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Sleep in adolescence: Physiology, cognition and mental health

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1. Introduction

Sleep is a core behavior of adolescents, consuming up to a third or more of each day. As part of this special issue on the adolescent brain, we review changes to sleep behaviors and sleep physiology during adolescence with a particular focus on the sleeping brain. We posit that brain activity during sleep may provide a unique window onto adolescent cortical maturation and complement waking measures. In addition, we review how sleep actively supports waking cognitive functioning in adolescence. Though this review is focused on sleep in healthy adolescents, the striking comorbidity of sleep disruption with nearly all psychiatric and developmental disorders (for reviews see Tesler et al., (2013), Kotagal, (2015)) further highlights the importance of understanding the determinants and consequences of adolescent sleep for the developing brain. Fig. 1 illustrates the overarching themes of our review, linking brain development, sleep development, and behavioral outcomes.

1.1. Adolescent sleep behavior

Adolescence is a time of increased independence and emergence of new social roles, all of which affect behavior: sleep is no exception. Driven in part by this newly acquired autonomy, combined with delays in the circadian timing system (reviewed by Hummer & Lee in this Special Issue) and changes to the homeostatic sleep regulating system that provide greater tolerance for sleep pressure

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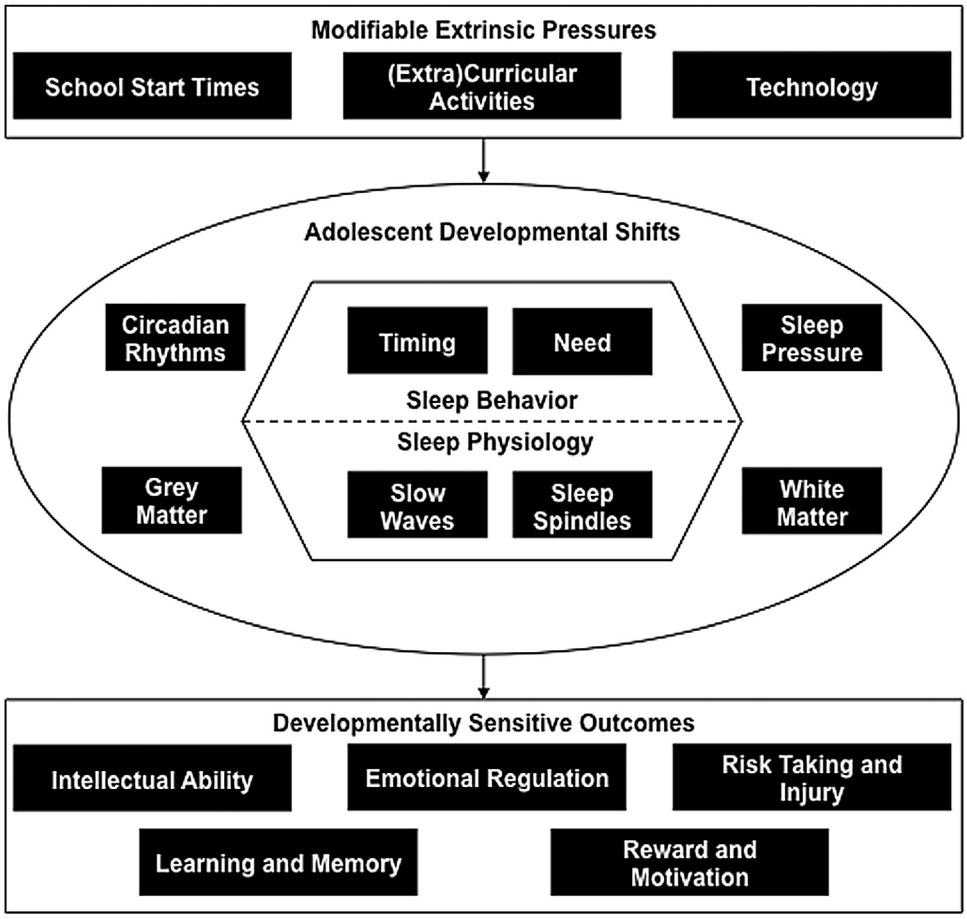

Fig. 1. Determinants and Consequences of Adolescent Sleep.
This diagram outlines the central theme of the review: a complex milieu of determinants and consequences of sleep interact during the sensitive window of adolescence. *Center*: Developmental shifts in sleep behavior (e.g., sleep need and timing) and physiology (e.g., slow waves and sleep spindles) index maturational changes in sleep and circadian regulatory systems emerging along with developmental trajectories of grey and white matter within the brain. *Top*: Several moderating and mediating extrinsic pressures can alter sleep behavior and physiology beyond intrinsic developmental forces, including school schedules, extra-curricular activities, and technology use. *Bottom*: Healthy development of sleep during adolescence underlies a variety of functional outcomes. Together this framework highlights sleep during adolescence as a "perfect storm" (Carskadon, 2011): a sensitive time-period where developmental changes, together with (mal)-adaptive environmental forces, may yield powerful consequences for behavior and cognition.

(Jenni et al., 2005), bedtimes become later with each passing year during adolescence. Rise times, by contrast, are more often determined by school start times and thus remain unchanged or move earlier (N.S. Foundation, 2006). Whether using self-report (N.S. Foundation, 2006) or objectively recorded sleep (Crowley et al., 2014), studies show that US teens lose about 90 min of sleep each school night from grade 6 (about 11–12 years old) to grade 12 (about 17–18 years old). With both approaches, the average school-night total sleep time for the youngest adolescents was about 8.4 h and about 6.9 h in the high school seniors. A more recent report from the Center for Disease Control using data from the Youth Behavior Risk Surveillance Data from 2007, 2009, 2011, and 2014 (N = 50,370 US students) found that two thirds of students in grades 9–12 reported 7 h or less sleep on school nights (Wheaton et al., 2016a). Trends are similar in other countries and circumstances appear worst for adolescents living in Southeast Asia. Yang et al. (2005), for example, showed that teens' reported school-night bedtimes progressively later than in the US from grades 5/6 (10:42 pm ± 78 m) to grades 11/12 (12:54 am ± 84 m) and that nightly total sleep time for school nights was nearly 3 h less in the older versus younger adolescents: 8 h 18 m vs. 5 h 24 min, much shorter in year 12 than in the US.

Despite the dwindling time spent asleep, studies suggest that sleep "need" *per se* does not undergo dramatic changes during adolescence. An early longitudinal study, following adolescents yearly from 10 to 12 until 15–18 years of age found that when given ten hours of sleep-opportunity, adolescents slept an average of approximately 9.25 h irrespective of age or maturational stage. Further evidence for the stability of sleep need comes from Ohayon et al., (2004), indicating a decline in sleep duration on school days, but no change on non-school days, leading the authors to conclude that the school day decline is driven by environmental rather than biological factors. Given the pervasive discrepancy between sleep need and sleep obtained for most teens, understanding the consequences of chronic insufficient sleep is paramount. For example, a laboratory study in which 10th graders slept on a self-selected school night schedule, found that during a morning nap opportunity (08:30, roughly equivalent to the first or second class-period of American high schools), participants fell asleep in approximately 5 min, nearly half the time the same participants took to fall asleep later in the day. About 50% of the sample fell asleep in less than 2 min and directly into REM sleep. This study indicates that these 10th graders may in fact suffer from pathological sleepiness during the start of the school day, perhaps a result of a simultaneous delay in their circadian rhythms and the abridgement of their sleep opportunity by earlier school-start times (Carskadon et al., 1998). Thus, starting the school day sleepy and unprepared for the cognitive and social challenges of adolescence is quotidian for many teens.