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Sleep improves memory for the content but not execution of intentions in adolescents

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ABSTRACT

Objective: Sleep benefits prospective memory in young adults probably in part due to its well-established role in enhancing declarative memory, thereby facilitating retrieval of the intention content. In prior work on adolescents, we did not detect differences in prospective memory comparing 5 nights of sleep restriction and adequate sleep. Here, we examined whether this might be attributed to a limited role of sleep in benefiting the declarative content in this age group, and whether a sleep benefit on prospective memory would be uncovered with a shorter retention interval.

Methods: A total of 59 adolescents (mean ± standard deviation: 16.55 ± 0.94 years) were instructed to remember to press a special key in response to two target words embedded in a semantic categorization task. Memory was tested after a 12-h retention interval, which included either overnight sleep (21:00−09:00, n = 29) or daytime wakefulness (09:00−21:00, n = 30).

Results: We found no significant group difference in the percentage of target words correctly responded to (mean ± standard error of the mean for the sleep group: 32.76 ± 6.69%; wake group: 41.67 ± 7.61%, $t = 0.88$, $p = 0.38$). However, participants who slept recalled more target words compared to those who stayed awake (98.28 ± 1.72% vs. 86.67 ± 5.32%, $t = 2.05$, $p < 0.05$). In addition, a significantly greater proportion of sleep participants (n = 28 of 29) compared to wake participants (n = 24 of 30) recalled both target words correctly ($\chi^2 = 3.76$, $p < 0.05$).

Conclusion: These findings suggest that during adolescence, sleep plays a more prominent role in improving memory for the content as compared to the execution of intentions.

1. Introduction

Prospective memory refers to the ability to remember to execute an intention at a particular moment in the future, for example, remembering to pass a message to a friend when you see her later (Cohen, 1996). Although prospective memory has a component of declarative memory (ie, remembering the content of the message), prospective memory tasks differ from cued recall tasks of declarative memory as the latter involves a memory search being directly initiated with an instruction from the experimenter (Tulving, 1983). Nonetheless, success on a prospective memory task requires the retrieval of the content of an intention (declarative memory) as well as its timely execution (prospective memory). Recent studies have revealed the beneficial effects of sleep on prospective memory (Diekelmann, Wilhelm, Wagner, & Born, 2013; Scullin & McDaniel, 2010), which could be in part due to its well-established role in facilitating retrieval of the declarative content (Rasch & Born, 2013).

However, most data on sleep and prospective memory comes from young adults. Neurodevelopmental studies indicate that the manner in which children and adolescents engage memory evolves as they gain knowledge and as the prefrontal cortex and hippocampus mature (Ofen et al., 2007). Significant changes to sleep architecture, slow-wave sleep in particular (Buchmann et al., 2011), occur in adolescence, potentially affecting how sleep benefits memory. For example, we recently found that adolescents exposed to5 nights of sleep restriction (time in bed = 5 hours) showed no difference in how often they executed learned intentions compared to those who received the recommended sleep opportunity of 9 hours (Leong, Koh, Tandi, Chee, & Lo, 2018). Although this finding might have arisen as a result of an overly long retention interval that resulted in floor performance in both groups, it could also be attributed to the limited impairing effect of multiple nights of sleep restriction on declarative memory consolidation in adolescents (Voderholzer et al., 2011).

In the present study, we investigated whether sleep would benefit adolescents' prospective memory over a shorter retention interval of 12 hours. We also examined the effect of sleep on the declarative component of prospective memory by assessing the recall of the intention content.

2. Methods

2.1. Participants

A total of 59 adolescents, 14−19 years of age (30 male and 29 female, mean ± standard deviation of age: 16.55 ± 0.94 years) took part in the study. They went through extensive screening during term time 1−3 months prior to the commencement of the study. They reported no history of chronic medical conditions, psychiatric illnesses, or sleep disorders; consumed <5 caffeinated beverages per day; were not habitual short sleepers (individuals with <6 hours of actigraphically assessed average time in bed [TIB] and no evidence of sleep extension for >1 hour on weekends); and had not traveled across more than two time zones per month prior to the study. Subjective sleep quality was indicated by the global score of the Pittsburgh Sleep Quality Index (PSQI) (Buysse, Reynolds, Monk, Berman, & Kupfer, 1989). We modified questions 1, 3, and 4 of the PSQI and asked the participants to report their bedtime, wake time, and actual sleep duration separately for weekdays and weekends. All participants and their parents or guardian provided informed consent, in compliance with a protocol approved by the National University of Singapore Institutional Review Board.

Participants were randomized into the sleep (n = 29) or wake (n = 30) group. The two groups did not differ in age, gender distribution, consumption of caffeinated beverages per day, body mass index, nonverbal intelligence (Raven's Advanced Progressive Matrices) (Raven, 1978), levels of anxiety (Beck Anxiety Inventory) (Beck & Steer, 1993) and depression (Beck Depression Inventory) (Beck, Steer & Brown, 1996), excessive daytime sleepiness (Epworth Sleepiness Scale) (Johns, 1991), morningness−eveningness preference (Morningness−Eveningness Questionnaire) (Horne & Ostberg, 1976), symptoms of chronic sleep reduction (Chronic Sleep Reduction Questionnaire) (Meijer, 2008), or subjective sleep quality (Pittsburg Sleep Quality Inventory) (Buysse, Reynolds, Monk, Berman & Kupfer, 1989) ($p > 0.44$; Table 1). Groups did not differ in self-reported and actigraphically assessed sleep habits during term time ($p > 0.23$; Table 1). In fact, sleep extension over weekends, as measured by TST, was similar to that of adolescents reported in a recent meta-analysis (Gradisar, Gardner, & Dohnt, 2011). The mean of MEQ scores was 48.97 for the sleep group and 50.90 for the wake group, which matched those found in other studies on adolescent chronotypes (Waterhouse, Fukuda, & Morita, 2012). Thus, our sample of adolescents was representative of the general adolescent population.

Table 1

Characteristics of the sleep and wake groups at screening.

	Sleep		Wake		t / χ^2	p
	Mean	SD	Mean	SD		
n	29	—	30	—	—	—
Age (y)	16.58	1.12	16.53	0.73	0.21	0.84
Gender (number of males)	15	—	15	—	0.02	0.89
Caffeinated drinks per day	0.58	0.80	0.53	0.68	0.26	0.79
Body mass index	21.25	3.46	20.70	2.75	0.68	0.50
Raven's Advanced Progressive Matrices score	8.83	1.91	9.13	1.66	0.66	0.51
Beck Anxiety Inventory score	9.34	6.68	10.63	6.34	0.76	0.45
Beck Depression Inventory score	10.97	5.29	9.27	5.44	1.22	0.23
Morningness−Eveningness Questionnaire score	48.97	7.54	50.90	7.01	1.02	0.31
Epworth Sleepiness Scale score	8.21	3.43	7.87	3.71	0.37	0.72
Chronic Sleep Reduction Questionnaire						
Total score	35.24	5.96	35.97	4.64	0.52	0.60
Shortness of sleep	12.72	2.09	13.03	2.01	0.58	0.56
Irritation	6.38	1.52	6.73	1.87	0.80	0.43
Loss of energy	8.48	2.05	8.00	1.98	0.92	0.36
Sleepiness	7.66	2.27	8.20	1.54	1.08	0.28
Pittsburgh Sleep Quality Index						
TIB on weekdays (h)	6.85	1.35	6.74	0.92	0.38	0.71

	Sleep		Wake		t / χ^2	p
	Mean	SD	Mean	SD		
TIB on weekends (h)	8.93	1.18	8.69	1.28	0.78	0.44
TIB on average (h)	7.45	1.08	7.29	0.80	0.62	0.54
TST on weekdays (h)	6.46	1.19	6.42	0.89	0.14	0.89
TST on weekends (h)	8.56	1.20	8.34	1.22	0.69	0.50
TST on average (h)	7.06	0.95	6.97	0.78	0.39	0.70
Global score	4.48	1.50	4.17	1.74	0.75	0.46
Actigraphy						
TIB on weekdays (h)	7.00	0.77	6.80	1.14	0.81	0.42
TIB on weekends (h)	8.45	1.13	8.14	1.03	1.13	0.26
TIB on average (h)	7.42	0.63	7.18	0.92	1.16	0.25
TST on weekdays (h)	5.51	0.75	5.46	0.90	0.20	0.84
TST on weekends (h)	6.76	1.14	6.60	1.00	0.55	0.58
TST on average (h)	5.86	0.68	5.79	0.75	0.41	0.69
Sleep efficiency (%)	79.02	5.57	80.87	6.60	1.16	0.25

SD, standard deviation; TIB, time in bed; TST, total sleep time.

2.2. Study protocol

In the week before the start of the study, participants adhered to a 9-hour time-in-bed (TIB) schedule (23:00–08:00) at home. This was intended for circadian entrainment as well as for minimizing any effect of prior sleep restriction on sleep and cognitive performance.

The present experiment was conducted during the 3-day baseline period of a 15-day protocol whereby participants resided in a boarding school with their sleep and cognitive performance on several tests assessed. All the participants were given a 9-hour sleep opportunity (23:00−08:00) during the 2 baseline nights.

The sleep group performed the intention-encoding session on the first baseline night at 21:00, and the intention retrieval session was conducted the following morning at 09:00. The wake group performed the intention encoding session on the third baseline day at 09:00, and the intention retrieval session was conducted at 21:00 of the same evening.

2.3. Prospective memory task

A prospective memory task (Scullin, McDaniel, & Einstein, 2010) was embedded in an ongoing semantic categorization task, consisting of 150 trials. In each trial, a word was presented in lower-case letters to the left of the computer screen, and participants had to determine whether it was a member of the category word presented in capital letters to the right of the screen (e.g., "hockey SPORT"). Participants responded "yes" or "no" by pressing "1" or "2" on the keyboard, respectively. Performance on the ongoing task was indicated by the percentage of trials with correct responses. Median and mean reaction times for correct trials were also analyzed.

Upon completion of the semantic categorization task during the encoding session, the encoding part of the prospective memory task was administered. Specifically, participants were informed that the researchers had a secondary interest in participants' ability to remember to execute actions in the future. They were instructed to remember to press the "Q" key when they encountered the words "table" and "horse" the next time that they performed the semantic categorization task. Participants were told that they would perform the semantic categorization task again approximately 12 hours later. The instructions for the prospective memory task were presented on the computer screens as follows: "In addition to all the different tasks you have been doing and will be performing, we have a secondary interest in your ability to remember to perform an action in the future. If you ever see the words "table" or "horse" during the Word Categorization task in the next experimental session, we would like for you to press the Q key. These words may appear as the lowercase word on the left, or the word in CAPITALS on the right. If you see either of these two keywords, press Q right away or as soon thereafter that you remember seeing one of those words (even if it's no longer on the screen). Please note that you will not be reminded of the words or this instruction. Also note that your primary goal during this experiment will be performing whatever ongoing task you are given."

To ensure successful encoding of the prospective memory target words and action, participants were required to type the two target words ("table" and "horse") as well as the target key that they had to respond with ("Q") after they were shown the instructions. Unsuccessful attempts and incorrect responses would return them to the screen displaying the prospective memory task instructions. Nonetheless, all participants took no more than one round to encode the two prospective memory words and the target key. In addition, a research assistant verbally reminded the participants that they would have to remember the instructions on their own, as there would be no instructions and reminders on screen the next time they performed the word categorization task.

During the retrieval test session, no mention of the prospective memory task or target words was made. Each target word occurred once. At the end of the retrieval session, participants were asked to type the two target words and the special response key.

Prospective memory performance, that is, the execution of intentions, was quantified by the percentage of target words correctly responded to within 5 trials of the semantic categorization task. However, all participants who responded correctly to the target words during the retrieval session did so on the exact target trial. Although this is a prospective memory task, measures of declarative memory regarding the declarative content of the target words and the target key were also derived. Specifically, we computed 1) the percentage of target words recalled, and 2) the proportions of participants who successfully recalled the target words and the target key for the sleep and the wake groups.

2.4. Actigraphy

Participants' habitual sleep patterns during school term time were assessed for screening purposes with wrist-worn actigraphy (Actiwatch 2, Philips Respironics Inc., Pittsburgh, PA), as well as a sleep diary for a 1-week period. Epoch length was set at 30 seconds, and data were scored with the Actiware software (version 6.0.6). Total sleep time (TST) was derived using a medium sensitivity algorithm, where an activity count greater than or equal to 40 was defined as waking. Bedtimes and wake times were determined by self-reported sleep−wake timings on the sleep diary and event markers on the actogram.

2.5. Statistical analyses

All analyses were performed with SPSS 24.0 (IBM Corp., Armonk, NY). Independent samples *t* tests and χ^2 tests were used to test for group differences in screening parameters, as well as sleep duration measures assessed in the week prior to the study. For declarative memory, a group difference in the percentage of target words recalled was tested using an independent-samples *t* test, whereas group differences in the proportion of participants who recalled the two target words and the target key were examined with χ^2 tests. For prospective memory, we used an independent-samples *t* test to investigate the group difference in the percentage of target words correctly responded to. Finally, we used independent-samples *t* tests to examine whether in the retrieval session, for participants who executed at least one intention, the cost to performance in the ongoing task (as indicated by reduced accuracy and increased median and mean reaction times relative to baseline) was affected by the type of retention interval (further details in section 3.3).

3. Results

3.1. Sleep duration

In the week prior to the encoding session, both groups complied with the 9-hour TIB schedule at home, and the two groups did not differ in TIB (mean ± standard error of the mean for wake: 9.08 ± 0.08 hours vs sleep: 8.99 ± 0.06 hours, $t = 0.86$, $p = 0.39$). In addition, there was no statistically significant difference in TST between groups (wake: 7.45 ± 0.10 hours vs sleep: 7.37 ± 0.08 hours, $t = 0.63$, $p = 0.53$).

3.2. Declarative memory performance

We found significant group differences in measures of declarative memory. Specifically, participants who slept had superior recall of target words (98.28% ± 1.72%) compared to those who stayed awake (86.67% ± 5.32%, $t = 2.05$, $p = 0.045$) (Fig. 1A). In addition, a significantly greater proportion of sleep participants (28 of 29) compared to wake participants (24 of 30) recalled both target words correctly ($\chi^2 = 3.76$, $p = 0.049$), indicating that sleep benefited declarative memory. However, there was no significant difference in the proportion of participants in the sleep group (24 of 29) and the wake group (25 of 30) who recalled the target key ($\chi^2 = 0.003$, $p = 0.95$).

3.3. Prospective memory performance

We found no significant group difference in the percentage of target words correctly responded to in the prospective memory task (sleep: 32.76 ± 6.69 % vs wake: 41.67 ± 7.61 %, $t = 0.88$, $p = 0.38$) (Fig. 1B). When we restricted the analysis to participants who at the retrieval session were able to correctly recall the two target words (“table” and “horse”) and the target key (“Q”), and therefore did not have a deficit in the declarative component of the task, we still did not find any significant group difference in the percentage of target words correctly responded to (sleep, n = 23: 41.30 ± 7.47 % vs wake, n = 21: 54.76 ± 9.07 %, $t = 1.15$, $p = 0.26$).

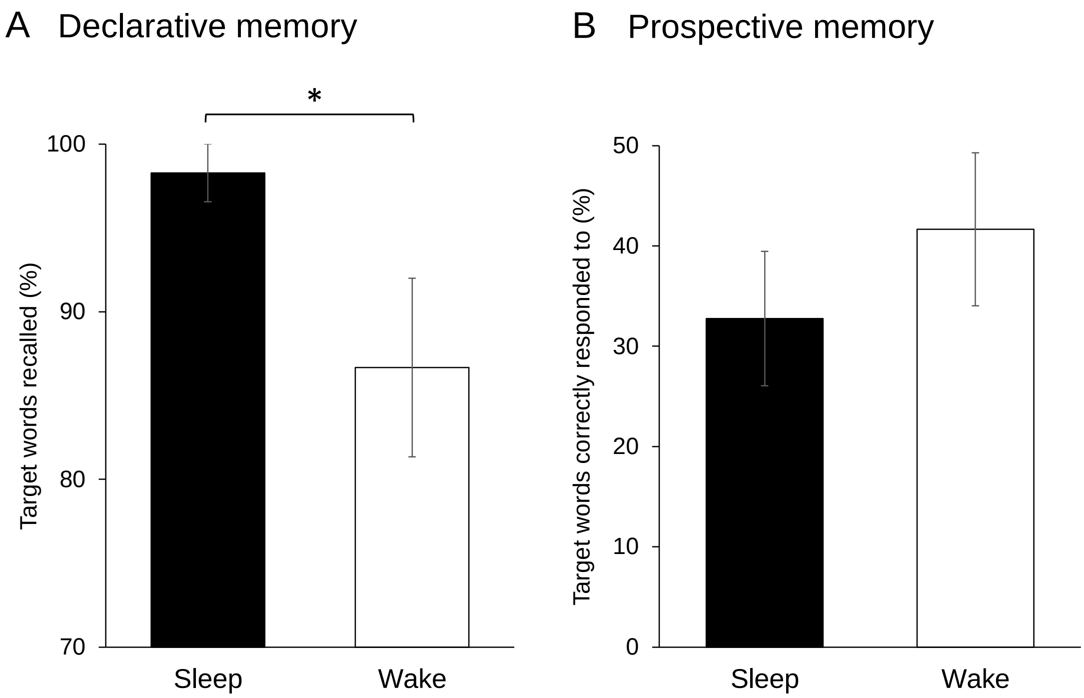

Fig. 1. Differential effects of sleep on declarative and prospective memory. Although (A) declarative memory was superior in the sleep group (black bars) as indicated by the significantly greater percentage of target words recalled than the wake group (white bars), (B) the two groups did not differ in prospective memory performance, that is the percentage of target words correctly responded to. $*p < 0.05$.

3.4. Ongoing task performance

Although the sleep and the wake groups did not differ in their prospective memory performance, the same level of performance could have been achieved using different strategies. Successful execution of intentions relies on conscious monitoring for the appearance of the target words and/or spontaneous retrieval of the word−action association. Here, we focused on the former strategy. Specifically, to examine whether the prospective memory task was accomplished by allocating resources to a monitoring strategy, we adopted a resource allocation account of prospective memory (Marsh, Hicks, & Cook, 2006; Smith, 2003). This account states that use of a monitoring strategy is evidenced by costs to the ongoing task performance, that is, in the forms of reduced accuracy and speed, in the retrieval session.

We focused on participants who were able to detect at least one target word, reflecting that, at minimum, these individuals remembered that there was an intention that they needed to execute (sleep group, n = 15; wake group, n = 17). Independent-samples *t* tests were used to determine the statistical significance of group differences in the changes in semantic categorization task accuracy and the median and mean reaction times between the encoding and retrieval sessions (retrieval – encoding). We found no significant group differences in the change in accuracy ($t = 0.79$, $p = 0.44$) (Table 2) as well as in median reaction time ($t = 0.50$, $p = 0.62$) and mean reaction time ($t = 0.72$, $p = 0.48$), suggesting that both groups used similar strategies to accomplish the prospective memory task. Given the small size of the restricted sample, it is possible that the low power of the present cost analyses limited conclusions regarding group differences in monitoring strategies. However, it may be noted that even when we conducted the same analyses with the full sample and greater statistical power, we found no significant interaction between group × session ($Fs > 0.18$, $ps > 0.54$), suggesting that the sleep and the wake groups did not differ in their monitoring strategies.

Table 2

Change in performance in the semantic categorization task from the encoding to the retrieval sessions for individuals who responded to at least one target word

	Sleep		Wake		*t*	*p*
	Mean	SEM	Mean	SEM		
Δ Task accuracy (%)	1.69	0.78	−2.98	5.50	0.79	0.44
Δ Median reaction time (ms)	82.67	42.22	106.76	26.43	0.50	0.62
Δ Mean reaction time (ms)	40.80	39.62	73.59	25.26	0.72	0.48

ms, Milliseconds; SEM, standard error of the mean.

Change measures (Δ) were derived by subtracting performance in the encoding session from that in the retrieval session.

4. Discussion

In the present study, we contrasted the performance in a prospective memory task of a representative sample of adolescents after a 12-hour retention interval involving either nocturnal sleep or daytime wakefulness. We found differential effects of sleep on declarative and prospective memory. Specifically, our data showed that although sleep enhanced the declarative memory component of the task, thereby enabling better retrieval of the intention content, it did not have any significant impact on the prospective memory component, that is, the execution of the intention.

Our findings shed light on a temporal dimension to the benefit of sleep on declarative memory in adolescents. Compared to adolescents who were tested after 4 nights of 9-hour time in bed (Voderholzer et al., 2011), our sleep group had relatively lower rates of forgetting the target words over a 12-hour period, pointing to increased forgetting with longer retention intervals. Although no significant group difference was found for the recall of the specific target key (“Q”), importantly, we found that our sleep group, compared to the wake group, had superior recall of the target words they were instructed to remember. Our findings are consistent with an earlier study conducted in a group of younger adolescents (10−14 years of age), which found better retention of word pairs following a 12-hour period of overnight sleep versus daytime wakefulness (Potkin & Bunney, 2012). Hence, it appears that selection of an appropriate interval between encoding and retrieval may be important in revealing the benefits of sleep on memory.

Another explanation for the poorer declarative memory performance in the wake group comes from the deactivation view of prospective memory intentions (Marsh, Hicks, & Bink, 1988; Scullin, Bugg, McDaniel, & Einstein, 2011). This account states that completed intentions become “deactivated” and less accessible once they have been performed, making it more difficult to retrieve the content of the intention later on. It is possible that the wake group experienced a stronger deactivation of the contents of the intention due to their numerically (albeit nonstatistically significantly) better prospective memory performance. This disadvantage, juxtaposed with sleep's facilitatory effect on declarative memory, may have resulted in the better recall of the target words in the sleep group relative to the wake group.

Contrary to the observations in adults (Scullin & McDaniel, 2010), we did not find a benefit of sleep on the execution of intentions in adolescents, replicating findings from our earlier study in this age group (Leong et al., 2018) with a shorter retention interval (12 hours vs. 5 nights). The superior recall performance of the sleep group relative to the wake group reported here rules out a declarative memory impairment as the explanation behind the null effect of sleep on prospective memory. Further, sleep did not increase monitoring processes, as we found no significant differences in monitoring costs in either accuracy or speed between the groups ($p > 0.44$).

Nevertheless, we offer two other possibilities for why the present study did not find a sleep benefit on the execution of intentions. First, the exposure to target words in the retrieval session was relatively low in this study. Each of the two target words appeared only once during 150 trials in the retrieval session, whereas in the study in adults by Scullin et al (2010), the two target words each appeared three times over three consecutive ongoing tasks of 150 trials each. Notably, the detection of target words increased with exposure to the target words, with a significant sleep effect emerging in the last of the three ongoing tasks (Scullin et al., 2010). It is possible that a higher frequency of target words appearing in the retrieval session would have raised their levels of activation, increasing the likelihood of being detected by a spontaneous retrieval process whereby cues are noticed and intentions are reflexively retrieved (McDaniel & Einstein, 2000).

A second possibility for why we did not find a benefit of sleep on intention execution is that the sleep benefit might manifest only when the availability of attentional resources is limited. Existing evidence suggests that sleep may benefit prospective remembering through the strengthening of spontaneous retrieval processes rather than by increasing monitoring for the target (Diekelmann et al., 2013; Scullin et al., 2010). To observe this, monitoring may need to be restricted such that retrieval is contingent on spontaneous retrieval. Consistent with this, Diekelmann et al (2013) and Barner et al (2017) found no effect of sleep in a full attention condition, in which participants were free to adopt monitoring strategies. In contrast, the sleep benefit emerged when attention was divided and participants had to rely on spontaneous retrieval. In our sample, as we did not limit attentional resources, the use of various strategies may have masked the influence of sleep on spontaneous retrieval processes.

This study does have several limitations. First, as mentioned, one limitation is that participants were free to engage in monitoring, thereby restricting a closer examination of spontaneous retrieval processes in prospective memory. Future work investigating the benefit of sleep on retrieval processes should attempt to tease apart retrieval strategies by controlling for monitoring (Bugg & Ball, 2017; Scullin et al., 2010).

Second, as each of the two target words was only presented once, the prospective and declarative memory measures were quite discrete, as participants could get 0%, 50%, or 100% of answers correct. Future work using this task may consider increasing the number of times that each target word is presented or by introducing more target words to enable more continuous measures of performance.

Third, the present study did not include a circadian control group, and both the sleep and the wake groups performed the encoding and retrieval sessions at different times of day. However, as previous studies investigating circadian influences did not find a time-of-day effect on declarative memory consolidation in high school students (mean age, 18.1 years)

(Gais, Lucas and Born, 2006), it is unlikely that the sleep benefit on declarative memory observed in our adolescent sample was due to circadian effects. Nevertheless, as recent findings suggest that time-of-day effects on prospective memory may vary as a function of age (Rothen & Meier, 2017), future studies should either directly test for circadian influences by including circadian control groups, or control time-of-day effects by using a nap paradigm that enables the nap and the wake groups to encode and retrieve information at the same clock times.

Finally, as we sought to simulate a typical day for adolescents, our wake participants were allowed to engage in typical activities such as games and other leisure activities. Thus, the superior declarative memory performance of the sleep group might in part be due to the *passive* role of sleep in protecting recently acquired memory from interference. However, the feature of sleep that might *actively* facilitate retrieval of declarative information in a prospective memory task remains to be addressed.

5. Conclusion

In the present sample of adolescents, post-learning sleep enhanced memory of the content of an intention, but not its execution. These differential effects of sleep suggest that during adolescence, sleep plays a more prominent role in improving memory for the content as compared to the execution of intentions.

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Conflict of interest

The authors declare no competing financial interests.

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Highlights

- This study inquired whether sleep enhances the content and execution of intentions in adolescents.
- A period of sleep, versus wakefulness, did not benefit execution of intentions.
- However, those who slept recalled more content compared to those who stayed awake.
- Sleep improved memory for the content, but not for the execution of intentions.