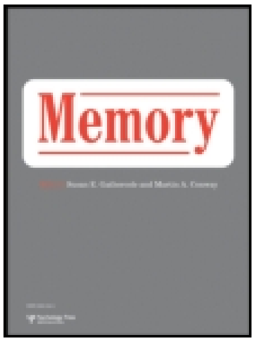

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The effects of sleep on episodic memory in older and younger adults

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Evidence on sleep-dependent benefits for episodic memory remains elusive. Furthermore we know little about age-related changes on the effects of sleep on episodic memory. The study we report is the first to compare the effects of sleep on episodic memories in younger and older adults. Memories of stories and personal events were assessed following a retention interval that included sleep and following an equal duration of wakefulness. Both older and younger adults have superior memory following sleep compared to following wakefulness for both types of material. Amount of forgetting of personal events was less during wakefulness in older adults than in younger adults, possibly due to spontaneous rehearsal. Amount of time spent sleeping correlated highly with sleep benefit in older adults, suggesting that quantity of total sleep, and/or time spent in some stages of sleep, are important contributors to age-related differences in memory consolidation or protection from interference during sleep.

Keywords: Ageing; Episodic memory; Sleep; Memory consolidation.

The notion that sleep may enhance our capacity for alert mental functioning is a widespread one, reflected in the popularity of advice to "sleep tight and wake bright". Far from mere folk wisdom, this idea has been given empirical validation with regard to memory in particular. As early as 1924 the studies of Jenkins and Dallenbach demonstrated superior memory for nonsense syllables following an interval containing sleep, compared to an equivalent duration of wakefulness. Since then many experiments employing different paradigms and assessing different aspects of memory have been conducted, providing support for both episodic and procedural memory consolidation during sleep (see Gais & Born, 2004; Paller & Voss, 2004; Payne & Nadel, 2004; Walker, Brakefield, Morgan, Hobson, & Stickgold, 2002; Walker et al., 2003). In this paper we examine for the first time the effects of ageing on the benefit that sleep has for episodic memory.

Despite a plethora of research on the topic, knowledge about the effects of sleep on memory is limited in two respects. First, while experiments investigating procedural memory improvements have consistently shown benefits gained from sleep, evidence of sleep-dependent *episodic memory* consolidation has been more elusive (for examples see Plihal & Born, 1997; Yaroush, Sullivan, & Ekstrand, 1971; Walker, 2005). Second, age-related changes in the effects of sleep on memory have been largely ignored. Our paper aims to rectify this situation.

Sleep may have differential effects on memory for older and younger adults, due to a multitude of changes in sleep architecture that occur with age (Hornung, Danker-Hopfe, & Heuser, 2005; Van Cauter, Leproult, & Plat, 2000; Wolkove, Elkholy, Baltzan, & Palayew, 2007). Most important for the present research is the finding that there is a substantial decline in slow-wave sleep with age, and eventually stages 3 and 4 are

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completely absent (Rosenzweig, Breedlove, & Watson, 2005). Since these stages of sleep presumably underlie the consolidation of episodic memories (Plihal & Born, 1997; Yaroush et al., 1971), deficits in SWS point to the possibility of less sleep-dependent episodic memory consolidation in older adults. Furthermore, older adults show impairments on hippocampus-dependent memory tasks (Lupien et al., 1998): changes in the structure and function of the hippocampus and prefrontal cortex may underlie memory deficits in older adults and affect the quality of sleep-dependent consolidation (Hornung et al., 2005).

Two studies that investigated the effects of sleep on memory in older and younger adults confirmed that older adults benefited less from sleep (Spencer, Gouw, & Ivry, 2007; Spencer, Sumn, & Ivry, 2006). Explicit and implicit contextual sequence learning tasks were used. Both tasks were presumed to engage hippocampal activity. These tasks are therefore similar to episodic memory tasks, which similarly depend on the hippocampus.

Younger adults showed greater memory improvements on these tasks following a 12-hour interval that included sleep, compared to an equal duration spent awake. Older adults showed no such sleep-dependent benefits, pointing to an age-related decline of sleep-dependent memory consolidation. Since this task presumably engaged hippocampal activity, the findings suggest the possibility that episodic memories, which similarly depend on the hippocampus, may also be differentially affected by sleep in older and younger adults.

Research has suggested, however, that age-related memory deficits may disappear when the studied material engages the older adults' interest rather than being neutral and indifferent (Carstensen & Turk-Charles, 1994; Rahhal, May, & Hasher, 2002). Because the material used in the above studies—word lists and sequences of lights—resemble the latter more than the former, it is possible that using material that is inherently more interesting for the older adults would eliminate the age-related decline in sleep-dependent memory consolidation. We decided, therefore, to use stories and personally experienced events, both because such material would engage the older adults' interest, and because memory for details of stories and personally experienced events is dependent on the hippocampus. We also thought it important to equate the initial memory for the material in older and younger adults, so that any age-related difference following periods of sleep or wakefulness would reflect only changes from a common baseline, rather than ones that would be confounded by baseline differences.

Although this is a strictly behavioural study, finding equivalent benefits of sleep in older and younger adults would suggest that those neurological processes that confer a beneficial effect on memory during sleep are sufficiently intact, at least in healthy older adults, to allow them to operate. If, however, even under conditions that promote encoding and retention, the age-related decline in memory consolidation persists, it would suggest that it is related to neurological changes that accompany old age, such as the reduction of SWS or hippocampal deterioration.

METHOD

Participants

A total of 10 younger (19–29 years old) and 12 older (69–80 years old) adults participated for $10 per hour. Younger adults were recruited through flyers placed around the University of Toronto. Older adults were volunteers in the Adult Volunteer Pool, and were recruited by phone. The data of two older adults were discarded because they did not follow instructions, leaving a sample of 10 older adults. Participants were fluent in English, did not have any self-reported neurological, psychological, or severe medical conditions (e.g. epilepsy, traumatic brain injury), and were not on any medication that affects sleep. Ethics approval was granted by the Department of Psychology Ethics Review Committee at the University of Toronto.

Materials

Two measures of episodic memory were used. The first was the Logical Memory section of the Wechsler Memory Scale III (WMS-III), which consists of two short-paragraph-length stories (Story A and Story B). The stories were scored in terms of the number of story units recalled, as specified in the WMS-III scoring protocol.

The second measure was a list of 12 questions to assess personal episodic memories for the first (or last) conversation the participant had that morning (or the previous evening), as well as memory for the first (or last) thing they read or saw on the news, radio, or television (see Appendix). The questions were the same for each session with the exception of the final two, of which one version was made to be appropriate for the morning and the other for the evening.

Finally, to gather information about participants' sleep the previous night and over the preceding week, the St. Mary's Hospital Sleep Questionnaire (Ellis et al., 1981) and the Pittsburgh Sleep Quality Index (Buysse, Reynolds, Monk, Berman, & Kupfer, 1989) were administered. Questions assess sleep latency, sleep quality, amount of sleep, and sleep satisfaction. This information was obtained to ensure that participants slept reasonably well the night before, and did not experience any unusual sleep problems. Only the measure of sleep duration was used in the data analysis.

Procedure

The study was conducted in three telephone sessions separated by 12-hour intervals. The morning time was scheduled to be relatively soon after the participant usually wakes up. Five younger adults were called in a PM-AM-PM order, and the remaining five in an AM-PM-AM order. Five older adults were called in a PM-AM-PM order, and the remaining five in an AM-PM-AM order. Half of the participants were read story A in the morning and story B in the evening, and the other half were read story B in the morning and story A in the evening.

Participants were instructed to stay in a quiet environment, and their responses were typed. At the beginning of each session participants were reminded that the study was a memory study and that they should not be writing down any notes, hints, or cues, and they were asked to give their word that they would follow instructions and not use any aids. At the end of the study participants were questioned about their strategies and/or use of memory aids; those who admitted to writing down parts of the stories were excluded from the analyses. Two older adults reported using notes or cues. Their data were not analysed, leaving 10 participants in each age group.

AM-PM-AM group. Participants were called in the morning. One of the two WMS-III stories was read to them, and they were asked to recall it immediately, in as much detail as they could remember. This was done to ensure that participants paid attention to the story, and also to equate older and younger adults on initial memory. In cases where older adults' memory was significantly poorer than the average of younger adults, the story was repeated until they approximated or passed the average (in all cases, only one repetition was required).

Participants were then asked the 12 questions about events that happened the previous evening. They were told to answer them in as much detail as they could, taking their time to think about the answer if that was needed, but at the same time keeping their answer limited to what the question is asking.

Finally, the participants were given the St. Mary's Hospital Sleep Questionnaire.

Participants were called again in the evening, 12 hours later, and were tested for recall of the story they heard that morning. Following this, the same procedure was followed as in the previous session except the second WMS-III story was used, and the 12 questions they were asked pertained to events of that morning. Lastly, since there is an increase in daytime napping with age (Hornung et al., 2005; Wolkove et al., 2007), and since a nap can confer similar memory-consolidation benefits as a night of sleep (Mednick, Nakayama, & Stickgold, 2003), participants were asked if they napped during the day, and were given the Pittsburgh Sleep Quality Index.

Participants were called again in the morning, 12 hours later, and their memory for the story they heard the previous evening was tested. They were once again asked questions about events of the previous evening, and given the St. Mary's Hospital Sleep Questionnaire.

PM-AM-PM group. The same procedure was followed as in the AM-PM-AM group, except that the order of events tested were those appropriate to the time of day (e.g., in the first session participants were asked questions about events from that morning, rather than events from the previous evening).

RESULTS AND COMMENTS

WMS-III stories

As a preliminary check, a 2 (encoding time: morning or evening) $\times$ 2 (age group: younger or older adult) mixed-model analysis of variance was conducted on the number of story units recalled at encoding. There was no main effect of encoding time or age group, and no interaction between the two, thus ensuring that our encoding manipulations yielded equivalent initial memory for all comparisons (morning encoding: 16.9 and 16.6; evening encoding: 15.2 and 16.3 story units for younger and older adults respectively). Furthermore, a 2 (order of testing: AM-PM-AM or PM-AM-PM) $\times$ 2 (age group: younger or older adult) analysis of variance on memory following sleep and following wakefulness revealed that order of testing had no effect on memory performance, nor did it interact with age group, all $p > .32$.

Having ensured that these variables did not affect results, a 2×2 mixed-model analysis of variance was conducted on proportion recall scores, with time of test (following wakefulness or following sleep) as the within-participants variable and age group (younger or older adult) as the between-participants variable. Proportion recall scores were obtained by dividing the number of story units recalled at the 12-hour delay test by the number of story units recalled initially at encoding. A score of 1.0 indicates no forgetting, a score greater than 1.0 indicates that more of the story was remembered following the retention interval than initially, and a score less than 1.0 indicates forgetting of the story over the delay.

As Figure 1 illustrates, older adults performed worse than young adults overall, but they benefited as much as younger adults from sleep. This latter impression was confirmed by a main effect of time of test, $F(1, 18) = 25.10$, $p = .001$. There was no main effect of age group, or an age group by time of test interaction. The absence of a significant main effect of age on memory, despite an apparent difference, may have arisen from low power due to the small number of participants.

Analysis of the simple main effect showed that younger adults' memories were significantly better following sleep than following wakefulness, $t(9) = 4.54$, $p = .001$. Proportion recall for younger adults was 0.96 following sleep, but only 0.68 following wakefulness, a difference of 0.28. Similarly, older adults' memories were significantly better following sleep than following wakefulness, $t(9) = 3.06$, $p = .014$. Proportion of recall for older adults was 0.86 following sleep, but only 0.56 following wakefulness, a difference of 0.30.

That this finding is a robust one was confirmed by an effect size calculation. Correcting for the dependence between means in this within-participants design, the effect size was large for both younger and older adults, Cohen's $d = 1.48$ and $d = 1.14$ respectively.

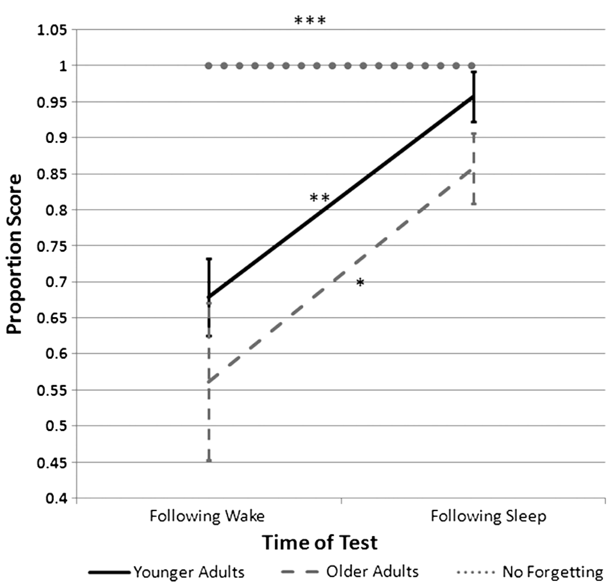

Figure 1. Mean proportion recall of WMS-III story following wakefulness and following sleep, for younger and older adults. Proportion recall is number of story units recalled at test divided by number of story units recalled at encoding. Error bars indicate ± 1 SEM $^{*}p = .01$, simple effect of time of test for older adults; $^{**}p = .001$, simple effect of time of test for younger adults; $^{***}p = .001$, main effect of time of test.

Personal memories

Participants were given a maximum of 2 points per question (with the exception of the first question, for which a maximum of 1 was possible), and performance was scored as the number of points received out of the total possible. Only the data from the first two personal memory tests were scored. As Figure 2 shows, both age groups seemed to benefit from sleep. This impression was confirmed by a 2×2 mixed-model analysis of variance which was conducted on the scores, with time of test (following wakefulness or following sleep) as the within-participants variable, and age group (younger or older adult) as the between-participants variable. There was a main effect of time of test, $F(1, 18) = 36.70$, $p = .001$, and a significant time of test by age group interaction, $F(1, 18) = 5.70$, $p = .028$.

Analysis of the simple main effect revealed that younger adults' personal memories were significantly better following sleep compared to following wakefulness, $t(9) = 5.87$, $p = .001$. Younger adults received an average score of 0.76 following wakefulness, compared to 0.94 following sleep, a difference of 0.18. Older adults' personal memories were also significantly superior following sleep compared to following wakefulness, $t(9) = 2.64$, $p = .027$. Older adults received an average score of 0.80 following wakefulness, compared to 0.88 following sleep, a difference of 0.08. Thus, although both groups benefited from sleep, older adults did so less than younger adults, with mean scores being 8% higher in the older adults, compared to 18% higher in the younger adults, following sleep. The difference, however, may have as much to do with older adults' forgetting less during wakefulness than improving less following sleep.

Sleep questionnaires

No participants reported any sleep disturbances or anything out of the ordinary in their sleep the night before, and none was very unsatisfied with his or her sleep. Thus we were ensured that all participants slept reasonably well the night before.

Younger and older adults did not differ in total number of hours slept during the sleep retention interval (6.60 and 7.48 hours for older and younger adults, respectively). However, the difference between time spent asleep in the first, SWS-rich half of the night was almost significant, with older adults having more early sleep than younger adults, $t(18) = 2.05$, $p = .056$ (3.26 and 2.24 hours for older and younger adults, respectively). Total number of hours slept during the sleep retention interval was significantly correlated with benefit

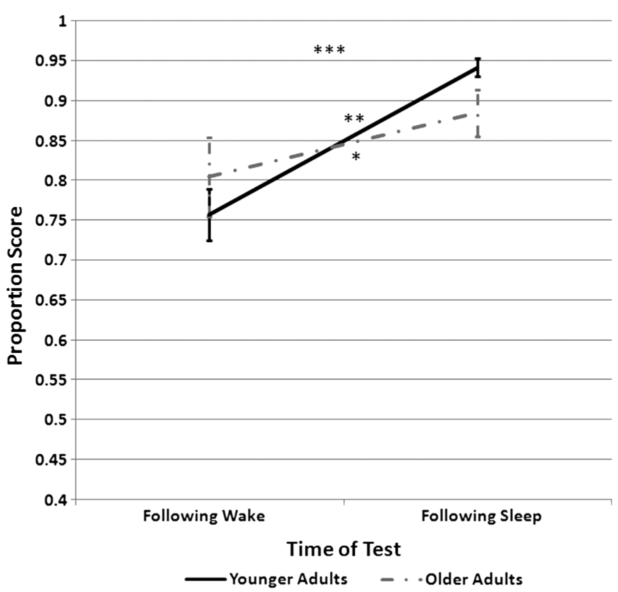

Figure 2. Mean proportion scores for details in personal event memories following wakefulness and following sleep, for younger and older adults. Scores are number of points obtained divided by the maximum number of points possible. Error bars indicate ± 1 SEM *$p = .03$, simple effect of time of test for older adults; **$p = .0002$, simple effect of time of test for younger adults; ***$p = .001$, main effect of time of test.

from sleep (defined as WMS proportion recall following sleep minus WMS proportion recall following wakefulness) for older adults, $r = .775$, $p = .008$, but not for younger adults. No other significant correlations between measures of sleep duration and measures of memory performance were found. Finally, daytime naps did not affect memory performance following wakefulness.

Thus, both younger and older adults' memories benefited from a night of sleep. This was true both for memories for stories and for personal memories. The interaction between age group and time of test for the personal memories could have arisen because older adults' memories did not benefit as much from sleep as the memories of younger adults. Alternatively, the interaction can be interpreted as older adults' memories not declining as much during wakefulness.

GENERAL DISCUSSION

Contrary to the possibility that older adults' episodic memories would not benefit as much from sleep as the memories of younger adults, it was found that memories benefited from sleep to a similar extent in both age groups. This was true of memories for short stories and for personally experienced events, although in the latter case the older adults did not benefit as much. Most interestingly, the number of hours slept correlated with memory benefit from sleep in older adults. These results suggest that the neurological mechanisms needed to confer a memory benefit following sleep as compared to wakefulness are sufficiently preserved in older adults, and can be observed under conditions that promote good encoding and retention.

Previous research on the effects of sleep on episodic memory, to our knowledge, has never been conducted with older adults, although some studies have been conducted on middle-aged adults (Backhaus et al., 2007). Episodic memory research in general has utilised paired-associates word lists as the to-be-remembered items, often failing to find better memory following sleep or finding effects that are fairly small. The present study found much larger and more consistent benefits from sleep using memories for events and episodes. Notably, the older adults often commented that they could relate to the stories and found them engaging, and remarked on the personal significance of their own event memories. This suggests that materials with a narrative structure, particularly those that are emotionally engaging or personally relevant, may be a more appropriate measure of the effects of ageing on sleep and memory than lists of paired words. Stories and personal events likely engage recollective processes more than single words or word pairs, memory for which may depend as much on familiarity as on recollection (Eichenbaum, Yonelinas, & Ranganath, 2007). Considering the crucial role of the hippocampus in recollection and in sleep-related effects (Gais & Born, 2004; Payne & Nadel, 2004), the results suggest that sleep confers benefits on recollection more than on familiarity.

The absence of a main effect of age group on memory for personal events provides support for research suggesting that age-related memory deficits on some tests may disappear when the to-be-remembered material engages the interests and emotions of older adults (Carstensen & Turk-Charles, 1994; Rahhal et al., 2002). Although there was also no significant age difference for story memory, there was a trend favouring younger adults which may not have reached significance due to low power. Even in this case, however, it is important to note that sleep confers an equal benefit to both groups, which is the main finding of interest.

We do not know why the difference between memories for personal events following sleep and following wakefulness in older adults was smaller than the corresponding difference for younger adults. We noted that older adults reported their personal memories as highly self-relevant, while younger adults rarely found their own memories emotionally engaging. One possibility is that only older adults ruminated on these events, which may have protected their memories from decay or interference throughout the day. This suggests that rehearsal during the day may make benefits from sleep appear smaller than may otherwise be the case. It is also important to note that the somewhat better score for after-wakefulness personal memories in older compared to younger adults may have been a factor: when memory is superior during wakefulness, there is little opportunity for equivalent improvement following sleep.

We are cautious in interpreting these data, however, since there was no way of independently confirming the accuracy of the personal memories. Nevertheless, to our knowledge there is no reason to think that memory accuracy would be differentially affected following sleep and wakefulness.

Whether the observed benefits from sleep are due to slow-wave sleep in particular, as opposed to sleep in general, or a period of relative quiescence and little interference, cannot be determined from the present research, nor was the study designed to answer that question. Nonetheless, the results from the sleep questionnaires provide a clue. While there was no difference between the age groups in total number of hours spent asleep before the morning test session, older adults slept more during the early part of the night than did younger adults. Backhaus et al. (2007) found that when middle-aged and younger-adult groups had the same amount of slow-wave sleep (following early sleep in the middle-aged group and late sleep in the younger-adult group), the effects of sleep on declarative memory did not differ between the two groups. Importantly, initial performance was equivalent in the two age groups, which coheres with the above-mentioned possibility that sleep-dependent episodic memory benefits may be observed only with initial memories of sufficient strength. In the present experiments the memories of both age groups may have benefited similarly from sleep if the older adults spent a comparable amount of time in the slow-wave stages of sleep as younger adults. For older adults, however, there was a significant positive correlation between story memory benefits following sleep and total number of hours spent asleep before the morning test session. This raises the possibility that the *entire* night of sleep, or a long period of quiescence and relatively little interference, may be an important factor in promoting better memory following the sleep retention interval. Because sleep stages were not monitored, no firm conclusions can be reached on the basis of our results about which stages of sleep, if any, are important in episodic memory consolidation.

Nonetheless, our study provides a crucial starting point in data and methodology from which future research can progress. It not only strengthens support for the possible beneficial effects of sleep on episodic memory, for which evidence has been elusive, but also extends previous findings by showing that these effects exist for young and old alike. Moreover, this experiment was the first to use memory for stories and for personally experienced events as the to-be-remembered items, showing that declarative memory benefits following sleep are not restricted to lists of words, and may even be magnified when material is used that has a narrative structure that engages the participant and his or her hippocampus. There seems, after all, to be some truth to the cliché "sleep tight and wake bright".

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APPENDIX

AM sessions: Questions about the previous evening

1. Do you live alone or with someone else? Who was the last person with whom you had a conversation last evening, other than someone with whom you live?
2. What did you talk about?
3. What were they wearing? [Omit if phone conversation.]
4. What was the last thing you said to them, other than something generic, like ‘‘goodbye’’?
5. What time did the conversation take place?
6. How long did the conversation last?
7. Where did the conversation take place? Where were you situated in that location?
8. Describe two aspects of the surroundings specific to that episode (i.e., do not say ‘‘refrigerator’’ if there is always a fridge in the kitchen).
9. What were you doing before the conversation?
10. What did you do after the conversation was over?
11. What was the last thing you watched on TV or heard on the radio? [Omit from scoring if they did not watch TV or listen to the radio.]
12. What was the last thing you read before bed? Describe one thing about it. [Omit from scoring if they did not read.]

PM sessions: Questions about that morning

1. Do you live alone or with someone else? Who was the first person with whom you had a conversation this morning, other than someone with whom you live?
2. What did you talk about?
3. What were they wearing? [Omit if phone conversation.]
4. What was the last thing you said to them, other than something generic, like ‘‘goodbye’’?
5. What time did the conversation take place?
6. How long did the conversation last?
7. Where did the conversation take place? Where were you situated in that location?
8. Describe two aspects of the surroundings specific to that episode (i.e., do not say ‘‘refrigerator’’ if there is always a fridge in the kitchen).
9. What were you doing before the conversation?
10. What did you do after the conversation was over?
11. Did you listen to, or read, the news this morning? Name one item from the news. [Omit from scoring if they did not listen to or read the news.]
12. Did you listen to music this morning? What was the first song you heard? [Omit from scoring if they did not listen to music.]