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The impact of sleep on novel concept learning

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ABSTRACT

Prior research demonstrates that sleep benefits memory consolidation. But beyond its role in memory retention, sleep may also facilitate the reorganization and flexible use of new information. In the present study, we investigated the effect of sleep on conceptual knowledge. Participants classified abstract dot patterns into novel categories, and were later tested on both previously seen dot patterns as well as on new patterns. A Wake group ($n = 17$) trained at 9 AM, continued with their daily activities, and then tested at 9 PM that evening. A Sleep group ($n = 20$) trained at 9 PM, went home to sleep, and was tested the following morning at 9 AM. Two Immediate Test control groups completed testing immediately following training in either the morning ($n = 18$) or evening ($n = 18$). Post-training sleep led to superior classification of all stimulus types, including the specific exemplars learned during training, novel patterns that had not previously been seen, and "prototype" patterns from which the exemplars were derived. However, performance did not improve significantly above baseline after a night of sleep. Instead, sleep appeared to maintain performance, relative to a performance decline across a day of wakefulness. There was additionally evidence of a time of day effect on performance. Together with prior observations, these data support the notion that sleep may be involved in an important process whereby we extract commonalities from our experiences to construct useful mental models of the world around us.

1. Introduction

A growing body of evidence suggests that offline periods of waking rest and sleep benefit memory (Alger, Lau, & Fishbein, 2012; Backhaus & Junghanns, 2006; Brokaw et al., 2016; Dewar, Alber, Butler, Cowan, & Della Sala, 2012; Djonlagic et al., 2009; Durrant, Taylor, Cairney, & Lewis, 2011; Mednick, Nakayama, & Stickgold, 2003; Rasch & Born, 2013; Stickgold, 2005; Tucker et al., 2006; Wagner, Gais, Haider, Verleger, & Born, 2004). But beyond a role in simple memory retention, sleep is also thought to reorganize memories, for example by extracting underlying patterns and generalities from sets of related stimuli (Batterink & Paller, 2015; Djonlagic et al., 2009; Durrant et al., 2011; Lewis & Durrant, 2011; Payne et al., 2009; Wagner et al., 2004). An important real-world cognitive ability that may rely on similar processes is the formation of "concepts", in which experience with a set of related stimuli allows us to abstract generalized knowledge about a category (Medin & Smith, 1984). Adaptively responding to novel situations relies critically on our ability to utilize this conceptual knowledge by quickly identifying new stimuli with categories that have known properties. Here, we hypothesized that the formation and use of conceptual knowledge might benefit from post-training sleep.

Concepts are mental models that contain summary knowledge about specific parts of the world (Hampton, 1981; Medin & Smith, 1984). According to one model, concepts are formed when we encounter specific "exemplars" in the environment and then abstract a "prototype" of those exemplars (Hampton, 1995; Rosch & Mervis, 1975; Smith & Minda, 2002). Exemplars are specific experiences with stimuli, whereas prototypes are abstract mental representations that summarize the common features of exemplars. Previous work has tested this model of concept learning using "prototype distortion" tasks, in which a set of exemplar stimuli are statistically generated by creating distorted versions of a central category prototype (Ashby & Maddox, 2005; Posner & Keele, 1968, 1970; Shin & Nosofsky, 1992; Strange, Keeney, Kessel, & Jenkins, 1970; Tunney, Fernie, & Astle, 2010). Interestingly, prototype stimuli appear to have a privileged status in memory – over the course of a week, memory for category exemplars deteriorates, but yet prototype categorization remains relatively preserved (Posner & Keele, 1968; Strange et al., 1970). This well-known memory advantage for prototypes echoes Bartlett's pro-

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posal that across time, we typically retain central information while forgetting peripheral details (Bartlett, 1932). Traditionally, it has been assumed that prototypes are simply less prone to decay or interference-based forgetting (Durrant et al., 2011; Lewis & Durrant, 2011; Payne et al., 2009). However, because a week-long delay necessarily contains sleep, another possibility is that memory consolidation during sleep actively supports the abstraction of prototype representations.

In support of this hypothesis, prior work suggests that sleep benefits the extraction of generalizations in a variety of situations including the discovery of statistical regularities (Djonlagic et al., 2009; Durrant et al., 2011) and the abstraction of general rules (Wagner et al., 2004). For instance, Durrant et al. (2011) demonstrated that following a night of sleep, relative to an equivalent period of daytime wakefulness, participants were better at extracting implicit statistical patterns from a set of auditory sequences, which enabled them to later draw inferences about novel sequences (Durrant et al., 2011). In a second study, this effect extended to even a brief nap (90 min) (Durrant et al., 2011). Similarly, (Djonlagic et al., 2009) showed that post-training sleep led to superior performance on the "weather prediction task", which requires participants to extract implicit probability rules governing how geometric figures relate to fictional weather events. These findings suggest that sleep may facilitate statistical learning and pattern recognition. Other work by Payne and colleagues showed that in contrast to wakefulness, a night of sleep led to higher production of false memories for highly central "theme" words not actually present in word lists seen at training (Payne et al., 2009).

Together, these studies suggest that sleep may be involved in an important process whereby we extract patterns from our environment to form useful mental models about the world around us. However, no studies have yet directly tested the impact of sleep on conceptual knowledge. The goal of the current research was therefore to determine how sleep impacts formation of and memory for concepts. We focused on the role of sleep with respect to three factors associated with concept development: *Category Knowledge*, *Concept-Based Inference*, and *Centrality*. To test the impact of sleep on *Category Knowledge*, we sought to determine how sleep affected the ability to classify training exemplars into novel categories. But a stronger indicator of novel concept formation is the ability to draw inferences about novel stimuli, which may require the abstraction of "summary" knowledge about higher-order category structures, beyond the memorization of specific exemplars. As such, we measured *Concept-Based Inference* by assessing how sleep impacts the ability to classify both novel exemplars and prototypes not initially presented at training. Finally, there is considerable evidence that concept exemplars are classified more easily when they are similar to the category prototype, even when participants have never actually seen the prototype (Posner, Goldsmith, & Welton, 1967; Rips, Shoben, & Smith, 1973). As such, to test the role of *Centrality*, we asked whether the effect of sleep on classification performance depends on the level of exemplar similarity to the category prototype.

One useful task for addressing these questions is the Dot Pattern Classification Task (DPC) (Posner & Keele, 1968, 1970; Posner et al., 1967), originally introduced by (Posner et al., 1967). The DPC is an artificial concept-learning task in which participants learn how to classify abstract dot patterns into novel categories. Each category contains several exemplars that are statistically derived by distorting a single prototype (see Methods). While considerable debate continues regarding the importance of "prototypes" in categorization tasks (Hampton, 1995; Shin & Nosofsky, 1992; Zaki & Nosofsky, 2004), at the very least, the prototypes of the DPC task provide an objective model for the central tendency of exemplars.

The DPC task probes *Category Knowledge* because participants must learn how to classify dot patterns into novel categories. This requires the acquisition of knowledge concerning which specific exemplars belong to which category. The DPC task probes *Concept-Based Inference*, because participants must also use their newly acquired conceptual knowledge to classify a novel set of stimuli into the categories learned at training (see Methods). Importantly, classification of new stimuli cannot be accomplished by memorizing simple stimulus-response associations between specific exemplars and category labels. Finally, the DPC task can be used to probe the role of *Centrality*, because the exemplars within each category systematically vary in similarity to the category prototype (see Methods). In the current study, we compare how an offline period of sleep impacts classification performance in relation to these three factors.

We hypothesized that sleep would benefit conceptual knowledge in terms of *Category Knowledge*, based on prior work suggesting that sleep promotes memory consolidation (Deuker et al., 2013; Diekelmann & Born, 2010; Fogel, Smith, & Cote, 2007; Rasch & Born, 2013; Tucker et al., 2006; Wagner, Hallschmid, Rasch, & Born, 2006; Wamsley, Tucker, Payne, Benavides, & Stickgold, 2010). In addition, we hypothesized that sleep would benefit *Concept-Based Inference*, based on prior evidence indicating that sleep facilitates pattern extraction (Djonlagic et al., 2009; Durrant et al., 2011; Wagner et al., 2004) and abstraction (Payne et al., 2009), which could facilitate drawing inferences about novel but related items. Finally, in terms of *Centrality*, we hypothesized that sleep would more strongly benefit the classification of prototypes, as opposed to exemplars, in light of prior evidence that these central prototypes are preferentially remembered across a delay interval (Posner & Keele, 1970; Strange et al., 1970).

2. Methods

Eighty native English speaking students at Furman University enrolled in the study. Participants were screened for history of mental illness, diagnosed sleep disorders, and medications known to interfere with normal sleep. Participants were also asked to keep a regular sleep schedule prior to participation, as confirmed by a sleep log. N = 6 subjects were excluded from data analysis because they failed to obtain an average of at least 6 h of sleep during the 3 nights prior to the study. One additional participant was excluded for taking lorazepam. The final sample for analysis consisted of n = 73 subjects (58 female), 18–30 years of age (10.9 yrs ± 1.4 SD). This research was approved by the Furman University Institutional Review Board.

Participants were randomly assigned to either the Sleep group (n = 20), Wake group (n = 17), or Immediate AM/PM control groups (n = 36). All participants reported to the laboratory, signed written informed consent, and completed initial paperwork including a demographics form, Epworth sleepiness scale (Johns, 1991), and Stanford Sleepiness Scale (Hoddes, Zarcone, Smythe, Phillips, & Dement, 1973), prior to training on the Dot Pattern Classification Task (DPC; Fig. 1). During the initial Training phase, subjects learned how to classify dot patterns (*old exemplars*) into 3 categories. During a subsequent Test phase, participants classified these *old exemplars*, as well as previously unseen *new exemplars* and the *prototype* patterns from which category exemplars were derived. As illustrated in Fig. 2, participants in the Sleep group completed Training on the DPC Task at 9 PM, left the laboratory to obtain a normal night of sleep at home, and returned to the laboratory for the Test session at 9 AM. In contrast, participants in the Wake group completed Training at 9 AM, left the laboratory to go about their daily activities, and returned to the laboratory for the Test session at 9 PM. Wake participants were asked to avoid drugs, alcohol, and caffeine during the retention interval, and to refrain from napping during the day.