British Journal of Developmental Psychology (2018)
© 2018 The Authors. *British Journal of Developmental Psychology* published by John Wiley & Sons Ltd on behalf of British Psychological Society

The British Psychological Society

www.wileyonlinelibrary.com

Post-encoding wakeful resting supports the retention of new verbal memories in children aged 13–14 years

Markus Martini*, Caroline Martini, Christine Bernegger and Pierre Sachse

University of Innsbruck, Austria

Evidence primarily exists in adults that engaging in task-related mental activity after new learning results in increased forgetting of learned information, compared with quietly resting in the minutes that follow learning, where less forgetting is observed. The current study investigated whether the beneficial effect of post-encoding rest can be observed in children aged 13–14 years. Each child (N = 102) encoded two word lists. After the presentation and immediate recall of one word list, children wakefully rested for 10 min (resting condition), after presentation and immediate recall of the other word list, they solved visuo-spatial problems for 10 min (problem-solving condition). Seven days later, a surprise free recall test for the two word lists took place. Our results showed that children retained more words over 7 days in the resting condition than with the problem-solving condition. Post-hoc analyses revealed that the resting effect was a function of the number of words recollected during the immediate recall. Specifically, those children who recalled fewest words (≤ 13/30 words) in the immediate recall showed a significant resting effect. There was no resting effect in those who recalled a mid-range (14–16/30 words) or a high number (>16/30 words) of words. These results provide new insights into the factors that influence memory in children, and suggest that a few minutes of wakeful rest benefits memory, relative to engaging in an ongoing task.

Statement of contribution

What is already known on this subject?

- Task-related mental activity after encoding weakens memory retention more than wakeful resting.
- Beneficial effect of resting after encoding was found primarily in younger and older adults.

What does this study add?

- We investigated children at the age of 13–14 years.
- 8-min post-encoding wakeful resting supports memory retention over 7 days.
- Individuals differ in the impact of a brief period of wakeful resting after learning.
- Only children with lower immediate memory performances profited from wakeful resting.

This is an open access article under the terms of the Creative Commons Attribution-NonCommercial License, which permits use, distribution and reproduction in any medium, provided the original work is properly cited and is not used for commercial purposes.

**Correspondence should be addressed to Markus Martini, University of Innsbruck, Innrain 52, 6020 Innsbruck, Austria (email: markus.martini@uibk.ac.at).*

DOI:10.1111/bjdp.12267

Evidence primarily exits in adults that engaging in task-related mental activity after new learning results in increased forgetting of learned information, compared with quietly resting in the minutes that follow learning, where less forgetting is observed. For instance, a study by Dewar, Cowan, and Della Sala (2007) showed that healthy young adults remembered significantly more words when required to sit in a comfortable chair and rest for 8 min compared with a post-encoding period of the same length, in which participants had to perform a spot-the-difference or tone-detection task, solve math problems, watch a video, or listen to the radio. The authors assumed that any mentally effortful task, independent of its content, following the encoding of new information has the potential to disrupt consolidation processes responsible for creating longer lasting memories (see McGaugh, 2015; Robertson, 2012; Wixted & Cai, 2013). Thus, competition between mental activities can lead to a decrease in memory storage and recall (McGaugh, 2015; Robertson, 2012; Wixted & Cai, 2013).

'Resting effects' on memory retention were found in healthy elderly and younger adults as well as amnesic and Alzheimer's disease patients with different encoding material and post-encoding interference tasks (Alber, Della Sala, & Dewar, 2014; Cowan, Beschin, & Della Sala, 2004; Craig, Dewar, Della Sala, & Wolbers, 2015; Della Sala, Cowan, Beschin, & Perini, 2005; Dewar, Alber, Butler, Cowan, & Della Sala, 2012; but see Martini, Riedlsperger, Maran, & Sachse, 2017; Varma *et al.*, 2017 for inconsistent findings). Neuroscientific evidence exists that during resting previously encoded information is replayed (Deuker *et al.*, 2013; Tambini, Ketz, & Davachi, 2010). This replay serves to consolidate the memory content to become longer lasting and less prone to interference (Carr, Jadhav, & Frank, 2011; Robertson, 2012). Mednick, Cai, Shuman, Anagnostaras, and Wixted (2011) hypothesized that the brain opportunistically consolidates previously encoded (hippocampus-dependent) memories whenever the hippocampus is not otherwise occupied by the task of encoding new memories. Sleep and quiet wakeful resting represent optimal states of reduced sensory input and task-related engagement, which should support memory consolidation (see Brown, Weighall, Henderson, & Gareth Gaskell, 2012 showing that sleep supported declarative memory consolidation in 7- and 12-year-old children). Furthermore, recent findings in young adults (Brokaw *et al.*, 2016) indicate that consolidation during wakeful resting is supported by a slow oscillatory EEG signature, which also is proposed to facilitate consolidation during sleep by promoting hippocampal–cortical communication (Bergmann & Staresina, 2017).

Studies investigating the impact of a brief period of quiet wakeful rest after learning in children are scarce. We found only one study investigating the impact of a brief period of post-encoding quiet wakeful rest on memory retention in children, compared with a cognitive task delay period. Fatania and Mercer (2017) investigated children (age range 6–7 years) and adults (age range 18–61 years) in Experiment 1, and children (age range 6–7 years) only in Experiment 2. In their study, children were required to learn two word lists. After learning one word list, children rested for 5 min, and after the other word list, they conducted a spot-the-difference task. The central findings of Experiment 1 were that children benefited from a brief post-learning wakeful resting phase. Adults showed no differences in the retention scores between the two post-learning conditions. Experiment 2 showed that when children had more time to learn and recall a word list the resting effect disappeared. Findings in children from studies focusing on the impact of retroactive interference with a different definition of the resting phase (e.g., eating and talking to the experimenter were allowed) found mixed results. For instance, Darby and Sloutsky (2015) found that memories of 5-year-old children were disrupted by task-related post-learning interference, whereas Bauer, Van Abbema, and de Haan (1999; Experiment 3) found no such differences in 20-month-old toddlers. Others found that preschoolers were either less or equally susceptible to retroactive interference than older children (Howe, 1995; Koppenaal, Krull, & Katz, 1964). A better understanding of the impact of post-encoding conditions on memory retention over shorter and longer temporal intervals in different age groups of children is of importance.

The current study investigated whether the beneficial effect of post-encoding rest (Brokaw *et al.*, 2016; Craig *et al.*, 2015; Dewar *et al.*, 2012; Mercer, 2015) can be observed in children aged 13–14 years over a retention interval of 7 days. Our experimental design was based on those used in similar previous studies (Craig *et al.*, 2015; Dewar, Alber, Cowan, & Della Sala, 2014; Dewar *et al.*, 2012; Fatania & Mercer, 2017). In a within-subject design, children were asked to encode and immediately recall two word lists. After the immediate recall of one word list, children wakefully rested for 10 min (eyes closed, relaxed; resting condition). After the immediate recall of the other word list, they were involved in a visuo-spatial problem-solving task for 10 min (problem-solving condition). Word lists and delay conditions were counterbalanced. In a delayed surprise free recall test after 7 days, children were asked to recall the words from both word lists. Based on the findings of previous work (Brokaw *et al.*, 2016; Craig *et al.*, 2015; Dewar *et al.*, 2007, 2012; Mercer, 2015), we hypothesized that children retain more words from the list followed by wakeful rest than they did from the list followed by the problem-solving task. Alternatively, if memory consolidation does not benefit from rest, there should be no significant difference between the conditions.

Method

Ethics statement

The present research was conducted with approval by the Institutional Review Board, Ministry of Education, principal of the school, and parents of participating children.

Participants

One hundred and two children who attended a local school were investigated (61 female; mean age = 13.62 years, age range = 13–14 years). Of these, 39 children were in their seventh and 63 in their eighth year of schooling.

Materials

Children encoded two word lists in their first language (German) taken from the Verbal Learning and Memory Test (Helmstaedter, Lendt, & Lux, 2001). Each word list consisted of 15 mono- and bi-syllabic, highly familiar nouns (e.g., 'Tisch' [table], 'Kirsche' [cherry], 'Vogel' [bird]). Words were semantically unrelated within as well as between the word lists. Words were presented sequentially in the middle of the computer screen for 1,000 ms with an interstimulus interval of 1,000 ms. The experiment was programmed in E-Prime. Order of the two word lists was counterbalanced. In the post-encoding problem-solving condition, children were required to solve abstract visuo-spatial problems taken from the Advanced Progressive Matrices test (Raven, Raven, & Court, 1998). The matrices test is a paper-and-pencil measure of abstract reasoning consisting of 48 tasks presented in ascending order of difficulty, each comprising nine geometric patterns. The target pattern of each task consists of 3 × 3 matrices of geometric patterns with the bottom right pattern missing. Among 4 × 2 alternative patterns, children's task was to select the one that fits into the missing part of the target pattern. Order of the problem-solving and resting condition was counterbalanced.

Procedure

The experiment consisted of two experimental sessions, Session 1 and 2, which were separated by 7 days.

Session 1. Children were tested in two consecutive post-encoding conditions (Brokaw *et al.*, 2016; Craig *et al.*, 2015; Dewar *et al.*, 2012). Prior to each encoding condition, the experimenter gave clear instructions to explain each experimental condition. In the resting condition, a sequence of words was presented in the middle of the screen one-by-one. The aim was to remember as many words as possible, and to recall them when an image of a 'writing hand' appeared on the screen. The image was presented 1,000 ms after presentation of the last word from the word list and an interstimulus interval of 1,000 ms. From then on, children were given 1 min to write down the words of the respective word list on a blank sheet of paper in any order they wanted. Immediate recall was followed by a 10 min wakeful resting phase, during which children were asked to close their eyes and relax quietly. As in previous work (e.g., Dewar *et al.*, 2012) the experimenter turned off the light to provide conditions of minimal sensory input and task engagement (window curtains were closed before the children entered the class room). The experimenter rested together with the children. The experimenter did not leave the room to ensure that children were not active during the resting phase. Instructions in the problem-solving condition were similar to the resting condition, but included an explanation of the matrices based on two examples. Children were asked to solve as many problems as possible within 10 min. After the resting and problem-solving condition, each child was asked to answer a question (in written form) how often she/he consciously rehearsed the words during the previous phase (1 = 'not at all' to 7 = 'very often'). At the end of the experimental session, children answered further questions, and were invited to another experimental session 1 week later.

Children received no information about the length of word lists. Presentation of the words and recall procedure were trained with 5 words, which were semantically unrelated to the words presented in the main experiment. Each child had a partition on her/his right and left. We assumed that partitions help to optimize the recall test condition (shielding each child's recalled words), resting condition (more privacy, increased level of relaxation, minimization of distraction through e.g., the desk neighbour), and problem-solving condition (minimizing effects of collaboration; performance comparison with others).

Session 2. After 7 days, a surprise free recall test took place. Children were required to recall as many words as possible from the two word lists encoded a week ago. They noted the words on a blank sheet of paper in any order they wanted. Recall time was limited to 2 min. Children, experimental conditions, and testing time were the same in the first experimental session and after 7 days.

Session 1 and 2 took always place before midday. Children were tested in groups of 12–26 children, always within one teaching unit.

Scoring

Children's recall responses were scored by giving 1 point for each correctly recalled word (15 per word list). Similarly, in the problem-solving task, children got 1 point for each correctly solved matrix (M = 10.48, SD = 3.98).

Results

The alpha level was set to $p \leq .05$. Descriptive statistics of correctly recalled words can be found in Table 1. Immediate memory performance did not differ between the resting and problem-solving condition, $F(1, 101) = 0.18, p = .671$. Recall performance of word list 1 and 2 did not differ significantly, $t(100) = 0.79, p = .434$, indicating that word list 1 and 2 were comparable, and that word list 1 and the following post-encoding condition seem to have not affected recall performance of word list 2. To analyse memory retention, we calculated a score separately for the resting and problem-solving condition, where we divided the delayed recall performance after 7 days by the immediate recall performance (Dewar *et al.*, 2012; Varma *et al.*, 2017). A graphical depiction of the percentage of retained words in the resting and problem-solving condition can be found in Figure 1. We conducted a mixed ANOVA with retention (rest, problem-solving) as within-subject factor and order (first rest – then problem-solving: $n = 47$, first problem-solving – then rest: $n = 55$) as between-subject factor. Results revealed a significant main effect of retention, $F(1, 100) = 9.97$, $p = .002$, $\eta_p^2 = 0.091$, with higher retention scores in the resting ($M = 0.32$, $SD = 0.24$) compared to the problem-solving condition ($M = 0.24$, $SD = 0.17$). We found a significant main effect of order, $F(1, 100) = 4.05$, $p = .047$, $\eta_p^2 = 0.039$, with higher retention scores in the first rest – then problem-solving condition ($M = 0.32$, $SD = 0.24$) compared to the first problem-solving – then rest condition ($M = 0.24$, $SD = 0.17$). The retention*order interaction was non-significant, $p > .1$. Through a full counterbalancing of children in the two order conditions ($n = 47$/condition), by randomly excluding eight children from the first problem-solving – then resting condition, the main effect of order became non-significant. Other results did not

Table 1. Post-encoding condition-specific mean number of correctly recalled words immediately after encoding and after 7 days, including the mean number of responses to the question whether children consciously rehearsed the words

	Condition	
	Resting *M* (*SD*)	Problem solving *M* (*SD*)
Immediate recall	7.34 (1.77)	7.43 (2.01)
Delayed recall	2.38 (2.05)	1.83 (1.37)
Conscious rehearsal[a]	2.60 (1.87)	1.76 (1.50)
Memory performer-specific retention scores[b]		
Higher performers	0.34 (0.24)	0.25 (0.13)
Middle performers	0.26 (0.17)	0.27 (0.16)
Lower performers	0.32 (0.25)	0.18 (0.19)

Note. [a]Likert scale from 1 ('not at all') to 7 ('very often').
[b]Group mean of the correctly recalled words in the delayed recall test divided by the correctly recalled words in the immediate recall test per child.

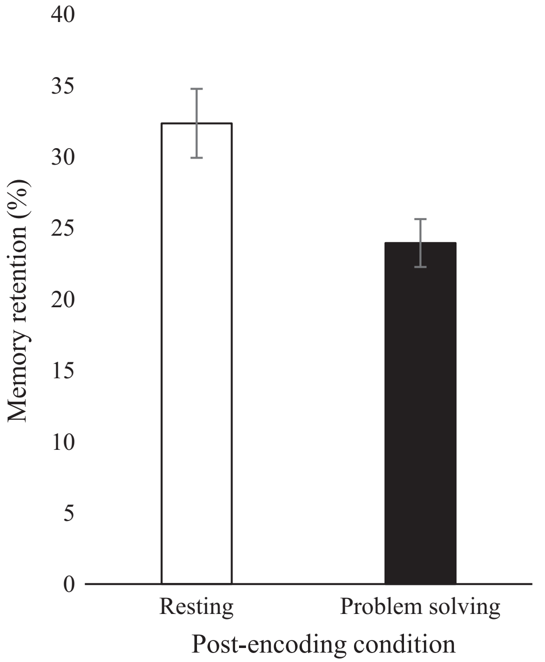

Figure 1. Mean memory retention scores of correctly recalled words (in %) plotted separately for the resting and problem-solving condition.

change. In sum, children retained more words in the resting than in the problem-solving condition.

Analysis of the question whether children consciously rehearsed the words (after fully counterbalancing the order of the post-encoding conditions) showed that rehearsal rates were generally low (Table 1). Children were more likely to rate themselves as having used rehearsal during resting than during problem-solving condition, $t(93) = 2.90$, $p = .005$, $d = .299$. Rehearsal rates during resting were significantly correlated with memory retention in the resting condition, $r_{Pearson} = .24$, $p = .014$. We found a significant negative correlation between rehearsal and memory retention in the problem-solving condition, $r_{Pearson} = -.21$, $p = .036$. To test whether rehearsal was a driving factor for higher retention scores in the resting condition compared to the problem-solving condition we ran the above ANOVA with children only who indicated that they have not consciously rehearsed the words ('1' on the Likert scale; $n = 34$). Our results showed that they retained similar amounts of words in the resting condition ($M = 0.24$, $SD = 0.17$) and problem-solving condition ($M = 0.22$, $p = .17$), $F(1, 32) = 0.57$, $p = .455$. Other results were non-significant, $p > .90$.

Next, exploratory analyses were conducted to test the assumption that memory retention in the respective post-encoding condition is influenced by immediate recall performance. We calculated the sum of correctly recalled words of list 1 and 2 immediately after encoding and based on tertiles, we categorized children into higher, middle, and lower memory performers (lower performers: $\leq 33.33\%$ or $\leq 13/30$ words, $M = 11.65$, $SD = 1.23$, $n = 28$; middle performers: $> 33.33\%$ and $\leq 66.66\%$ or 14–16/30 words, $M = 14.92$, $SD = 0.89$, $n = 37$; higher performers: $> 66.66\%$ or $> 16/30$ words, $M = 18.71$, $SD = 2.19$, $n = 37$). A mixed ANOVA with retention (rest, problem-solving) as within-subject factor and order (first rest – then problem-solving, first problem-solving – then rest) and memory performers (higher, middle, lower) as between-subject factors showed a significant main effect of retention, $F(1, 96) = 10.26$, $p = .002$, $\eta_p^2 = 0.097$. The retention*memory performers interaction was significant, $F(2, 96) = 3.08$, $p = .050$, $\eta_p^2 = 0.060$. Other significant results were not found, $p \geq .2$, except for a near significant effect of order, $F(1, 96) = 3.32$, $p = .071$. A full counterbalancing of children in the respective order condition did not change our results. Memory performer specific analyses (Bonferroni corrected for multiple comparisons, $p = .05/3 = .017$) with a full counterbalancing of children revealed that, only in lower memory performers, retention scores differed significantly, $t(33) = 3.33$, $p = .002$, $d = .571$, in that more words were retained in the resting compared to the problem-solving condition (Table 1). Non-significant results were found in higher memory performers, $t(23) = 1.41$, $p = .171$, and middle memory performers, $t(27) = -0.13$, $p = .896$.

Analysis of the question whether children consciously rehearsed the words in the respective post-encoding condition (rest, problem-solving) revealed that memory performers differed regarding the problem-solving, $F(2, 101) = 4.36$, $p = .015$, but not resting condition, $p > .70$. Bonferroni corrected *post-hoc* tests showed that during problem solving lower memory performers ($M = 2.16$, $SD = 1.79$) rehearsed the words significantly more often, $p = .014$, than higher memory performers ($M = 1.11$, $SD = 0.32$). Other results were non-significant, $p > .10$ (rehearsal of middle memory performers: $M = 1.86$, $SD = 1.58$). Memory performers showed similar problem-solving performances, $F(2, 85) = 0.20$, $p = .818$ (higher: $M = 10.67$, $SD = 4.11$; middle: $M = 10.57$, $SD = 3.81$; lower: $M = 10.06$, $SD = 4.11$).

Discussion

The present study investigated whether the beneficial effect of post-encoding rest on memory retention compared to engaging in another ongoing task, extended to children aged 13–14 years. Overall, the result showed that memory retention over 7 days was higher in the wakeful resting condition than in the problem-solving condition. This result supports recent findings on relatively short temporal retention intervals of several minutes in children aged 6–7 years (Fatania & Mercer, 2017) as well as previous findings in healthy younger adults (mean age ~21 years; Brokaw *et al.*, 2016; Dewar *et al.*, 2007; Mercer, 2015) and older adults (mean age > 60 years; Craig *et al.*, 2016; Dewar *et al.*, 2012). These overall findings also support existing views that new memories are in a labile state after their acquisition and prone to interference (Dewar *et al.*, 2007; Mednick *et al.*, 2011; Wixted, 2005). Low interference states immediately after the acquisition of new memories (like during resting) support memory consolidation, whereas high interference states (like during problem solving) have a detrimental effect on memory consolidation (Wixted, 2005).

The most interesting result was revealed when we exploratively tested whether post-encoding conditions differently affected memory retention as a function of immediate memory performance. We found that higher retention scores in the resting condition than in the problem-solving condition were mainly driven by children who showed lower immediate memory performances. Behavioural and neuroscientific studies primarily in adults identified a host of different factors why interindividual differences emerge. Such factors are, among others, working memory capacity (e.g., the function to maintain a limited amount of information in the presence of distraction; Unsworth & Engle, 2007), emotional arousal (McGaugh, 2015), memory strategies (Unsworth, 2016), knowledge (Ericsson & Kintsch, 1995), degree of learning (Loftus, 1985; Slamecka & McElree, 1983) (Unsworth, 2016; Unsworth, Spillers, & Brewer, 2012), and neurophysiological features like the amount of baseline dopamine release (Cools & D'Esposito, 2011), fibre density (Kanai & Rees, 2011), and associated differences in neural activity and communication between brain areas relevant for encoding and consolidation of the information (Ben-Yakov, Dudai, & Mayford, 2015; Fell & Axmacher, 2011; Hermans *et al.*, 2017; Shrager, Kirwan, & Squire, 2008; Tambini *et al.*, 2010; Wislowska, Heib, Griessenberger, Hoedlmoser, & Schabus, 2017).

During learning and subsequent recall, memory representations are in a labile state, that is, easily tend to get lost through interference as long as they are not stabilized through consolidation (Mednick *et al.*, 2011; Robertson, 2012; Wixted, 2005). On a neural level, memory consolidation is often described as replay activity, that is, learned memory contents are repeated until they are stabilized and embedded into long-term memory, making them more resistant to retroactive interference (Wixted & Cai, 2013). In this context, interindividual differences may originate from memory representations of varying stability that are more or less prone to distraction, which in turn leads to forgetting. Given that the exact time course of consolidation is still unclear, it is conceivable that memories of lower memory performers stabilized less quickly, which made them more susceptible to the subsequent intervention (problem-solving task). Memories of higher and middle performers were probably stabilized to a higher degree, and less prone to interference through the problem-solving task, resulting in similar memory retention scores in the resting and problem-solving conditions.

An alternative explanation of the individual differences focuses on the role of the immediate recall test (Kornell, Bjork, & Garcia, 2011; Roediger & Butler, 2011). Views exist that a retrieval helps to integrate new memories into pre-existing knowledge structures and differentiate new memories (Antony, Ferreira, Norman, & Wimber, 2017). Both processes, that is, integration and differentiation seem to have protected memories from retroactive interference at least in higher and middle memory performers. A speculative assumption for lower memory performers is that their memory representations were longer in a labile state through the recall process and therefore more prone to interference. Consequently, a low interference phase (resting) after immediate recall led to higher retention scores than with the high interference phase (problem solving).

It could be argued that higher, middle, and lower memory performers were differently involved in the problem-solving task, which therefore led to interindividual differences in delayed memory performances. However, our results indicate that memory performers did not differ in their problem-solving scores. Thus, even though variance in selective attention and concentration was spread similarly across groups, we observed group-specific differences regarding delayed recall performance.

One may argue that the resting effect was prominent in those who recalled fewer words during the immediate recall test, as there were fewer memory traces to be consolidated from the point, that is, more consolidation 'resources' to be shared over fewer items. The prerequisite that higher, middle, and lower memory performers had the same amount of consolidation resources that could be distributed over the to-be-remembered items, we should have found higher or at least similar retention scores in lower memory performers than with higher and middle memory performers. Our results, however, indicate that higher memory performers retained more words than middle memory performers, and middle memory performers more words than lower memory performers. From this point of view, lower memory performers immediately recalled and retained fewer words, indicating that those had the lowest consolidation capacities. This view parallels recent findings from studies showing that sleep-related consolidation seems to be limited (Feld, Weis, & Born, 2016) and individual differences in sleep-related neural activity as a function of baseline memory performance exist (Wislowska *et al.*, 2017).

A final explanation for the findings that higher and middle memory performers showed no effect of resting, while lower memory performers did, focuses on the mental activity during the resting phase. Evidence exists that during resting the brain is highly active (Buckner, Andrews-Hanna, & Schacter, 2008). It is assumed that during resting mental processes like mind wandering, autobiographical thinking, future planning, and monitoring processes take place (Andrews-Hanna, 2012), which can interfere with the consolidating words (Craig, Della Sala, & Dewar, 2014). For instance, Craig *et al.* (2014) examined healthy young adults (mean age ~21 years) and found that a 9-min autobiographical retrieval/future imagination task after encoding a word list significantly lowered memory retention compared with a 9-min wakeful resting phase. Accordingly, it could be argued that higher and middle memory performers showed more interfering thoughts during resting than lower memory performers.

Our results on children's conscious rehearsal activity indicated that overall rehearsal rates influenced the resting effect. Analysis of children who indicated that they had rehearsed the words 'not at all' showed no resting effect. This result indicates that conscious rehearsal was a driving factor for the beneficial effect of a brief period of rest. However, such retrospective item responses have to be taken with caution as they represent mean classifications of what happened during the whole delay period, and rehearsal of the word lists or parts of them can fluctuate over time. Furthermore, rehearsal activity was generally low, which can be viewed as an indicator that rehearsal activity is not the only explaining variable for the resting effect. This view is supported by a recent study by Dewar *et al.* (2014) showing that, when rehearsal of the learning material is prevented (e.g., through the presentation of non-words, e.g., phiefnierds), the resting effect is still present, indicating that consolidation is sufficient for a rest-induced memory support. Findings from the memory performer-specific conscious rehearsal effects revealed that groups differed in the problem-solving task only, in that lower memory performers indicated to have rehearsed the words more often than higher memory performers. It can be speculated that the detrimental effect of the problem-solving task was the result of an incorrectly applied rehearsal strategy. This means that the reactivation of previously encoded information during the task delay period, not the problem-solving task itself, was responsible for a decreased memory retention. Less stabilized, but still active representations may profit from incidental and/or intentional degrees of refreshing through attention and/or rehearsal (Raye, Johnson, Mitchell, Greene, & Johnson, 2007). However, activation of the to-be-maintained information at the wrong time (e.g., high interference phase) can have a detrimental effect.

Our data have to be taken cautiously with regard to an oversimplified interpretation. First, although our data suggest that only lower memory individuals profit from resting, even higher and middle individuals might profit from a brief period of rest after learning in another, probably more complex or exhausting learning context. Second, lower memory performers should not be equated with individuals lower in general cognitive abilities. Our results indicate that children did not differ in their scores on a problem-solving task that is often applied to test fluid intelligence. Accordingly, memory performance in a given task may be independent of a general cognitive ability measure (like fluid intelligence or working memory capacity) and depend more on other factors, which we explained above.

To conclude, we found that resting immediately after encoding supports memory retention over 7 days more than working on a problem-solving task. An exploratory categorization of children into higher, middle, and lower immediate memory performers showed that the resting effect was mainly driven by children who showed lower immediate memory performance. The resting effect as a function of immediate memory performance has to be verified in other studies. It is conceivable that with a different study design (e.g., longer and more complex learning conditions) also middle and higher memory performers might profit from resting after learning. These investigations should be conducted in the light of a possible modulating role of conscious rehearsal during resting. Adding a few minutes of wakeful resting to learning would be a simple and effective strategy for children to support memory retention over the long term and might serve as helpful learning advice in educational settings.

References

Alber, J., Della Sala, S., & Dewar, M. (2014). Minimizing interference with early consolidation boosts 7-day retention in amnesic patients. *Neuropsychology*, *28*, 667–675. https://doi.org/10.1037/neu0000091

Andrews-Hanna, J. R. (2012). The brain's default network and its adaptive role in internal mentation. *Neuroscientist*, *18*, 251–270. https://doi.org/10.1177/1073858411403316

Antony, J. W., Ferreira, C. S., Norman, K. A., & Wimber, M. (2017). Retrieval as a fast route to memory consolidation. *Trends in Cognitive Sciences*, *21*, 573–576. https://doi.org/10.1016/j.tics.2017.05.001

Bauer, P. J., Van Abbema, D. L., & de Haan, M. (1999). In for the short haul: Immediate and short-term remembering and forgetting by 20-month-old children. *Infant Behavior & Development*, *22*, 321–343. https://doi.org/10.1016/S0163-6383(99)00014-4

Ben-Yakov, A., Dudai, Y., & Mayford, M. R. (2015). Memory retrieval in mice and men. *Cold Spring Harbor Perspectives Biology*, *7*, a021790. https://doi.org/10.1101/cshperspect.a021790

Bergmann, T. O., & Staresina, B. P. (2017). Neuronal oscillations and reactivation subserving memory consolidation. In N. Axmacher & B. Rasch (Eds.), *Cognitive neuroscience of memory consolidation* (pp. 185–207). Cham, Switzerland: Springer International Publishing. https://doi.org/10.1007/978-3-319-45066-7

Brokaw, K., Tishler, W., Manceor, S., Hamilton, K., Gaulden, A., Parr, E., & Wamsley, E. J. (2016). Resting state EEG correlates of memory consolidation. *Neurobiology of Learning and Memory*, *130*, 17–25. https://doi.org/10.1016/j.nlm.2016.01.008

Brown, H., Weighall, A., Henderson, L. M., & Gareth Gaskell, M. (2012). Enhanced recognition and recall of new words in 7- and 12-year-olds following a period of offline consolidation. *Journal of Experimental Child Psychology*, *112*(1), 56–72. https://doi.org/10.1016/j.jecp.2011.11.010

Buckner, R. L., Andrews-Hanna, J. R., & Schacter, D. L. (2008). The brain's default network: Anatomy, function, and relevance to disease. *Annals of the New York Academy of Sciences*, *1124*, 1–38. https://doi.org/10.1196/annals.1440.011

Carr, M. F., Jadhav, S. P., & Frank, L. M. (2011). Hippocampal replay in the awake state: A potential physiological substrate of memory consolidation and retrieval. *Nature Neuroscience*, *14*, 147–153. https://doi.org/10.1038/nn.2732

Cools, R., & D'Esposito, M. (2011). Inverted-U-shaped dopamine actions on human working memory and cognitive control. *Biological Psychiatry*, *69*, e113–e125. https://doi.org/10.1016/j.biopsych.2011.03.028

Cowan, N., Beschin, N., & Della Sala, S. (2004). Verbal recall in amnesiacs under conditions of diminished retroactive interference. *Brain*, *127*, 825–834. https://doi.org/10.1093/brain/awh107

Craig, M., Della Sala, S., & Dewar, M. (2014). Autobiographical thinking interferes with episodic memory consolidation. *PLoS ONE*, *9*, e93915. https://doi.org/10.1371/journal.pone.0093915

Craig, M., Dewar, M., Della Sala, S., & Wolbers, T. (2015). Rest boosts the long-term retention of spatial associative and temporal order information. *Hippocampus*, *25*, 1017–1027. https://doi.org/10.1002/hipo.22424

Craig, M., Wolbers, T., Harris, M. A., Hauff, P., Della Sala, S., & Dewar, M. (2016). Comparable rest-related promotion of spatial memory consolidation in younger and older adults. *Neurobiology of Aging*, *48*, 143–152. https://doi.org/10.1016/j.neurobiolaging.2016.08.007

Darby, K. P., & Sloutsky, V. M. (2015). The cost of learning: Interference effects in memory development. *Journal of Experimental Psychology. General*, *144*, 410–431. https://doi.org/10.1037/xge0000051

Della Sala, S., Cowan, N., Beschin, N., & Perini, M. (2005). Just lying there, remembering: Improving recall of prose in amnesic patients with mild cognitive impairment by minimizing interference. *Memory*, *13*, 435–440.

Deuker, L., Olligs, J., Fell, J., Kranz, T. A., Mormann, F., Montag, C., . . . Axmacher, N. (2013). Memory consolidation by replay of stimulus-specific neural activity. *Journal of Neuroscience*, *33*, 19373–19383. https://doi.org/10.1523/jneurosci.0414-13.2013

Dewar, M., Alber, J., Butler, C., Cowan, N., & Della Sala, S. (2012). Brief wakeful resting boosts new memories over the long term. *Psychological Science*, *23*, 955–960. https://doi.org/10.1177/0956797612441220

Dewar, M., Alber, J., Cowan, N., & Della Sala, S. (2014). Boosting long-term memory via wakeful rest: Intentional rehearsal is not necessary, consolidation is sufficient. *PLoS ONE*, *9*, e109542. https://doi.org/10.1371/journal.pone.0109542

Dewar, M., Cowan, N., & Della Sala, S. (2007). Forgetting due to retroactive interference: A fusion of Muller and Pilzecker's (1900) early insights into everyday forgetting and recent research on anterograde amnesia. *Cortex*, *43*, 616–634. https://doi.org/10.1016/S0010-9452(08)70492-1

Ericsson, K. A., & Kintsch, W. (1995). Long-term working memory. *Psychological Review*, *102*, 211–245. https://doi.org/10.1037/0033-295X.102.2.211

Fatania, J., & Mercer, T. (2017). Nonspecific retroactive interference in children and adults. *Advances in Cognitive Psychology*, *13*, 314–322. https://doi.org/10.5709/acp-0231-6

Feld, G. B., Weis, P. P., & Born, J. (2016). The limited capacity of sleep-dependent memory consolidation. *Frontiers in Psychology*, *7*, 1368. https://doi.org/10.3389/fpsyg.2016.01368

Fell, J., & Axmacher, N. (2011). The role of phase synchronization in memory processes. *Nature Reviews: Neuroscience*, *12*, 105–118. https://doi.org/10.1038/nrn2979

Helmstaedter, C., Lendt, M., & Lux, S. (2001). *Verbal learning and memory test*. Göttingen, Germany: Hogrefe.

Hermans, E. J., Kanen, J. W., Tambini, A., Fernandez, G., Davachi, L., & Phelps, E. A. (2017). Persistence of amygdala-hippocampal connectivity and multi-voxel correlation structures during awake rest after fear learning predicts long-term expression of fear. *Cerebral Cortex*, *27*, 3028–3041. https://doi.org/10.1093/cercor/bhw145

Howe, M. L. (1995). Interference effects in young children's long-term retention. *Developmental Psychology*, *31*, 579–596. https://doi.org/10.1037/0012-1649.31.4.579

Kanai, R., & Rees, G. (2011). The structural basis of inter-individual differences in human behaviour and cognition. *Nature Reviews: Neuroscience*, *12*, 231–242. https://doi.org/10.1038/nrn3000

Koppenaal, R. J., Krull, A., & Katz, H. (1964). Age, interference, and forgetting. *Journal of Experimental Child Psychology*, *1*, 360–375. https://doi.org/10.1016/0022-0965(64)90029-3

Kornell, N., Bjork, R. A., & Garcia, M. A. (2011). Why tests appear to prevent forgetting: A distribution-based bifurcation model. *Journal of Memory and Language*, *65*(2), 85–97. https://doi.org/10.1016/j.jml.2011.04.002

Loftus, G. R. (1985). Evaluating forgetting curves. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *11*, 397–406.

Martini, M., Riedlsperger, B., Maran, T., & Sachse, P. (2017). The effect of post-learning wakeful rest on the retention of second language learning material over the long term. *Current Psychology*, 1–8. https://doi.org/10.1007/s12144-017-9760-z

McGaugh, J. L. (2015). Consolidating memories. *Annual Review of Psychology*, *66*(1), 1–24. https://doi.org/10.1146/annurev-psych-010814-014954

Mednick, S. C., Cai, D. J., Shuman, T., Anagnostaras, S., & Wixted, J. T. (2011). An opportunistic theory of cellular and systems consolidation. *Trends in Neurosciences*, *34*, 504–514. https://doi.org/10.1016/j.tins.2011.06.003

Mercer, T. (2015). Wakeful rest alleviates interference-based forgetting. *Memory*, *23*, 127–137. https://doi.org/10.1080/09658211.2013.872279

Raven, J. C., Raven, J. E., & Court, J. H. (1998). *Progressive matrices*. Oxford, UK: Oxford Psychologists Press.

Raye, C. L., Johnson, M. K., Mitchell, K. J., Greene, E. J., & Johnson, M. R. (2007). Refreshing: A minimal executive function. *Cortex*, *43*(1), 135–145. https://doi.org/10.1016/S0010-9452(08)70451-9

Robertson, E. M. (2012). New insights in human memory interference and consolidation. *Current Biology*, *22*(2), R66–R71. https://doi.org/10.1016/j.cub.2011.11.051

Roediger, H. L., & Butler, A. C. (2011). The critical role of retrieval practice in long-term retention. *Trends in Cognitive Sciences*, *15*(1), 20–27. https://doi.org/10.1016/j.tics.2010.09.003

Shrager, Y., Kirwan, C. B., & Squire, L. R. (2008). Neural basis of the cognitive map: Path integration does not require hippocampus or entorhinal cortex. *Proceedings of the National Academy of Sciences of the United States of America*, *105*, 12034–12038. https://doi.org/10.1073/pnas.0805414105

Slamecka, N. J., & McElree, B. (1983). Normal forgetting of verbal lists as a function of their degree of learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *9*, 384–397.

Tambini, A., Ketz, N., & Davachi, L. (2010). Enhanced brain correlations during rest are related to memory for recent experiences. *Neuron*, *65*, 280–290. https://doi.org/10.1016/j.neuron.2010.01.001

Unsworth, N. (2016). Working memory capacity and recall from long-term memory: Examining the influences of encoding strategies, study time allocation, search efficiency, and monitoring abilities. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *42*(1), 50–61. https://doi.org/10.1037/xlm0000148

Unsworth, N., & Engle, R. W. (2007). The nature of individual differences in working memory capacity: Active maintenance in primary memory and controlled search from secondary memory. *Psychological Review*, *114*(1), 104–132. https://doi.org/10.1037/0033-295x.114.1.104

Unsworth, N., Spillers, G. J., & Brewer, G. A. (2012). Working memory capacity and retrieval limitations from long-term memory: An examination of differences in accessibility. *The Quarterly Journal of Experimental Psychology*, *65*, 2397–2410. https://doi.org/10.1080/17470218.2012.690438

Varma, S., Takashima, A., Krewinkel, S., van Kooten, M., Fu, L., Medendorp, W. P., . . . Daselaar, S. M. (2017). Non-interfering effects of active post-encoding tasks on episodic memory consolidation in humans. *Frontiers in Behavioral Neuroscience*, *11*, 54. https://doi.org/10.3389/fnbeh.2017.00054

Wislowska, M., Heib, D. P. J., Griessenberger, H., Hoedlmoser, K., & Schabus, M. (2017). Individual baseline memory performance and its significance for sleep-dependent memory consolidation. *Sleep Spindles & Cortical Up States*, *1*(1), 2–13. https://doi.org/10.1556/2053.1.2016.001

Wixted, J. T. (2005). A theory about why we forget what we once knew. *Current Directions in Psychological Science*, *14*(1), 6–9. https://doi.org/10.1111/j.0963-7214.2005.00324.x

Wixted, J. T., & Cai, D. J. (2013). Memory consolidation. In K. N. Ochsner & S. Kosslyn (Eds.), *The Oxford handbook of cognitive neuroscience*. Oxford, UK: Oxford University Press.

Received 23 February 2018; revised version received 14 August 2018