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Editorial

Editorial

Adolescent sleep: a bulwark for healthy brain development

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Adolescence involves rapid brain maturation [1], including well-documented cortical pruning extending toward frontal cortices [2], increasing white matter myelination [3], and evolving subcortical limbic morphology [4]. Functional changes allow for improved reasoning and decision making as teens get older. These trajectories are non-linear, non-stationary, and extend into young adulthood. Atypical adolescent neurodevelopment portends neurodevelopmental and neuropsychiatric impairment.

This development coincides with shifts in sleep biology and behavior. Evolutionarily conserved puberty-gated changes in circadian rhythms [5–9] and sleep homeostasis [10, 11] push adolescent sleep onset later into the night. Psychosocial factors (e.g. technology use [12]) apply further pressures to remain awake [13, 14]. Societal policies such as school start times can short-change adolescent sleep by imposing developmentally inappropriate early wake times. This perfect storm ripples through adolescent daily life to manifest in chronic insufficient and mistimed sleep, particularly on school nights [13, 14]. This widespread sleep disruption during a key developmental period has motivated research into its consequences for adolescent brain development [15] and mental health [16].

The science of sleep loss in humans has revealed that inadequate sleep—both short- and long-term—can have devastating impacts to vigilance [17–19], cognitive [20, 21], and affective function [22] and can increase risk for risk-taking and mental illness [23, 24]. Nevertheless, the exact consequences of spending much of adolescence experiencing near-ubiquitous social jetlag and chronic sleep restriction are unknown. Despite this gap, the benefits of healthy sleep for adolescent health and wellness have propelled our field to advocate for healthier sleep opportunities for adolescents. The state-wide law mandating later high school start times in California is the most prominent example of this evidence-based change [25]. These efforts are predicated on healthy sleep supporting healthy brain development. This premise is largely rooted in correlational data, a gap Wild and colleagues begin to address in their new prospective study reported in Sleep.

In their study of 39 adolescents aged 10–14 years [26], Wild and colleagues collected two structural MRI scans 6 months apart to quantify the trajectory of brain volume in a series of a priori regions-of-interest in a socioemotional network critically relevant for adolescent mental health. These regions include cortical areas of the orbital frontal cortex (linked to motivational and social behavior) and precuneus (a core node of the default-mode network involved in self-referential processing) as well as subcortical regions regulating emotion (i.e. the amygdala), episodic memory (i.e. the hippocampus), and arousal and information-processing (i.e. the thalamus). Between scans, youth wore a wearable-grade sleep tracker (the Jawbone UP move) to quantify four orthogonal components of sleep health: sleep duration (total sleep time), circadian timing (the midsleep phase), quality (sleep efficiency), and regularity (sleep regularity index). Sleep data were split between free and non-free nights and entered into a series of moderation models to examine how the slope of brain volume over 6 months varies by a teen's sleep behavior. Their data indicate that it does.

Wild's results indicate that sleep matters for the course of socioemotional brain development. The pattern of exact results varied across regions of interest, sleep parameters, and choice of free/school data, yet the general message is clear: healthy sleep (appropriately long, high quality, and well-timed) supports brain health. Diminished sleep may alter these developmental changes. These data join other recent investigations which have proposed that sleep during adolescence may reflect neurodevelopment and brain aging [15].

Beyond the benefits of a moderately long (6 months) sleep monitoring period, there are multiple key strengths to Wild's approach. For one, the team was analytically disciplined. They focused their work on a series of carefully selected sleep and brain measures, limiting the potential for spurious brain–behavior correlations. The authors direct their sleep analyses to the actionable dimensions of sleep health which combine to paint the full picture of adolescent sleep yet have distinct developmental and biosocial determents. We applaud the researchers for a focused, hypothesis-driven assessment of socioemotional brain regions, with clear implications for mental health. A whole-brain analysis would require a large sample size to detect reliable and interpretable effects.

Some ambiguity remains (e.g., null effects in the hippocampus, exact nature of school-nights vs. free nights, etc.). This may reflect understandable limitations. A 6-month delay between imaging sessions, while a key advance, remains an overall short timeframe for adolescent brain development, and one not bound to any observed event such as puberty. To that end, the authors did not observe statistically significant effects of time in their regional gray matter volumes. While sleep significantly moderated gray matter volume changes in many regions, it remains unclear whether these sleep-dependent changes in structure are functionally meaningful in the short- or long-term. Future research should prioritize longer and repeated follow-ups to unravel the function implications of these trajectories.

The study's focus on modifiable aspects of sleep strengthens the clinical relevance of these findings. Wild and colleagues demonstrate a robust relationship between modifiable dimensions of sleep health and adolescent brain development indicating that sleep may represent an intervention target for promoting healthy brain development and even reducing risk for psychiatric disorders during adolescence. Many psychiatric disorders first emerge in adolescence [27]. Relevant to Wild, psychotic disorders, such as schizophrenia, have been associated with co-occurring decreases in regional gray matter volume [28] and pronounced sleep disturbances [29]. Adolescents at risk for psychosis show similar patterns [30, 31]. Preliminary evidence indicates that sleep interventions may reduce psychiatric symptoms [32], though more work is needed. Wild's findings sustain this possibility that sleep health may be a feasible target for influencing neurodevelopmental trajectories and decreasing psychiatric risk through its influence on brain maturation.

These findings also have implications for neurodevelopmental conditions that may onset earlier in childhood which have been linked to sleep disturbances, such as attention-deficit/hyperactivity-disorder (ADHD) [33]. ADHD symptoms and sleep disturbances share common neural correlates [34, 35], and neuroimaging markers have been shown to mediate the relationship between ADHD and sleep disturbances [36]. Further, there is some evidence that adolescents with ADHD may be more vulnerable to the effects of sleep loss; experimental sleep restriction resulted in larger changes in the brain's functional architecture (via fMRI) in adolescents with more severe ADHD symptoms [37]. While there is currently no evidence on how long-term sleep restriction or circadian misalignment (e.g., from early school start times) impacts developmental trajectories in youth with neurodevelopmental disorders, Wild's findings motivate future investigation. Whether neurodevelopmental disorders expose these trajectories to differentially respond to perturbations in sleep during adolescence, or whether altered sleep exacerbates the trajectories of neurodevelopmental disorders is of vital interest.

When considering Wild's results against the backdrop of the perfect storm [13, 14], which erodes adolescent sleep for far too many teens worldwide, the implications become more sober. While our field has focused on the short-term consequences of insufficient sleep for the brain and for behavior [17, 38, 39], Wild's data indicate that this sleep insufficiency in adolescence may have long-standing costs. The message is clear: sleep mattered for the course of brain development. Efforts to bolster sleep, whether through shifting school start times [25], or interventions targeting sleep health [40], sleep behavior [41, 42], or circadian rhythms [43, 44], have focused on immediate gains in school outcomes, cognition, mental health, and general well-being. Wild's findings indicate that if scaled to the full lens of adolescence, these efforts may have a long-term rectifying effect to ensure that all youth benefit from both healthy sleep and healthy brain development. That is an opportunity that anyone who cares about adolescents' wellbeing cannot afford to sleep on.

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