"JUST GO TO SLEEP!" SLEEP & LEARNING

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> "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? (Matricciani 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 though 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.

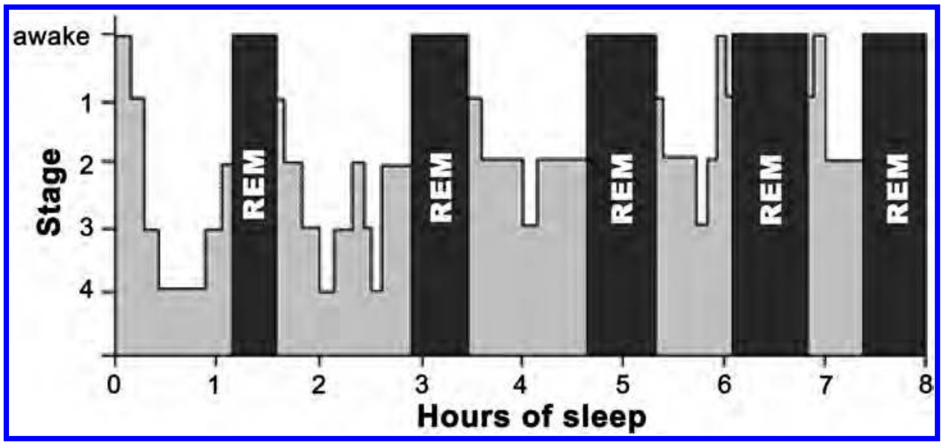

Figure 1. A typical hypnogram from a young, healthy adult. Light gray areas represent non–rapid eye movement (NREM) sleep (http://science.education.nih.gov/supplements/nih3/sleep/guide/info-sleep.htm).

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In a systematic review of world literature, involving data from almost 700,000 children from 20 countries over a century from 1905 to 2008, Matriccani 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!

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