EDITORIAL

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# Sleep's Role in Human Spatial Learning

Commentary on Nguyen et al. Overnight sleep enhances hippocampus-dependent aspects of spatial memory. SLEEP 2013;36:1051-1057.

Bhavin R. Sheth, PhD

*Department of Electrical & Computer Engineering, University of Houston and Center for Neuroengineering and Cognitive Science, University of Houston, Houston, TX*

In this issue of *SLEEP*, Nguyen and colleagues[1] use a novel spatial navigation paradigm to probe the effect of sleep on hippocampus-based spatial learning in humans. The recent surge of research on the influence of sleep on learning and memory began with behavioral studies of perceptual learning[2-4] and motor skill learning[5] in humans, and neurophysiological studies on rodents showing reactivation of hippocampal neural patterns during slow wave sleep.[6] The study of Nguyen et al. provides a cross-species link between mechanism and behavior.

A number of studies in recent years have shown hippocampal contributions to human memory during sleep.[7-10] Some of these studies found a correlation between hippocampal activity in sleep and post-sleep performance but did not find a benefit of sleep-dependent memory reactivation.[10] Studies either did not assess[9] or failed to find[8] a unique benefit of sleep on spatial memory consolidation. In a study where a unique benefit of sleep on spatial memory consolidation was found,[7] factors such as differences in vigilance state between wakefulness and sleep or in the capacity to relearn the memory were not eliminated as alternative accounts. The study by Nguyen et al.[1] is a distinct departure in several key methodological aspects that go a long way in addressing these issues. First, it directly compares the effects of sleep following learning with the effects of wake using *multiple* measures of performance with fine-grained *trial-by-trial* pre- and post-assessments. Second, it simultaneously assesses vigilance state in participants. Thus, in terms of behavioral assessment, Nguyen et al. is arguably the most thorough to date. In addition, Nguyen et al. measure accuracy of spatial navigation within a virtual three-dimensional environment resembling a maze, an environment ideally suited to engage the hippocampus. Nguyen et al. report overnight benefits of sleep on the accuracy of navigation, providing support for the idea of sleep-dependent human spatial memory consolidation involving the hippocampus.

A closer look at the data illustrated in Figure 4 of Nguyen et al.[1] (bottom, and especially Figure S1 in supplementary materials) bears hints of a more nuanced interpretation. An argument can be made that Nguyen shows overnight "catch-up" by the participants undergoing sleep following training. Nguyen measured distance traveled and amount of backtracking during the time participants navigated through a virtual three-dimensional maze. They randomly assigned participants to either a sleep or a wake group. Each participant was subject to training and retest sessions. The sleep group, which slept after but not before the training, encoded the spatial map less well during training as compared to the wake group. In support of this, the sleep group traveled numerically farther to reach the goal during training. This observation is broadly in accord with a report of impaired ability to form new hippocampal memories without sleep[11] but could also be because of time-of-day differences. In and of itself, the observation may not mean much, as the effect of group on encoding did not reach significance ($P > 0.1$). However, note that the distance traveled by the sleep and wake groups at retest was indistinguishable (Figure S1; compare also light gray bars of Figure 4, top left showing comparable distance traveled at retest). Together with the fact that spatial encoding is somewhat weaker in the sleep compared with the wake group, this implies greater room for improvement in the sleep group at retest. That the sleep and wake groups end up at the same level of accuracy at retest indicates that sleeping after the training does not differentially (compared with wakefulness) enhance performance at the end of retest, but rather it helps performance of the sleep group reach par with the wake group.

Further analysis is consistent with other roles for sleep besides memory consolidation. In each training or retest session, participants navigated the maze three times. Figure S1 from Nguyen et al.[1] suggests spatial learning during the course of both training and retest, as illustrated by the lower values of distance traveled on the terminal versus the initial trial in each. In order to observe a beneficial effect of sleep on overnight spatial learning, one ought to look at the last training trial and the first retest trial following the sleep/wake manipulation. In case of retest trials, performance on subsequent retest trials is a combination of the effects of overnight sleep on both memory consolidation *and* one's capability to learn more efficiently, which can be thought of as offshoots of sleep's restorative effect on brain function.[12,13] Change in distance traveled (1st retest trial - 3rd training trial) show no between-group difference, which does not comport with the idea of sleep-dependent improvement in hippocampus-dependent spatial learning in humans (completion time also shows little difference in Figure 4).

In sum, Nguyen et al.[1] have conducted a thorough study to relate sleep with hippocampal based spatial learning. Their behavioral findings argue for a role for sleep in hippocampal spatial learning that goes above and beyond memory consolidation. Indeed, sleep is likely to have different effects on different kinds of memories, including passive shielding of fragile memories from sensory interference,[14,15] restitution of brain function that can increase the capacity to form certain new kinds of

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Address correspondence to: Bhavin R. Sheth, PhD, University of Houston, Houston, TX 77204-4005; Tel: (713) 743-4935; Fax: (713) 743-4444; E-mail: brsheth@uh.edu

memories and unmask latent learning of certain kinds of memories formed earlier,[13,16,17] active memory reactivation,[18-20] and synaptic downscaling.[21] Studies such as that of Nguyen et al.[1] will furnish valuable data for sifting through these and hitherto undiscovered roles for sleep in learning and provide data for a future unifying model of sleep's role and indispensability in different stages of the memory process.

## CITATION

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## DISCLOSURE STATEMENT

Dr. Sheth has indicated no financial conflicts of interest.

## REFERENCES


1. Nguyen ND, Tucker MA, Stickgold R, Wamsley EJ. Overnight sleep enhances hippocampus-dependent aspects of spatial memory. Sleep 2013;36:1051-7.
2. Gais S, Plihal W, Wagner U, Born J. Early sleep triggers memory for early visual discrimination skills. Nat Neurosci 2000;3:1335-9.
3. Karni A, Tanne D, Rubenstein BS, Askenasy JJ, Sagi D. Dependence on REM sleep of overnight improvement of a perceptual skill. Science 1994;265:679-82.
4. Stickgold R, James L, Hobson JA. Visual discrimination learning requires sleep after training. Nat Neurosci 2000;3:1237-8.
5. Smith C, MacNeill C. Impaired motor memory for a pursuit rotor task following stage 2 sleep loss in college students. J Sleep Res 1994;3:206-13.
6. Wilson MA, McNaughton BL. Reactivation of hippocampal ensemble memories during sleep. Science 1994;265:676-9.
7. Ferrara M, Iaria G, De Gennaro L, et al. The role of sleep in the consolidation of route learning in humans: a behavioural study. Brain Res Bull 2006;71:4-9.
8. Orban P, Rauchs G, Balteau E, et al. Sleep after spatial learning promotes covert reorganization of brain activity. Proc Natl Acad Sci U S A 2006;103:7124-9.
9. Peigneux P, Laureys S, Fuchs S, et al. Are spatial memories strengthened in the human hippocampus during slow wave sleep? Neuron 2004;44:535-45.
10. van Dongen EV, Takashima A, Barth M, et al. Memory stabilization with targeted reactivation during human slow-wave sleep. Proc Natl Acad Sci U S A 2012;109:10575-80.
11. Yoo SS, Hu PT, Gujar N, Jolesz FA, Walker MP. A deficit in the ability to form new human memories without sleep. Nat Neurosci 2007;10:385-92.
12. Sheth BR. Memory consolidation during sleep: A form of brain restitution. Behav Brain Sci 2005;28:81-2.
13. Sheth BR, Janvelyan D, Khan M. Practice makes imperfect: restorative effects of sleep on motor learning. PLoS One 2008;3:e3190.
14. Sheth BR, Nguyen N, Janvelyan D. Does sleep really influence face recognition memory? PLoS One 2009;4:e5496.
15. Sheth BR, Serranzana A, Anjum SF, Khan M. Sleep's influence on a reflexive form of memory that does not require voluntary attention. Sleep 2012;35:657-66.
16. Censor N, Sagi D. Global resistance to local perceptual adaptation in texture discrimination. Vision Res 2009;49:2550-6.
17. Censor N, Sagi D. Benefits of efficient consolidation: short training enables long-term resistance to perceptual adaptation induced by intensive testing. Vision Res 2008;48:970-7.
18. Buzsaki G. Two-stage model of memory trace formation: a role for "noisy" brain states. Neuroscience 1989;31:551-70.
19. Buzsaki G, Leung LW, Vanderwolf CH. Cellular bases of hippocampal EEG in the behaving rat. Brain Res 1983;287:139-71.
20. Oudiette D, Paller KA. Upgrading the sleeping brain with targeted memory reactivation. Trends Cogn Sci 2013;17:142-9.
21. Tononi G, Cirelli C. Sleep and synaptic homeostasis: a hypothesis. Brain Res Bull 2003;62:143-50.