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Two Independent Sources of Short Term Memory Problems during Sleep Deprivation

Commentary on Wee et al. Sleep deprivation accelerates delay-related loss of visual short-term memories without affecting precision. SLEEP 2013;36:849-856.

Adrienne M. Tucker, PhD

Research Institute Psychology, University of Amsterdam, Amsterdam, The Netherlands

Accidents related to sleep loss are estimated to cost billions of dollars annually,[1] yet the effects of sleep deprivation on aspects of cognition have yet to be unraveled. For example, short term memory (STM) plays a vital role in the performance of a wide range of tasks such as decision making and problem solving.[2] During sleep loss, STM performance is slower and less accurate with large individual differences in the magnitude of impairment,[3-8] yet the underlying mechanism(s) for these performance changes are not clear.

In this issue of *SLEEP*, Wee and colleagues[9] take a model-based approach to understanding cognitive performance by fitting quantitative mathematical parameters which are theorized to reflect latent cognitive processes. Theoretically, this approach allows one to disentangle the multitude cognitive processes contributing to a single behavioral output variable such as reaction time (RT) or accuracy.[10] Another way to isolate cognitive processes is via parametric manipulations, which place increasingly greater difficulty on a given process of interest (such as a requirement to remember 1, 3, or 6 letters).[11] These approaches allow more specific conclusions to be drawn and can help pinpoint which of the following processes underlie the STM deficits seen during sleep deprivation: memory encoding, memory maintenance, memory retrieval and/or a more general deficit in basic perceptual and attentional processing. Below I summarize what is known about the effects of sleep deprivation on these specific processes from the study by Wee and colleagues,[9] as well as previous approaches involving cognitive modeling, parametric task manipulation, and neuroimaging.

Memory Maintenance

Wee et al. tested 19 healthy young participants twice in a counterbalanced order, once after sleep and once after a night of sleep deprivation. Three colored squares were presented and at a delay of either 1 or 10 s subjects were cued to retrieve the square presented at the identified location by selecting the matching color from a wheel including 180 choices. Bayes' probabilistic model was used to separate the response error distribution into three parts: one representing precision of target items, one representing distractor items, and one representing random guesses.

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Address correspondence to: Adrienne Tucker, PhD, University of Amsterdam, Nieuwe Achtergracht 129, Rm DS.18, 1018 WS Amsterdam, The Netherlands; Tel: +31 (0)20 525 6376; E-mail: A.M.Tucker@uva.nl

The model parameter reflecting random guesses increased as a function of sleep deprivation and delay, which suggests that participants were more likely to drop items from STM during sleep loss (i.e., that participants had a harder time maintaining items in STM). Intriguingly, two studies using a parametric approach have also reported selective deficits in working memory maintenance in sleep deprivation, as well as one other model-based analysis described further below.[12-14] In this issue of *SLEEP*, Wee et al. also observed that sleep deprived subjects were more likely to erroneously report a non-target item.[9] Sleep deprivation did not affect the model parameter reflecting the precision of remembered items, however, which suggests that encoding quality is not impacted for those items that are successfully maintained.

Memory Encoding

Rakitin et al. investigated the effects of 48-h sleep deprivation on a letter recognition task where the difficulty of encoding the probe was manipulated by randomly scrambling 0%, 25%, or 50% of the image's pixels.[15] Contrary to prediction, there was no interaction between sleep deprivation and degradation. In line with the result reported by Wee et al.,[9] this suggests that stimulus encoding is not primarily responsible for the working memory deficits seen.

Memory Retrieval

In other studies, the difficulty of memory retrieval was manipulated by using memory set sizes of one, three, or six letters. After two nights of sleep loss there was no interaction between sleep deprivation and memory set size on either RT or accuracy, suggesting that working memory retrieval was not impaired.[16] Another study used a similar task, also after two nights of sleep loss. In this task the memory probes were manipulated such that 50% that were not in the current set were in the set previous; this recency places an additional proactive interference demand on retrieval. Again, there were no interactions between sleep deprivation and set size nor between sleep deprivation and recency, providing even stronger evidence that memory retrieval is not greatly impacted by sleep loss.[17]

Basic Perceptual and Attention Processing

Converging evidence suggests that decrements in basic perceptual and attention processing contribute to STM impairment during sleep deprivation. First, sleep-deprived subjects show failures to respond on STM tasks similar to the attentional lapses seen in the psychomotor vigilance test (PVT).[18-23] Second,

more complex STM tasks which are more attentionally engaging—and thus put lesser demands on endogenous attentional control—are better preserved during sleep loss.[24,25] Third, sleep deprived participants have a harder time maintaining attention in the face of distracting items presented during working memory tasks.[26,27] Finally, some brain regions (e.g., occipital and parietal cortex) identified in neuroimaging studies implicate deficits in basic perceptual and attentional processing.[7,28-32] Notably, after 53-57 h of sleep deprivation, rTMS to facilitate left upper middle occipital cortex in BA19 (a region involved in perceptual processing) was shown to significantly decrease RT on a delayed letter recognition task.[33] That is, facilitating a brain region involved in perceptual processing was able to at least partially restore performance, suggesting that perceptual processing deficits underlie some of the STM impairment seen during sleep deprivation. The finding is replicated and shown to persist for up to 18 hours in an article by Luber et al. in this issue of *SLEEP*.[34]

Two Sources of STM Impairment

Intriguingly, two independent sets of neural correlates of working memory impairment during sleep deprivation have been dissociated.[35] Further, basic attentional versus working memory maintenance deficits have been dissociated using computational modeling.[14] The effects of sleep deprivation on STM were investigated using a letter string recognition task across lags of 0-4 trials. A computational model based on Atkinson was used to estimate three parameters representing attention, working memory span, and encoding. In line with the report by Wee et al.,[9] sleep deprivation significantly reduced attention and working memory span parameters, but it did not reduce the encoding parameter. Specifically, sleep deprivation reduced working memory span by 38%—a large effect ($\eta^2 = 0.21$). This was reflected in a significantly greater drop in accuracy with lag (or delay), reflecting trouble maintaining items in working memory span. The effect on attention was slightly more than half that of working memory span ($\eta^2 = 0.13$) and the change in these two parameters was not correlated with each other. Indeed, individual differences in the profile of cognitive impairment were of such a degree that some individuals were selectively vulnerable to attention decrements, while others were selectively vulnerable to working memory span decrements.

Summary

Behavioral, cognitive modeling, and neuroimaging results converge to suggest that deficits in short term memory during sleep deprivation arise from decrements in basic attentional and perceptual processing as well as decrements in memory maintenance, while memory encoding and retrieval processes seem to be relatively spared. Thus, the study by Wee et al.[9] adds further evidence to the conclusion that there are at least two independent ways that short-term memory deficits can occur during sleep deprivation: one related to basic attention and perceptual processing; and the other related to memory maintenance. Individuals can experience deficits in one or both processes when sleep deprived. More studies that use quantitative modeling as reported by Wee et al. can help provide a greater understanding of the underlying mechanisms responsible for the effects of sleep loss on STM.

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DISCLOSURE STATEMENT

The authors have indicated no financial conflicts of interest.

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