleep quality (PSQI)	4.50	0.29	4.59	0.30
Depression	2.93	0.75	3.03	0.63
Anxiety	4.27	0.69	3.86	0.94
Stress	7.80	1.05	7.10	1.08
Morningness-Eveningness	13.00	0.60	13.52	0.69
ESS	6.90	0.46	7.41	0.48
SSS pre-learning	2.63	0.16	2.62	0.15
SSS post-testing	2.77	0.21	3.00	0.22

Change in image memory from T1 to T2

The change score in memory was calculated as T2 percentage correct minus T1 percentage correct, following the method used by Payne et al. (2008) and Cairney et al. (2015). Thus, the more negative the number, the more images were forgotten after the interceding period of sleep or wake. A main effect of condition was present, $F(1,52) = 6.231, p = .016$, partial eta sq = .107, with the sleep condition forgetting less information than the wake condition (Figure 2). There was no valence × condition interaction, $F(2,104) = 0.375, p = .688$, and no main effect of valence, $F(2,104) = 0.968, p = .383$. An independent t-test comparing memory for positively valenced items between the two conditions was marginally significant, $t(52) = 1.957, p = .056$, while groups did not differ on memory change for negative ($t(52) = 1.398, p = .168$) or neutral items ($t(52) = 1.081, p = .285$). These results indicate that individuals who slept forgot less information than those who did not sleep, with the effect being marginally greater for positive emotions.

Correlations of image task performance change with sleep architecture and waveband power measures

Table 4 shows the means of the sleep variables for the naps. Due to some artefacts in the EEG records of three participants, data presented are from 25 sleep group participants. Eight participants had more than 10 minutes of REM, 15 participants had more than 5 minutes of REM.

In order to assess whether specific sleep microstructure was related to the amount of forgetting, we conducted correlations between spectral power in different frequency bands and change in overall image memory performance. Overall change scores are used in this analysis as change scores on this task did not differ as a function of valence. There were no significant Pearson correlations for left or right derivations of delta ($ps > .63$), theta ($ps > .63$), or sigma ($ps > .59$) with change in image memory. There were also no significant correlations between minutes of total sleep, N2, N3, or REM sleep and change in image memory (all $ps > .22$).

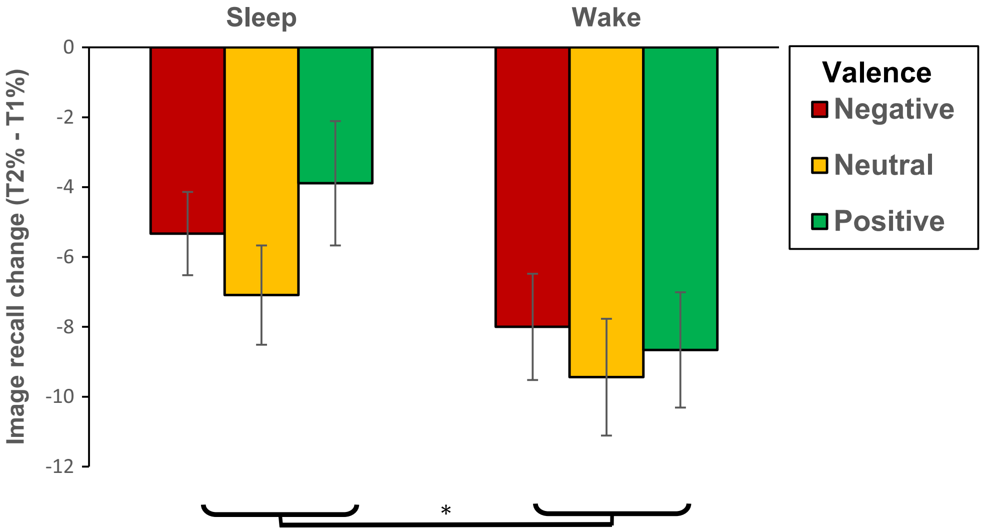

FIGURE 2 Change in image recall (T2% - T1%) as a function of sleep ($n = 28$) versus wake ($n = 26$) condition and valence of image (negative, neutral and positive). Values are M (± SE). *Note*: * $p < .05$

TABLE 4 Means (SEs) of sleep architecture (mins) and EEG power ($\mu V^2/Hz$) variables for the naps

	Mean	*SE*
	Length (mins)	
Sleep latency	20.36	2.45
N1	11.00	1.46
N2	29.50	2.43
N3	26.10	3.40
REM	8.32	1.66
	Power ($\mu V^2/Hz$)	
F3-delta	9.82	1.36
F4-delta	9.71	1.32
F3-theta	0.83	0.08
F4-theta	0.83	0.08
F3-sigma	0.15	0.02
F4-sigma	0.15	0.02

Note: n = 25.

Story task analyses

Story task performance at T1

As stated above, two participants in the sleep group slept for less than 30 minutes and were thus excluded from the memory analyses. One further sleep group participant was excluded from story task memory analyses due to story task data loss at Time 2, resulting in analysis of memory data for 56 participants in the story task (sleep group, *n* = 27, mean sleep duration = 64.33 mins, *SE* = 4.50; wake group, *n* = 29).

Number of words recalled at immediate testing was computed for the 56 participants on the three valence conditions. Immediate recall means (SEs) were: Negative story, mean = 36.16 (0.89); Neutral story, mean = 38.30 (1.08); Positive story, mean = 35.91 (1.09). For immediate recall of the three stories Cronbach's alpha = .81 (number of items = 3, number of cases = 56). There was no effect of group (*F*(1,54) = 1.03, *p* = .315), and no significant interaction between group and valence (*F*(2,108) = 0.189, *p* = .828). Although mean differences between valence conditions were less than 3 words, the conditions did differ significantly in immediate recall, (*F*(2,108) = 3.915, *p* = .023, partial eta sq = .068): LSD post-hoc contrasts showed significantly higher recall for Neutral than for Positive stories (*p* = .006, partial eta sq = .132), and significantly higher recall for neutral than for negative stories (*p* = .036, partial eta sq = .080). Positive and negative stories did not differ significantly on immediate recall (*p* = .811).

Change in story memory from T1 to T2

The story recall change variable was calculated in the same way as for the image task as T2 percentage correct words minus T1 percentage correct words. This variable was entered into a 3 × 2 mixed-effects ANOVA with valence (positive, neutral, or negative) as the within-participants variable and condition (sleep or wake) as the between-participants variable. A significant main effect of condition was present, *F*(1,54) = 9.796, *p* = .003, partial eta sq = .154 (see Figure 3). There was no main effect of valence, *F*(2,108) = 1.935, *p* = .149 and no condition × valence interaction, *F*(2,108) = 0.691, *p* = .503. Regarding the study aim of comparing conditions on change scores for the valences

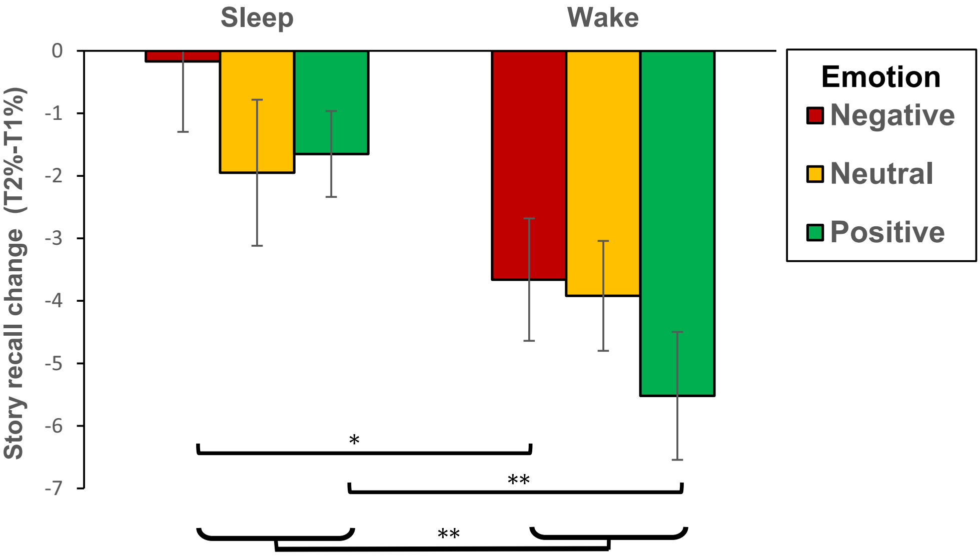

FIGURE 3 Change in word recall (T2% - T1%) as a function of sleep (*n* = 27) versus wake (*n* = 29) condition and valence of text (negative, neutral and positive). Values are *M* (± *SE*). *Note*: * *p* < .05, ***p* = .003

separately, independent t-tests revealed that emotional text recall decreased more in the wake condition relative to sleep for both negative (*t*(54) = 2.35, *p* = .023, Cohen's d = .628) and positive texts (*t*(54) = 3.09, *p* = .003, d = .826); there was no significant difference between groups on neutral text recall (*t*(54) = 1.36, *p* = .180). Post-hoc analyses were then conducted to assess differences between negative and positive text recall within-subjects, for the sleep and wake groups separately, given that for both groups, there was better retention of the negative in comparison to the positive story. For both groups using LSD pairwise comparisons, there was no significant difference in word recall between the negative and positive valence conditions: sleep group, *p* = .223; wake group, *p* = .114. There were also no significant differences in word recall between the negative and neutral valence conditions: sleep group, *p* = .209; wake group, *p* = .830, or between the neutral and positive valence conditions: sleep group, *p* = .810; wake group, *p* = .181.

Note that an alternative story memory change measure was used by Wagner et al. (2001), of T2 score/T1 score expressed as a percentage. Performance above 100% would mean participants are remembering more at T2 than T1, conversely scores below 100% on this measure indicate forgetting. Negligible differences in inferential statistics occurred for this measure, in comparison to the T2 percentage correct – T1 percentage correct measure.

Correlations of story task performance change with sleep architecture and waveband power measures

As above, three participants were removed from sleep stage and EEG power analyses due to artefactual traces; thus, for these analyses, sleep group *n* = 24. Correlations were conducted to assess whether power in specific EEG frequency bands and lengths of N2, N3, and REM sleep, and total sleep length, were associated with change in word recall for the three valences. Twenty-one correlations were conducted (three waveband and one sleep length and three sleep stage length variables, correlated with three story memory change variables), and so threshold *p* was set at *p* = .0024 (.05/21). All correlations were non-significant.

DISCUSSION

The findings confirmed our hypothesis that text and image recall would be superior in the sleep condition compared to the wake condition. As also hypothesized, this effect was greater for positively and negatively valenced information rather than neutral valenced, but only for the story task. For the images task, whereas the sleep effect was found, it was only marginally greater for positively, rather than neutral and negatively valenced stimuli. While the majority of prior research has focused on the role of sleep in negative and neutral valenced memory retention, these findings add to existing literature and suggest that memory for positive stimuli are benefitted by sleep at least as much as for negative stimuli. The story memory results support bi-valent theoretical accounts of the relationship between sleep and emotional memory consolidation (Perogamvros & Schwartz, 2012). However, although the sleep effect was present for negative and positive stories and is hence driven for this task by intensity of emotion rather than being specific to one valence, there may be different neural mechanisms behind these similar changes, and future work should address this. This should take account of the extensive literature showing that for individual learning tasks, where negatively and positively valenced stimuli are both learned, different neural mechanisms may support each type of learning. For example, Namburi et al. (2015) found that whereas the basolateral amygdala is involved in fear and reward learning in two versions (avoidance versus approach) of the same association learning task, it projects to the nucleus accumbens for reward learning and to the centromedial amygdala for fear learning, the latter two areas having reciprocal activities. Similarly, Niznikiewicz and Delgado (2011) showed that similar learning effects could occur in a gambling task for positive and negative reinforcers, but that only the latter was mediated by the striatum.

For the two tasks, we did not find any significant correlations of memory change with sleep electrophysiology or sleep-stage variables. As reviewed earlier, previous findings on the relationship between sleep variables and emotional image memory are inconsistent. Our findings of no relationships with electrophysiology should be seen in the light of this inconsistent literature. Regarding this inconsistency, it may be that variations in image materials, sleep timing and duration alter the relationship between sleep stages, electrophysiology and performance, or it may be that there are no consistent replicable relationships between these variables. The findings here taken alone could thus be interpreted as sleep simply reducing memory decay or eliminating interference from encoding new memories during the time period before delayed testing, rather than that sleep is engaged in active consolidation (Ellenbogen et al., 2006). Nevertheless, the simple reduction in decay of memories during the period asleep may be part of active memory consolidation, in that memories must be maintained so as to be consolidated. Future work addressing active memory consolidation for the narrative memory task should utilize EEG data collection at central, parietal, and occipital sites, as the current study used only frontal placements.

There has been evidence that sleep enables gist memory such that generalizations and abstractions of multiple stimuli can be formed during sleep (Horváth et al., 2016; Lutz et al., 2017), and also that false memories can result from gist processes during sleep (Pardilla-Delgado & Payne, 2017). We class the narrative memory assessed in the present study as episodic rather than as generalized or gist memory because the scoring system required exactly presented words or their synonyms to be recalled. Future work should assess generalized gist narrative recall, which will require much longer and more complex narratives than used in the present study.

Limitations

The ratings of the pictures on the 9-point scale (where 1 = negative, 9 = positive) indicated that the negative pictures were not severely unpleasant: negative pictures, $M = 2.79$; neutral pictures, $M = 4.42$; positive pictures, $M = 6.17$. It may be that the lack of an interaction of the sleep effect with valence on the picture task was due to this mildness of the stimuli. However, the emotional story texts were similarly not extreme, on the 7-point scale (where −3 = negative, +3 = positive): negative story, $M = -1.64$;

neutral story, $M = 0.53$, positive story, $M = 2.18$, and yet here the sleep effect was significant for emotional but not neutral texts.

We accept that in this study, as in many previous studies on sleep and emotional memory, valence is associated with arousal and so apparent effects of valence might be explained partly by arousal. Future studies should aim to disaggregate these variables, but this will require studies with sufficient numbers of stimuli so as to enable multiple levels of arousal within each valence level, with a factor of arousal level included in analyses. In the image task, this will require matching of stimulus characteristics for sets and subsets of images to be done for the arousal factor, just as was done in the current study for the valence factor. Importantly, however, there needs to be cognizance of the measurement issues for arousal that are detailed in Marchewa et al. (2014), and their deliberations on how with the NAPS database positive images are the least arousing, with negative images most arousing and neutral images in between, whereas in the IAPS database, positive and negative pictures were rated as arousing, with neutral pictures rated as falling at the other, non-arousing, extreme.

In order to diminish the likelihood of the wake group participants rehearsing the stories and photos, they were allowed to choose documentaries to watch in the 2-hour wake period. Although we ensured that the contents of the documentaries did not have similarities to the contents of the stories or photos, there is the possibility that wake participants may have each chosen a documentary on the basis of what they would find interesting or enjoyable or pleasant. It is thus possible that any positive effects on mood resulting from this choice may have had a differential effect for the wake group and also for memory for the positively valenced stories. There is also the converse possibility that watching documentaries interfered with story memory in general for this group. These limitations are acknowledged. Nevertheless, it is standard procedure to provide narrative materials for the wake condition in a nap study, and we suggest that this is necessary despite the above possible eventualities.

Our use of two emotional memory tasks does raise the issue of whether there may have been interference between them. Nielsen et al. (2015) found that presenting two procedural tasks together altered the sleep correlates from when the tasks are presented separately, and they concluded that the use of two tasks in one study might lead to capacity constraints for processing in sleep, as well as interference in performance of the two tasks. They also raise the issue of interaction with individual differences in baseline performances on the tasks. On the latter, Peters et al. (2007) show that electrophysiological correlates can alter with baseline level of skill, or lack of skill, of participants, a finding that may become more complex when two tasks are presented. This limitation is important given that both tasks were declarative memory tasks, which can be contrasted to the lack of interference during sleep between procedural and declarative memory tasks found by Brown and Robertson (2007).

CONCLUSIONS

It is important to include positive as well as negative and neutral emotional stimuli in tasks that test the effects of sleep on memory. Image memory was found to be greater after a nap than after the same period of wake but this effect did not alter for the different image valences. The major importance of the present paper is the use of story texts, given that much of human memory is narrative based, rather than item based. Whereas item and list materials have been commonly used in sleep research, there is a major research question of how narrative memory is affected by sleep. This is the first study to address this question using negative, neutral, and positively valenced stories. Story memory was found to be better retained across a nap than across a wake period, this effect being greatest for the positive and negative stories. There were no electrophysiological correlates for performance on the two tasks, and thus no resolutions regarding the inconsistent literature in this area were obtained. Other groups are invited to use these three standardized stories, so as to replicate and extend our results of a sleep effect for emotional story learning, and to address further the possibilities of EEG and sleep stage correlates of the sleep effect.

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CONFLICTS OF INTEREST

We have no conflicts of interest to disclose.

AUTHOR CONTRIBUTION

Alex M. Reid: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Project administration; Software; Validation; Visualization; Writing – original draft; Writing – review & editing. **Anthony Bloxham:** Investigation; Methodology; Software; Writing – review & editing. **Michelle Carr:** Data curation; Formal analysis; Methodology; Software; Validation; Visualization; Writing – review & editing. **Elaine van Rijn:** Investigation; Methodology; Writing – review & editing. **Nasreen Basoudan:** Investigation; Methodology; Writing – review & editing. **Chloe Tulip:** Validation; Visualization; Writing – review & editing. **Mark Blagrove:** Conceptualization; Data curation; Formal analysis; Funding acquisition; Resources; Supervision; Writing – original draft; Writing – review & editing.

OPEN RESEARCH BADGES

This article has earned an Open Data Badge for making publicly available the digitally-shareable data necessary to reproduce the reported results. The data is available at http://doi.org/10.5281/zenodo.5046431.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are openly available in zenodo at http://doi.org/10.5281/zenodo.5046431, reference Sleep and story and photograph memory study (Version 1).

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