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Immediate as well as delayed post learning sleep but not wakefulness enhances declarative memory consolidation in children

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Abstract

While there is mounting evidence for the importance of sleep for declarative memory consolidation in adults, so far this issue has not been investigated in children despite considerable differences in sleep duration and sleep architecture between children and adults. Here, 27 children (aged between 9 and 12 yr) were examined on two conditions: on the Sleep–Wake condition, subjects learned word pairs in the evening and delayed recall was tested first in the next morning after sleep and then again in the following evening after daytime wakefulness. On the Wake–Sleep condition, learning took place in the morning and delayed recall was tested in the evening of the same day and again in the next morning after sleep. In both conditions retention of declarative memory was significantly increased only after an interval of sleep that either followed immediately after learning (as in the Sleep–Wake condition) or that followed after daytime wakefulness (as in the Wake–Sleep condition), respectively. The results support the hypothesis that sleep plays an active role in declarative memory consolidation even if delayed and further show for the first time the importance of sleep for declarative memory consolidation during childhood.

Keywords: Consolidation of declarative memory; Sleep; Children

1. Introduction

There is growing evidence that sleep critically contributes to the consolidation of memory (Born, Rasch, & Gais, 2006; Ellenbogen, Hulbert, Stickgold, Dinges, & Thompson-Schill, 2006; Maquet, Smith, & Stickgold, 2003; Smith, 2001; Stickgold, 2005). Sleep enhances the consolidation of procedural memories for skills (Fischer, Hallschmid, Elsner, & Born, 2002; Walker, Brakefield, Morgan, Hobson, & Stickgold, 2002) as well as declarative memories for facts and episodes, the storage of which involves hippocampal function (Backhaus et al., 2006, 2007; Ekstrand, 1967; Ellenbogen et al., 2006; Gais, Lucas, & Born, 2006; Plihal & Born, 1997). Even short daytime naps facilitate memory consolidation in adults (Backhaus & Junghanns, 2006; Mednick, Nakayama, & Stickgold, 2003; Tucker et al., 2006).

Although children have usually a longer sleep duration and a different sleep architecture with particularly high amounts of slow wave sleep (SWS) in comparison with adults (Kahn, Dan, Groswasser, Franco, & Sottiaux, 1996; Ohayon, Carskadon, Guilleminault, & Vitiello, 2004) the sleep associated consolidation of declarative memory has not been investigated in children so far. Whether declarative memory consolidation in children benefits from sleep similarly like in adults, is a tempting question, also in light of recent findings indicating differences between children and adults in sleep-dependent consolidation of non-declarative skill memories (Fischer, Wilhelm, & Born, 2007). In this study employing a serial reaction time task, 9–11 yr old children unlike adults did not improve but showed an acutely impaired implicit mem-

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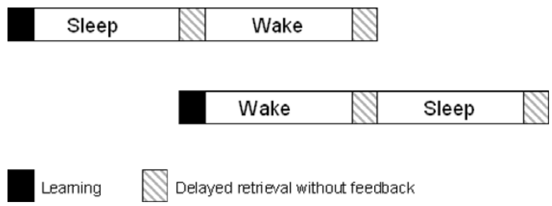

Fig. 1. Study-design. In the Sleep–Wake condition children learned the word pair associate task (to a criterion of 50% correct responses) in the evening before sleep and delayed retrieval was tested first the next morning and a second time in the following evening after daytime wakefulness. In the Wake–Sleep condition, children learned the word pairs in the morning and delayed retrieval was tested first in the evening of the same day and then again the next morning after sleep. Only during the learning phase, but not at the first and second delayed retrieval time children received feedback by subsequent presentation of the correct response word for 1 s.

ory for the task sequence after a period of nocturnal retention sleep. In another study, 15-months old infants who napped after acquisition of a language task appeared to improve in learning an abstract rule underlying the language stimuli (Gomez, Bootzin, & Nadel, 2006).

Here, we investigated the function of sleep for declarative memory consolidation in children between 9 and 12 yr of age. The children were examined on two conditions (Fig. 1). In the Sleep–Wake condition they learned a list of word pairs (to a criterion of 50% correct responses) the evening before regular nocturnal sleep, and delayed retrieval was tested first the next morning and a second time in the following evening after the children had stayed awake during the day. In the Wake–Sleep condition, the children learned the word pairs in the morning and delayed retrieval was tested first in the evening of the same day after daytime wakefulness, and then again the next morning after regular nocturnal sleep. We expected that sleep during the interval between learning and delayed retrieval enhances retention of word pairs. The comparison between memory retention after consolidation periods during sleep and wakefulness implies the problem of differences in nonspecific interference effects (Ellenbogen et al., 2006), which are unavoidable during wakefulness but negligible during sleep. Here, we investigate the specific function of sleep with two delayed retrieval times in two different sequences of retention periods during sleep and wakefulness (Sleep–Wake and Wake–Sleep order). If sleep had a specific effect on memory consolidation there should be a further increase in recall performance at the second retrieval (i.e., after the first post learning sleep period) of the Wake–Sleep condition.

2. Methods

2.1. Subjects

Twenty-seven children (13 female) aged between 9 and 12 (10.1 ± 0.1 yr) participated in the study. Subjects were recruited from public schools, had a regular sleep–wake rhythm and no sleep disorder. Children taking regularly daytime naps were not included in the study. Participants had neither a psychiatric nor any somatic disorder and did not take any psychoactive drugs or medications that might affect sleep or memory. The study was approved by the local ethics committee and was conducted according to the Declaration of Helsinki. After a complete description of the study to the children and their parents, written consent was obtained from the children and their parents.

2.2. Procedure and tasks

Each child participated in both experimental conditions, i.e., the Sleep–Wake and Wake–Sleep condition. The two conditions for each subject were separated by an interval of 1 week, and order of conditions was balanced across the children. Measurements were performed at the children's home. On the Sleep–Wake condition children learned the memory task in the evening before they went to bed at their usual bedtime. After a night of normal sleep retrieval was tested the first time in the next morning. A second retrieval test was conducted in the evening of the same day after a period of daytime wakefulness that had the same duration as the child's habitual nocturnal sleep period.

In the Wake–Sleep condition, learning took place in the morning and retrieval was tested first in the evening of the same day after a period of wake-time (again corresponding in length with the child's habitual sleep time). The first retrieval was followed by a night of regular sleep, after which the second retrieval took place in the next morning.

Declarative memory was tested using a word pair associate task consisting of 40 related word pairs of German concrete nouns that were standardized with respect to word frequency, length, emotionality, meaningfulness and concreteness. Two additional word pairs at the beginning and end of the test served to buffer primacy and recency effects and were not included in the analysis. Parallel versions of the word pair list were used (in random order) for the two subject's experimental conditions. The word pairs were presented visually for 5 s each at the first presentation of the list and for 2 s for all following trials. The presentation of each word pair of the list was followed by cued recall testing where the subject was asked to recall orally the second word in a pair upon presentation of the first word. The list of word pairs was presented repeatedly in different order until the subject correctly recalled at least 20 words (50% criterion). During learning subjects were given feedback so that the subject's response was always followed by presentation of the correct word pair for 1 s. At the first and second retrieval testing after, respectively, sleep and wakefulness subjects were again asked to recall the word pairs using the same cued recall procedure as during the learning phase except that no feedback was given, i.e., the subject's oral response was not followed by presenting the correct word pair.

2.3. Polysomnography and actigraphic recordings

In both study conditions sleep was measured with an ambulatory polysomnography system. Standard polysomnographic recordings were obtained using EEG electrodes positioned at C3 and C4 and referenced against electrodes attached at A2 and A1, respectively (as defined by the international 10–20 system). Furthermore, eye movements and electromyographic activity were recorded. Sleep stages were scored according to standard criteria (Rechtschaffen & Kales, 1968) by experienced staff blind to the experimental condition. During wake-time children wore an actigraph to measure activity and to rule out that children took a nap.

2.4. Statistical analyses

Differences between the sleep conditions were analyzed by analyses of variance (ANOVA). Post hoc t-tests were used to specify significant main and interaction effects. Correlation analyses were performed between time in sleep stages and performance at delayed retrieval test. Retrieval performance was defined by absolute numbers of recalled words and by retention rates as determined by the difference in recalled words at the first/second retrieval minus the number of recalled words at the criterion trial during learning before the retention period. Accordingly, in the Sleep–Wake condition sleep-related retention of word pairs was defined