Neurobiology of Learning and Memory 125 (2015) 98–105

Contents lists available at ScienceDirect

Neurobiology of Learning and Memory

journal homepage: www.elsevier.com/locate/ynlme

The role of sleep timing in children's observational learning

Frank J. van Schalkwijk [a,*], Jeroen S. Benjamins [a], Filippo Migliorati [a], Jacqueline A. de Nooijer [b], Eus J.W. van Someren [a,c,d], Tamara van Gog [b], Ysbrand D. van der Werf [a,e]

[a] *Netherlands Institute for Neuroscience, Dept. Sleep, Emotion, and Cognition, Meibergdreef 47, 1105 BA Amsterdam, The Netherlands*
[b] *Institute of Psychology, Erasmus University, Burgemeester Oudlaan 50, P.O. Box 1738, 3000 DR Rotterdam, The Netherlands*
[c] *Dept. Medical Psychology, VU University Medical Center, De Boelelaan 1117, 1081 HV Amsterdam, The Netherlands*
[d] *Dept. Integrative Neurophysiology, VU University, Neuroscience Campus, De Boelelaan 1085, 1081 HV Amsterdam, The Netherlands*
[e] *Dept. Anatomy and Neurosciences, VU University Medical Centre, PO box 7057, 1007 MB Amsterdam, The Netherlands*

A R T I C L E   I N F O

Article history:
Received 8 April 2015
Revised 22 July 2015
Accepted 5 August 2015
Available online 22 August 2015

Keywords:
Sleep
Learning by observation
Memory consolidation
School-aged children
Online testing

A B S T R A C T

Acquisition of information can be facilitated through different learning strategies, classically associated with either declarative or procedural memory modalities. The consolidation of the acquired information has been positively associated with sleep. In addition, subsequent performance was better when acquisition was quickly followed by sleep, rather than daytime wakefulness. Prior studies with adults have indicated the viability of the alternative learning strategy of observational learning for motor skill acquisition, as well as the importance of sleep and sleep timing. However, relatively little research has been dedicated to studying the importance of sleep for the consolidation of procedural memory in children. Therefore, this study investigated whether children could encode procedural information through observational learning, and whether sleep timing could affect subsequent consolidation and performance. School-aged children aged 9–12 years ($N = 86$, 43% male, $M_{age} = 10.64$ years, $SD = .85$) were trained on a procedural fingertapping task through observation, either in the morning or evening; creating immediate wake and immediate sleep groups, respectively. Performance was evaluated the subsequent evening or morning on either a congruent or incongruent task version. Observation and task execution was conducted using an online interface, allowing for remote participation. Performance of the immediate wake group was lower for a congruent version, expressed by a higher error rate, opposed to an incongruent version; an effect not observed in the immediate sleep group. This finding showed that observational learning did not improve performance in children. Yet, immediate sleep prevented performance reduction on the previously observed task. These results support a benefit of sleep in observational learning in children, but in a way different from that seen in adults, where sleep enhanced performance after learning by observation.

1. Introduction

The acquisition and consolidation of information can be allocated to two memory modalities: the first dedicated to events and facts (declarative memory) and the second to procedural skills (procedural memory; Cohen, Eichenbaum, & Deacedo, 1985; Rajaram & Roediger, 1993; Roediger, 1990; Squire, 1992). The consolidation of newly acquired information has been positively associated with sleep. Following training, sleep can positively affect subsequent motor task performance (Hill, Tononi, & Ghilardi, 2008; Walker, Brakefield, Morgan, Hobson, & Stickgold, 2002) and recollection (Gais, Lucas, & Born, 2006; Stickgold & Walker, 2007). Improvements of performance following sleep can be stronger compared to an identical wake period (Gais et al., 2006; Hu, Stylos-Allan, & Walker, 2006; Walker et al., 2002; Wilhelm, Diekelmann, & Born, 2008). In addition, the timing of sleep relative to acquisition can affect memory consolidation and subsequent performance. When acquisition was followed by a period of sleep rather than daytime wakefulness, subsequent performance was found to be higher for both declarative (Gais et al., 2006; Talamini, Nieuwenhuis, Takashima, & Jensen, 2008) and procedural memory tasks (Van der Werf, Van der Helm, Schoonheim, Ridderikhoff, & Van Someren, 2009). These studies implemented similar durations of wakefulness and sleep, the only differences being the timing of sleep relative to acquisition. In addition, it has been suggested that the different memory modalities benefit from different sleep stages. While declarative memory has been

* Corresponding author. Fax: +31 20 566 6121.
E-mail address: frankvanschalkwijk@gmail.com (F.J. van Schalkwijk).

http://dx.doi.org/10.1016/j.nlm.2015.08.003
1074-7427/

positively associated with slow-wave sleep (SWS), procedural memory has been positively associated with rapid-eye movement (REM) sleep (reviewed by Marshall and Born (2007) and Plihal and Born (1999)). The time spent in these sleep stages, as well as total sleep time, has been observed to change over the life-span. Compared to adults, children spend more time in SWS and have a longer sleep duration, while adults spend relatively more time in REM sleep and have a shorter sleep duration (Ohayon, Carskadon, Guilleminault, & Vitiello, 2004). Thus, it is possible that the two memory modalities benefit differently from sleep for children and adults. Consolidation through declarative memory appears to be similar between children and adults (Prehn-Kristensen et al., 2009; Wilhelm et al., 2008), while procedural memory was found to not benefit as strongly from sleep in children as in adults (Fischer, Wilhelm, & Born, 2007; Prehn-Kristensen et al., 2009; Wilhelm et al., 2008). These changes in time dedicated to different sleep stages could potentially affect memory consolidation processes, and consequently lead to differences in performance between children and adults for declarative and procedural tasks. In addition to changes in the sleep architecture, another important aspect is that learning mechanisms and trajectories undergo marked changes from childhood to adulthood (Casey, Tottenham, Liston, & Durston, 2005). A major difference between children and young adults that might lead to differences in (observational) learning, is that children's working memory and executive functions that are prerequisites for learning, such as cognitive control, integrative processes, and speed of information processing, are still developing (e.g., Friedman, Nessler, Cycowicz, & Horton, 2009; Gathercole, 2005; Gathercole, Pickering, Ambridge, & Wearing, 2004; Kail, 2000). Consequently, children are less efficient in processes such as strategy use/development, rehearsal, chunking, encoding, and error monitoring/correction, which are imperative for the acquisition of motor skills (Thomas, 1980).

A study by Wilhelm et al. (2008) investigated the benefits of sleep for the declarative and procedural memory modalities in children and adults by training them on word pairs and a fingertapping task (Walker et al., 2002), respectively. Following acquisition, participants were either awake or asleep during the retention period. At recollection, performance was evaluated on the number of recollected word pairs and on fingertapping performance on a version that was similar (congruent) or different (incongruent) to the trained version. Performance on the declarative memory task following sleep improved for children and adults alike. Participants from the sleep groups showed higher performance opposed to the wake groups. Differences in performance and differential effects of sleep between children and adults were found on the procedural task. Adults belonging to the sleep group showed higher performance on a congruent task version as opposed to the wake group. No difference in performance was found between the two adult groups on an incongruent version. In contrast, children from the wake group had a significant increase in performance on a congruent task version opposed to the sleep group. Additionally, the wake group showed significantly higher performance on an incongruent version opposed to the sleep group. These results indicated that children and adults could benefit from sleep in a similar fashion for declarative memory consolidation, yet showed different effects of sleep on procedural memory consolidation. Adults only benefitted from a period of nocturnal sleep, whereas children's performance was positively affected by a similar period of wakefulness, rather than sleep. These observations showed the relevance of sleep for memory consolidation and subsequent performance, which can be different for children and adults depending on the memory modality.

The majority of studies that investigated the benefits of sleep on memory consolidation explicitly trained adult participants through practice, whereas little research has been done on alternative learning strategies such as observational learning. Observational learning can be an effective strategy during initial skill acquisition (Bandura, 1986; van Gog & Rummel, 2010) and can be used by children as a stepping stone to acquire new strategies and improve performance (Crowley & Siegler, 1999). Studies that focused on learning by observation have generally evaluated performance on procedural motor tasks directly following observation in adults (Bird & Heyes, 2005; Heyes & Foster, 2002). Specifically, a study by Van der Werf et al. (2009) trained adult participants on a fingertapping task through observational learning. Participants were shown a demonstration video of an experimenter novel to the task; observation took place either in the morning or evening. Observation was either followed by a period of daytime wakefulness or nocturnal sleep, thus assigning participants to either a delayed or immediate sleep group, respectively. Performance was evaluated the following morning or evening on either a congruent or incongruent fingertapping task. For the immediate sleep group, performance on a congruent task was significantly higher as opposed to an incongruent task. Interestingly, no difference in performance due to congruence was found for the immediate wake group. These results indicated the importance of sleep timing relative to acquisition for subsequent consolidation and performance. In addition, performance from the immediate sleep group indicated that performance on a procedural motor task could be improved through observational learning, with subsequent consolidation during sleep. Trempe, Sabourin, Rohbanfard, and Proteau (2011) evaluated the effects of observational learning and offline consolidation on a motor sequence task in adults. Following observation, performance was evaluated either 5 min or 24 h later. In addition, performance was also evaluated for a control group without prior observation of the task (exp. 1). Performance was improved relative to a control group due to observational learning, yet no differences in performance were observed between the 5 min and 24 h retention groups. Interestingly, Trempe et al. (2011) showed in exp. 2 that motor skill information acquired through observational learning can be consolidated and stabilized within an 8 h time period, demonstrated by a low variability in performance and no apparent negative effects of observation of a secondary sequence 8 h later. They suggested that observational learning led to consolidation processes that stabilized the acquired information of the motor skill. While this study demonstrated the possible benefit of observational learning on performance, no close investigations were executed regarding timing of subsequent sleep on consolidation and subsequent performance. The effectiveness of observational learning for procedural information should be further evaluated in light of the possible benefits of nocturnal sleep and sleep timing for subsequent consolidation, especially in children. Therefore, the present study investigated (1) whether school-aged children could learn a procedural motor task through observation, and (2) whether sleep timing relative to acquisition affected memory consolidation and subsequent performance.

The present study investigated whether school-aged children were able to encode a procedural motor task through observational learning, and whether timing of sleep relative to acquisition affected memory consolidation and subsequent performance. Eighty-six school-aged children were shown a demonstration video of a task-naïve model executing the fingertapping task. Observation took place either in the early morning or late evening; effectively creating immediate wake and immediate sleep groups, respectively. The observation took place in the children's home environment by streaming the videos through an online connection. Performance was evaluated in the early morning or late evening on either a congruent or incongruent fingertapping task, relative to the demonstration video, in order to correct for time of day effects on memory retrieval. Integration of the two memory modalities during observational learning was expected to result in