SLEEP-DEPENDENT MEMORY INTEGRATION

By Matthew P. Walker

Substantive evidence supports a role for sleep in the consolidation (solidification) of newly acquired memories. However, as critical as consolidation may be – an operation concerned with *individual memory items* – the integration of new experiences into pre-existing networks of knowledge is equally, if not more, important. Here, I champion the thesis that the end goal of sleep, and especially REM-dreaming, is not simply the strengthening of individual memories across a single night, but instead,

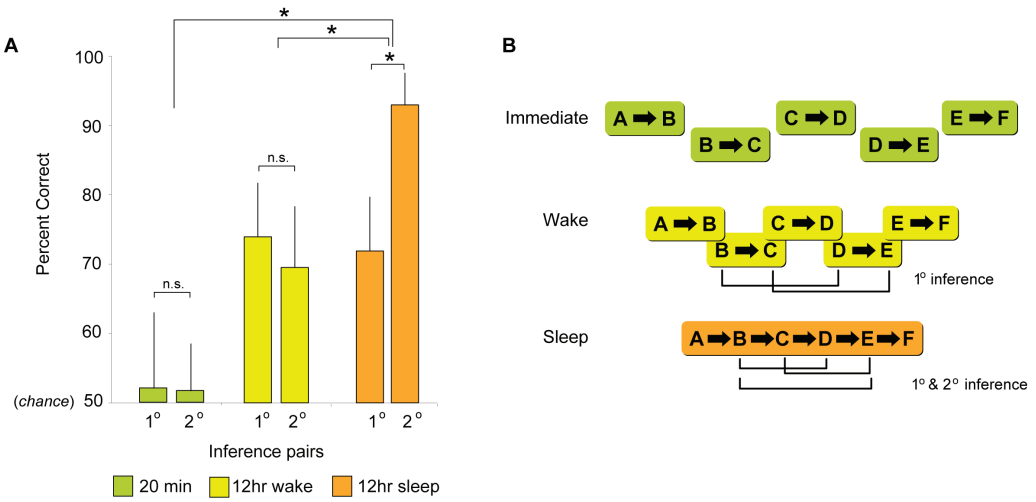

Figure 1. Sleep-dependent integration of human relational memory. A) Delayed inference (associative) memory performance (% correct) in a relational memory task following different offline delays. B) A conceptual model of the effects of sleep on memory integration. *$p < 0.05$; error bars indicate s.e.m.

their integration into a common knowledge schema across multiple nights (McClelland et al., 1995; Walker, 2009).

For example, a recent study required participants to initially learn five individual premises; the object memory pairs (A>B, B>C, C>D, D>E, E>F) (Ellenbogen et al., 2007). Unknown to subjects, the pairs contained an embedded hierarchy (A>B>C>D>E>F). Following a delay of 20min., 12 hours across the day or 12 hours containing a night of sleep, knowledge of this associative-hierarchy was tested by examining relational judgments for novel "inference" pairs, either separated by 1-degree of associative distance (B>D, C>E pairs), or by 2-degrees of associative distance (B>E pair). Subjects tested soon after learning in the 20 min. delay group showed no evidence of inferential ability, performing at chance levels (Figure 1). In contrast, both 12 hour groups displayed highly significant relational memory developments. Most remarkable, however, if the 12 hour delay contained a night of sleep, a 25% advantage in relational memory was seen for the most distantly connected, non-obvious inferential judgment (B>E pair). Therefore, sleep preferentially biased the development of more distant/weak associative links amongst related, yet separate, memory items.

Additional quantitative data further confirm such sleep-inspired creativity (reviewed in Walker, 2009). For example, solution performance on tests of cognitive flexibility using anagram puzzles is more than 30% better following awakenings from REM sleep compared with non-REM awakenings. Similarly, performance on a semantic priming task following REM sleep awakenings shows a greater priming effect by weakly related words than by strong primes. Furthermore, the likelihood of gaining insight into hidden task rules can be increased three-fold by an intervening night of sleep. Even the study of mental activity (dreams) from REM sleep indicates that there is not a concrete episodic replay of daytime experiences, but instead, more associative, semantic-integration processing.

In summary, emerging evidence suggests that sleep serves a meta-level role in memory processing that moves far beyond the consolidation of individual items, and instead, intelligently assimilates these details offline. In doing so, sleep (and perhaps dreaming) may offer the ability to test and/or build common informational schemas of generalized knowledge, affording increasingly accurate statistical predictions about the world, and even creative insights. Is it a wonder, then, that we are never told to stay awake on a problem?

Matthew P. Walker earned his Ph.D. in Neurophysiology from the Medical Research Council, UK, and subsequently became an Assistant Professor of Psychology at Harvard Medical School. He is currently an Assistant Professor of Psychology and Neuroscience at University of California Berkeley. His research examines the impact of sleep on human brain function, with a particular focus on the role of sleep in memory processing, neural plasticity and emotional regulation.
mpwalker@berkeley.edu

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