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Changes to sleep-wake behaviors are associated with trajectories of pubertal timing and tempo of secondary sex characteristics[☆]

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ABSTRACT

We examined relations between sleep-wake behaviors and pubertal development from age 8.5 through 15.5 years in a US-based sample of 488 boys (75% White) and 478 girls (78% White). Applying conditional nonlinear growth models to 7-waves of longitudinal data, we examined how sleep-wake behaviors are related to individual differences in the developmental timing and tempo of secondary sex characteristics. For girls, results supported the hypothesis that circadian changes in bedtimes, wake times, sleep duration, and eveningness preference were uniquely related to development of discrete aspects of secondary sex characteristics. For boys, the hypothesis was generally not supported. Different endocrine systems related to discrete secondary sex characteristics may be responsible for more relations between sleep and pubic hair development than for breast or genital development. Further research into associations between adrenarche and sleep during puberty may help researchers understand more about the origins and timing of adolescent sleep changes.

Sleep-wake behaviors exhibit marked changes during puberty and adolescence in part due to maturation of biological and neuroendocrine systems. Prior research presumed environmental reasons for shifting sleep patterns, but recent findings suggest that regulatory control by intrinsic brain mechanisms may play a more prominent role in sleep cycles than previously thought (Carskadon, Acebo, & Jenni, 2004; Hagenauer, Perryman, Lee, & Carskadon, 2009). Sleep-wake changes include delayed bed times and shortened sleep on school nights and a shift to later bedtimes and wake times on weekends (Gradisar, Gardner, & Dohnt, 2011). Maturational changes to sleep typically result in insufficient sleep on school nights with compensatory sleep on weekends, and this pattern can lead to academic difficulties, daytime sleepiness, and depressive symptoms (Wolfson & Carskadon, 1998).

The timing of developmental changes in sleep has been described vaguely as occurring *during puberty* (e.g., Hagenauer & Lee, 2012), *at the onset of puberty* (e.g., Sadeh, Dahl, Shahar, & Rosenblat-Stein, 2009), *or during adolescence* (e.g., Crowley, Acebo, & Carskadon, 2007). Even though the terms *adolescence* and *puberty* are often used interchangeably, they represent discrete life phases (Sisk & Zehr, 2005). While puberty is a specific set of biological events, adolescence is a broader period of life. Adolescence refers to the transition from childhood to adulthood, with growth in physical, cognitive, and emotional development that may extend from around 10 years-of-age to the mid-20s (Dorn, Dahl, Woodward, Hermi, & Biro, 2006). On average, it lasts five to eight years after pubertal onset (Rosenfeld & Nicodemus, 2003). Given the negative outcomes associated with insufficient sleep in adolescence, it seems worthwhile to focus more closely on the relation between the developmental timing of delayed phase sleep changes and the timing and pace of specific developmental changes during puberty.

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Puberty consists of two separate phases: adrenarche, triggered by the maturation of the zona reticularis of the adrenal gland, and gonadarche, associated with the maturation of the hypothalamic-pituitary-gonadal (HPG) axis. Adrenarche and gonadarche represent unique but overlapping periods of development that are activated and controlled by independent mechanisms (Byrne et al., 2017). Adrenarche typically begins around 5 to 7 years-of-age when levels of the adrenal androgens dehydroepiandrosterone (DHEA) and its sulfate (DHEA-S) and androstenedione, secreted from the adrenal glands, gradually increase before the HPG axis is reactivated (Nakamura, Gang, Suzuki, Sasano, & Rainey, 2009). Adrenal androgen production (DHEA and DHEA-S) contributes to the appearance of axillary and pubic hair, increased skin oil production, body odor, and skeletal maturation around 8 years-of-age. Girls begin adrenarche about 1–2 years earlier than boys.

In contrast, gonadarche usually begins around 9–10 years for girls and 10–11 years for boys. It reflects the reactivation of the HPG axis characterized by pulsatile section of gonadotropin-releasing hormone (GnRH; Grumbach, 2002). Pubertal onset is marked by the physical manifestation of these hormonal changes through development of secondary sex characteristics (breast, genital, and pubic hair).

Not only do girls typically enter puberty earlier than boys, but there are also important differences in the endocrine-hormone processes underlying the development of their secondary sex characteristics. For girls, pubic hair development is associated primarily with adrenal androgens. In boys, pubic hair development results from increases in androgens (e.g., testosterone) and adrenal androgens. Girls' breast development results mainly from increases in estrogen. Boys' genital development results primarily from increases in testosterone (Ojeda, 2004). The five stages of puberty originally described by Tanner (Marshall & Tanner, 1969, 1970) consist of a sequence of physical changes in breast and pubic hair development in girls and genital and pubic hair development in boys.

The pulsatile sleep-dependent release of luteinizing hormone (LH) during slow-wave sleep leads to the release of sex steroids (Bordini & Rosenfield, 2011). Release of the sleep-related hormone, LH, begins to rise during the peripubertal period preceding the physical changes associated with puberty. Congruent with this temporal sequence, Sadeh et al. (2009) showed that circadian changes to sleep occurred prior to the physical changes of puberty. Still unknown is whether circadian changes to sleep are uniquely related to increases in the endocrine-hormone processes of one or more of these secondary sex characteristics.

Interindividual differences exist for the timing and tempo of puberty. Timing of puberty, whether early, on time, or later relative to peers differs among both boys and girls (Susman et al., 2010). Tempo of puberty—speed of progression from Tanner Stage 1 (prepubertal) to Tanner Stage 5 (full sexual maturity)—also exhibits considerable interindividual variability and sex differences among boys and girls (Marceau, Ram, Houts, Grimm, & Susman, 2011; Mendle, Harden, Brooks-Gunn, & Graber, 2010).

Even though very little research has investigated circadian changes to sleep and pubertal timing and tempo, the extent of variability in pubertal timing suggests the possibility that earlier maturing youth experience sleep changes sooner than on time or later developing youth. Similarly, faster pubertal tempo may result in these sleep changes occurring over a shorter period of time compared to youth with average or slower tempo. While the adverse effects of early pubertal timing and sleep changes may seem apparent, the effects of faster tempo may appear less clear. According to the maturation compression hypothesis (Mendle et al., 2010), a faster rate of pubertal progression requires more rapid adaptation to biological and social milestones relative to a slower rate. For this reason, faster tempo has been associated with poorer psychosocial outcomes during the pubertal transition. Individuals with faster tempo may experience the risks associated with circadian changes to sleep such as shortened sleep duration and phase delays over a compressed period of time compared to individuals with average or slower tempo. Failure to rapidly adapt to these sleep changes may lead to compromised daytime functioning.

Multiple teams of researchers have investigated individual differences in pubertal timing and tempo because deviations from average timing and tempo have generally been associated with psychosocial problems. Mendle et al. (2010) reported that, for girls, earlier pubertal timing was associated with more depressive symptoms. For boys, stronger effects were found for pubertal tempo and depressive symptoms than for pubertal timing and depressive symptoms. In a more recent study, Beltz and colleagues (Beltz, Corley, Bricker, Wadsworth, & Berenbaum, 2014) confirmed the relation only in girls between early and fast puberty and more internalizing problems in girls only.

The effects of timing and tempo extend to ethnic differences between pubertal development and depression in girls. Keenan and colleagues (Keenan, Culbert, Grimm, Hipwell, & Stepp, 2014) showed that Black girls mature earlier than White girls but Black girls exhibited a slower rate of pubertal progression. For all girls, earlier timing was associated with higher levels of depressive symptoms for breast, pubic hair, and overall pubertal development. Slower tempo was associated with higher depressive symptoms at age 10 and increasing depressive symptoms from ages 13 to 17.

Marceau et al. (2011) broadened the range of psychosocial dimensions and showed that individual differences in timing and tempo across secondary sex characteristics were associated with emotional and behavioral functioning. For girls, timing and tempo of both breast development and pubic hair development were uncorrelated suggesting independent endocrine processes underlying timing and tempo. Both earlier timing and faster tempo in girls were related to more internalizing behaviors. However, tempo of pubic hair development appeared more closely related than tempo of breast development to internalizing problems. Overall, for boys, timing and tempo for both genital and pubic hair development were inversely related suggesting a common endocrine mechanism. Boys tended to move through puberty more quickly when timing was earlier, and timing and tempo were less predictive of psychosocial functioning for boys compared to girls. Thus, underlying endocrine differences related to secondary sex characteristics for boys and girls coupled with discrete patterns of pubertal timing and tempo appeared to differentially influence psychosocial functioning during puberty.

Only one study, to our knowledge, has investigated relations between sleep-wake behaviors and pubertal timing and tempo. In a large sample of girls using a parallel-process growth model, Hoyt et al. (2018) studied racial and ethnic differences in Black, White,