

“There is a time for many words, and there is also a time for sleep.”

—Homer, *The Odyssey*

Does it matter that children and adolescents are sleeping more than an hour less per night than they did a century ago? (Matriccioni et al., 2011). Could this difference influence their learning or other aspects of their lives? The answer to each of these questions is a resounding **YES**.

We explore relationships between sleep, learning, and health, starting with basic information about sleep, which occurs in five phases: stages 1–4 and REM (rapid eye movement) sleep. Stage 4, slow-wave sleep (based on electroencephalograph measurements) occurs mostly in the first half of a night's sleep; REM sleep occurs more during the second half (Figure 1). Falling asleep, we start in stage 1 and then move progressively through stages 2–4 and into REM. Each cycle lasts about 90 minutes.

All five stages of sleep – each with its own changes in neurophysiology – facilitate some aspect of learning and memory (Poe et al., 2010); REM and slow-wave sleep are the most important. REM sleep is characterized by increased acetylcholine and reduced serotonin and norepinephrine neurotransmission. In REM sleep, plasticity-related gene transcription increases in hippocampal neurons, resulting in increased long-term potentiation (LTP) or long-term depression (LTD), the basis of the synaptic remodeling critical for learning and cognition (Poe, 2010).

Levels of acetylcholine are greater during REM sleep than when awake, whereas serotonin and norepinephrine fall “uniquely silent during REM sleep” (Poe, 2010). Monoamine neurotransmitters enhance LTP – but it is LTD that is needed for the recycling of the hippocampal neurons used for temporary

storage of memories until consolidated in the neocortex. LTD is also important during the intensive learning in development and when integrating previous knowledge with new and novel information (Poe, 2010).

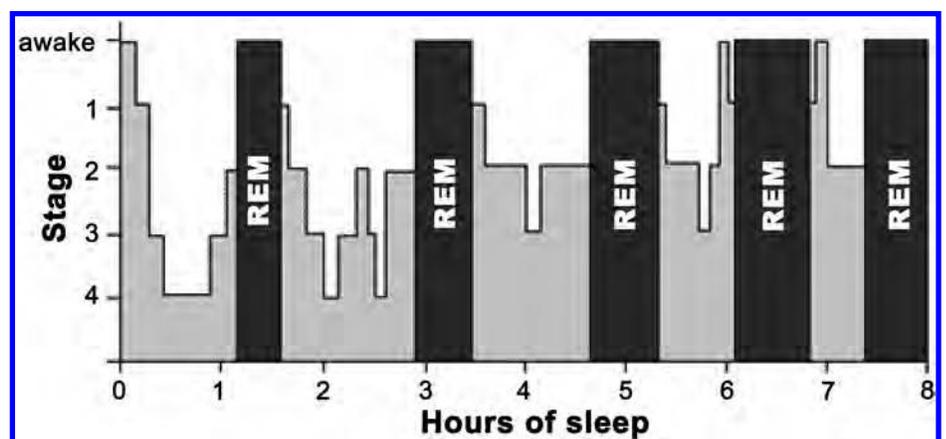
Animal and human research reveal prolonged and/or intensified REM sleep after learning (Poe, 2010). During REM sleep, the brainstem creates waves of glutaminergic excitation that project to the hippocampus, amygdala, and forebrain. Learning increases the intensity and density of these waves, a change correlated with task retention. Certain cytokines, produced by both immune and neural cells, are important in the hippocampus for LTP creation and maintenance, especially in spatial learning (del Rey et al., 2013). REM sleep deprivation leads to decrease in LTP formation and maintenance along with diminished neurogenesis in the dentate nucleus of the hippocampus (Poe, 2010), resulting in decreased learning and memory.

Slow-wave sleep is characterized by delta waves and protein synthesis. It is posited that during slow-wave sleep, short-term LTP

is converted into long-lasting LTP via protein synthesis. Slow-wave sleep reactivates the same neuronal circuits used in awake learning and REM sleep, stabilizing the strongest synapses used (Poe, 2010).

In adolescence, the brain increases myelination and decreases synaptic density as it becomes ever more efficient, so it is not surprising that sleep also changes then. Bedtimes become later and adolescents change from “early birds” to “night owls” as the circadian rhythm increases the period of daytime wakefulness. Environmental factors like homework, friends, and jobs create their own pressures to stay awake longer. This shift peaks around age 20, then slowly changes back to earlier waking.

In adolescence, slow-wave sleep decreases by 40% compared with that in infants and younger children (Colrain, 2011). The amplitude, slope, and total slow-wave counts also decrease. REM sleep decreases, too, although the ratio of REM sleep to the total amount of sleep remains unchanged. The duration of sleep lessens across adolescence – a result of biology, social pressures, and environment.



**Figure 1.** A typical hypnogram from a young, healthy adult. Light gray areas represent non-rapid eye movement (NREM) sleep (<http://science.education.nih.gov/supplements/nih3/sleep/guide/info-sleep.htm>).

In a systematic review of world literature, involving data from almost 700,000 children from 20 countries over a century from 1905 to 2008, Matricciani et al. (2011) found that sleep time for adolescents has been decreasing in the United States, Canada, Europe, and Asia. The greatest decline occurred in boys and on school nights.

Various health and behavioral issues are linked to sleep deprivation. Chronic sleep deprivation results in increased inflammatory cytokines such as IL-6, decreased numbers of natural killer cells, and a diminished B cell response to influenza virus immunization (Gamaldo et al., 2012). Increased body weight and obesity are both associated with short sleep duration (Cappuccio et al., 2008; Arora et al., 2013). Substance abuse, depression, and anger are also possibly associated with sleep deprivation (Colrain & Baker, 2011). Colrain and Baker (2011) also reported that sleep deprivation heightened adolescents' perceptions of stress and caused more worry, depression, suicidal ideation, and other mental health issues. In addition, poor or inadequate sleep can lead to decreased school achievement and enjoyment (Colrain & Baker, 2011).

Sleep, like oxygen or water, is essential to our life and health. We should view

it as a fundamental need for adolescents whose brains, bodies, and sleep patterns are changing so drastically. This article concludes our series on the neurobiology of learning. Thanks for your interest; we hope you have learned a lot!

### Acknowledgment

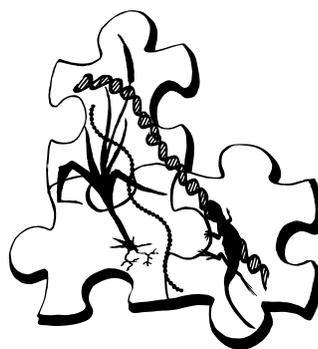
Funded by the NIH Blueprint for Neuroscience Research and administered by National Institute on Drug Abuse (NIDA), part of the National Institutes of Health.

### References

- Arora, T., Hussain, S., Lam, K.-B.H., Yao, G.L., Thomas, G.N. & Taheri, S. (2013). Exploring the complex pathways among specific types of technology, self-reported sleep duration and body mass index in UK adolescents. *International Journal of Obesity*, 37, 1254–1260.
- Cappuccio, F.P., Taggart, F.M., Kandala, N.B., Currie, A., Peile, E., Stranges, S. & Miller, M.A. (2008). Meta-analysis of short sleep duration and obesity in children and adults. *Sleep*, 31, 619–626.
- Colrain, I.M. & Baker, F.C. (2011). Changes in sleep as a function of adolescent development. *Neuropsychology Review*, 21, 5–21.

- del Rey, A., Balschun, D., Wetzel, W., Randolph, A. & Besedovsky, H.O. (2013). A cytokine network involving brain-borne IL-1 $\beta$ , IL-1ra, IL-18, IL-6, and TNF $\alpha$  operates during long-term potentiation and learning. *Brain, Behavior, and Immunity*, 33, 15–23.
- Gamaldo, C.E., Shaikh, A.K. & McArthur, J.C. (2012). The sleep–immunity relationship. *Neurologic Clinics*, 30, 1313–1343.
- Matricciani, L., Olds, T. & Petkov, J. (2012). In search of lost sleep: secular trends in the sleep time of school-aged children and adolescents. *Sleep Medicine Reviews*, 16, 203–211.
- Poe, G.R., Walsh, C.M. & Bjorness, T.E. (2010). Cognitive neuroscience of sleep. *Progress in Brain Research*, 185, 1–19.

JENNY L. WILLIAMSON is Project Director for How Do I Learn at the University of Washington, School of Nursing, T610A Health Sciences, 1959 NE Pacific Street, Seattle, WA 98195-7266; e-mail: jenlw@uw.edu. HELEN T. BUCKLAND is Project Director of Online Neuroscience Education about Drug Addiction at the University of Washington, School of Nursing; e-mail: trezbu@uw.edu. SUSANNA L. CUNNINGHAM is Professor at the University of Washington, School of Nursing; e-mail: susannac@uw.edu. For questions about this article, please contact Jenny L. Williamson at jenlw@uw.edu.



## Online MS in Biology

### Master of Science (Non-thesis option)

Online Master's Degree in Biological Sciences for K-12 teachers and other science educators

- All courses offered online
- Reduced tuition
- No out-of-state tuition differential
- No residency requirement
- 30 semester hours of graduate credits
- Up to 12 credits of graduate courses may transfer for the degree requirements

For Information:  
tjarret@clemson.edu  
864-656-2153



The courses offered in the **BIOL ONLINE** Program are fully accredited through Clemson University by the Southern Association of Colleges and Schools (SACS). CU is an equal opportunity employer