Learning, Memory, and Sleep in Children

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Are we getting enough sleep to learn and function optimally? Sleep loss is endemic in our population, with many adults and children receiving less sleep than needed.[1–3] What are the effects of variations in sleep on childhood learning? Despite a burgeoning literature on sleep and learning in adults[4–6] there is little known about the direct effects of sleep on child learning. There is indirect evidence from developmental work in animals and from correlational work investigating the relationship between children's sleep-wake state organization and their performance on cognitive outcomes, with the literature on long-term disordered sleep also contributing to the understanding of the effects of sleep on childhood learning. More direct evidence comes from a small body of experimental work on restricted sleep in children.[7] Finally, a very small number of studies have begun to investigate the direct effects of sleep on learning by comparing learning after periods of sleep versus wake.[2] Although one might expect continuity in the effects of sleep on learning in children compared with adults, the experimental evidence paints an intriguing, picture, one that is explored in this article along with a review of correlational work investigating the effect of sleep variables on cognitive outcomes in children and experimental work investigating the effects of sleep restriction on learning. The authors begin by providing a brief outline of the development of sleep in children.

DEVELOPMENT OF SLEEP

Gestational Sleep

Sleep plays an essential role in the development and plasticity of the brain.[8] Crucial neurologic growth and development of the primary sensory systems occur both prenatally and postnatally. For typical development, both genetic factors and early experience are highly influential during these critical periods to establish and refine the basic connections.[9,10] Prenatal diagnostics have shown that as the fetus develops in the womb, so does sleep.[11] This development largely parallels the maturation of the fetus' cortex and central nervous system (CNS).[10,12] A cyclic physiologic rhythm oscillating between active and restful states can be identified in the second trimester. Using real-time ultrasonography, these distinct states can be detected by physical movements of the fetus, specifically of the limb and eye.[11,12] Cyclic patterns present in the basic activity-rest cycles are thought to be manifestations of the CNS ultradian rhythm. This ontogeny of sleep continues to develop systematically from the ultradian rhythm during early gestation to characterizable states of active sleep and quiet sleep.[11,13] Around the 25th week of gestation, these sleep states are observable in cycles ranging from 40 to 60 minutes. At 27 to 28 weeks' gestation, the electric patterns of the states are more distinctive, becoming a fully formed sleep cycle at 35 weeks' gestation.[12]

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Neonatal and Infant Sleep: Ages 0 to 12 Months

After a full-term birth, occurring between 38 and 42 weeks' gestation, there is rapid development of the neonate's CNS, but until around 6 months of age, the neonatal cortex is unable to sustain the waves that have higher frequency and amplitude that are present in later life sleep. At this stage of development rapid eye movement (REM) and non-REM (NREM) are not yet sufficiently organized identifiable states. Sleep is thus defined in these early months using a combination of electroencephalogram (EEG), respiration, heart rate, and behavioral data.[14]

Using such scoring, there are 3 distinct states of sleep at birth and in the immediate neonatal period, including active, quiet, and indeterminate states. Active sleep is defined electrophysiologically as constant activity throughout the neocortex. Active sleep that precedes quiet sleep is characterized by high-amplitude activity (up to 70 μV), whereas active sleep that follows a period of quiet sleep shows lower-amplitude waves (20–50 μV).[15,16] At this time, cortical activation is not distinguishable between active sleep and wake states, with both states showing similar high-frequency high-amplitude waves.[12] Quiet sleep exhibits a background pattern of noise with alternating bursts of theta and delta waves, with amplitudes up to 200 μV. Periods of quick alpha and beta activity are intermingled in this theta and delta activity, with amplitudes falling between 50 and 70 μV.[14,16] During quiet sleep, these oscillating amplitudes can synchronize in both hemispheres. In these early months, this pattern of sleep is known as trace alternant, after its characteristic changes from high- to low-amplitude activity over the entire neocortex. Trace alternant is also known as discontinuous sleep because of its patterned bursts of initial moderate- to high-voltage activity followed by low-voltage activity.[12,16] The final sleep state is indeterminate, encompassing many of the transitions between identifiable active and quiet sleep and characterized by disorganized EEG signals.[16]

Neonates sleep in polyphasic cycles, sleeping between 12 and 17 hours a day, typically for short periods, from 3 to 4 hours, marked by frequent arousals. Transition to sleep from the waking state is accomplished through an initial short period of active sleep. As the infant matures, this initial period of active sleep disappears and forms into the transition typical of adults, through NREM1. After this initial short period of active sleep, the infant enters the typical alternating cyclic oscillations of active/quiet sleep, similar to that of adults, with the infant sleep cycles typically lasting 50 minutes as compared with the adult cycles of 90 minutes.[12,16] As neonates progress into infancy, their polyphasic sleep begins to normalize, with their sleep architecture becoming more durable and adultlike. As neonates age, the infantile sleep pattern becomes diurnal, and at the age of about 6 months, characterizable REM and NREM sleep states have developed. This change may be caused by the maturation of the infant cortex, which is now able to sustain the high-amplitude waves exhibited in delta sleep.[17] The trace alternant pattern also disappears by 47 weeks postterm, having developed into the known NREM sleep state, with constant fluid delta waves.[12]

The emergence of sleep spindles and K complexes marks the transition from neonatal to infantile sleep. At 8 to 11 weeks postterm, typically developing infants display bursts of activity during NREM2 quiet sleep of 11 to 15 Hz. In the first year of life, the spindle activity becomes identifiable in the sleep state NREM2, showing increased synchrony; the bursts of spindle activity show increases in bilateral synchrony and symmetry as the infant develops, up to 70% at 12 months.[12,14,18,19] Until about 24 months, there is not consistent synchronous spindle activity across the hemispheres.[12] In addition, between the ages of 5 and 6 months, K complexes appear during NREM2. K complexes are brain waves that present as an initial sharp negative high-voltage wave followed by a positive wave.[18] These waves are the classic markers of the transition from neonatal to infant sleep.

Early and Middle Childhood: Ages 1 to 12 Years

During early and middle childhood, sleep and wakeful patterns become more consistent and durable, similar to those of adults. During early childhood, that is, ages 1 to 5 years, children continue to need a modified polyphasic sleep cycle composed of multiple naps during the day and an extended period of sleep at night. In this prepubertal age group, there is a steady decline in the percentage of REM sleep in total sleep time, from around 25% at 12 months of age to 18.5% by 12 years of age.[20] NREM sleep increases slightly during early childhood, and then, it too has a slight gradual decline during this age range.[20] Around the age of 5 years, the polyphasic cycle has ended, and nocturnal sleep is typically between 10 to 12 hours, with at most one nap during the day.[21] Between the ages of 4.5 and 7 years, sleep is marked by latent REM. Before this age, children typically ascend into the