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Consistency of Sleep Across Development and Relations to Executive Functions; Applications to Emerging Adults Transitioning to College and Adolescents with Spina Bifida

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CONSISTENCY OF SLEEP ACROSS DEVELOPMENT AND RELATIONS TO EXECUTIVE FUNCTIONS; APPLICATIONS TO EMERGING ADULTS TRANSITIONING TO COLLEGE AND ADOLESCENTS WITH SPINA BIFIDA

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ABSTRACT

Sleep is a fundamental human resource essential for adequate cognitive functioning. Emerging research as begun to consider the unique impact of sleep consistency on important outcomes, including cognitive functioning. This dissertation includes three related papers that aim to address how sleep consistency changes across development and how this may relate to executive functions, such as inhibition. The first study explores normative changes in sleep consistency across development, including individual and contextual factors that may influence sleep timing. A major take away from this paper was that the sleep regularity index (SRI) may be a developmentally appropriate measure of sleep consistency among adolescents and emerging adults since it incorporates napping patterns. The second study investigated relations between performance-based measures of inhibition and sleep consistency (i.e., SRI) among a sample of college females. This study also explored deviations in "typical" sleep the night before completing the inhibition tasks. A major finding was that getting more sleep than "typical" could support inhibition performance. The third study investigated relations between a multi-informant report of executive functioning and concurrent and longitudinal relations of youth with spina bifida. Findings suggested that less regular sleep (lower SRI) was related to more executive functioning problems concurrently (as reported by parents) and longitudinally (as reported by teachers). Collectively, these results suggest that inconsistent sleep routines may contribute to worsened executive functioning in daily life (e.g., home, school), however positive changes in

sleep patterns (e.g., getting more sleep than typical) could be immediately protective for aspects of executive functions (i.e., inhibition).

CHAPTER ONE

INTRODUCTION

Sleep is a fundamental human resource that is essential for health and well-being across the lifespan. In particular, adequate sleep is vital for brain development, such that poor sleep patterns (e.g., short sleep duration) may contribute to altered brain structures (Jalbrizikowski et al., 2021) and worsened cognitive functioning (Kronholm et al., 2009; Galván, 2020). Indeed, changes in sleep patterns have been thought to coincide with the maturation of brain structures and function (Iglowstein et al., 2003; Huber & Born, 2014; Jan et al., 2010; Dahl & Lewin, 2002) and sleep continues to affect brain development throughout adolescence (Fontanellaz-Castiglione et al., 2020). Although the extant research on sleep has typically focused on how *long* individuals sleep, the past several decades of research has begun to consider *consistency* of sleep duration and timing.

Studies suggest that inconsistent sleep is associated with reduced white matter integrity (Telzer et al., 2015) altered brain function (Hasler et al., 2012), and less connectivity within the default mode network (DMN; Lunsford-Avery et al., 2020) in adolescents and emerging adults. While studies indicate neural consequences, few studies have considered how sleep consistency is related to cognitive functioning. In particular, executive functions (EF) are a set of higher order cognitive skills including the ability to plan, organize, and prioritize in order to maintain daily tasks, solve problems, and achieve goals (Best & Miller, 2010; Gioia et al., 2001; Miyake et al., 2001; Zhou et al., 2012). Prior work has proposed that EF may be sensitive to changes in sleep that occur throughout development (Turnbull et al., 2013), however few studies have explored relations between sleep consistency and EF. Therefore, the present collection of works aims to consider how individual (e.g., biological, cognitive, social) and contextual factors, and the transactional interplay between these factors, shapes sleep consistency across development. In addition, the present works emphasizes adolescence and emerging adulthood as critical periods to investigate relations between sleep consistency and EF.

Individual factors (e.g., biological processes) and contextual factors may change across development and additively contribute to poor sleep patterns and routines. In terms of biological factors, the regulation of sleep is comprised of two biological processes, (1) homeostatic sleep process and the (2) circadian process, together comprising the Two-Process Model (Borbély, 1982). First, the homeostatic system is based on propensity to sleep, including the accumulation of sleep pressure (or desire to sleep) and the dissipation of sleep pressure (or desire to wake), both of which are largely influenced by the previous night of sleep. Second, the circadian process is an internal timing system and governed by the superchiasmatic nucleus (SCN) within the hypothalamus, regulated by biological processes (e.g., melatonin) that respond to the 24-hour light and dark cycles of the sun and therefore are thought to be consistent from day to day (Vitaterna et al., 2001). During puberty, adolescents experience a change across both systems, such that the accumulation of sleep pressure builds more slowly, while dissipation of sleep remains stable (Crowley et al., 2018). In other words, adolescents feel less tired at night and tend to go to bed later, however they continue to need the same amount of sleep at night. However, contextual factors (e.g., school) require youth to wake up early and therefore prevent youth from obtaining adequate sleep during the school week. As a result, adolescents may sleep in on weekends. This shift in sleep timing creates a disruption in sleep patterns across the week. Other individual factors (e.g., underdeveloped impulse control) combined with contextual factors (e.g., accessibility to portable devices at night) can increase exposure to light from devices which can be alerting and further delay bedtimes (Cajochen et al., 2011; Wood et al., 2013; van der Lely et al., 2015). This interaction between biological and contextual factors can alter sleep patterns throughout development and contribute to less sleep consistency. These developmental changes in individual and contextual factors and how they influence sleep are key factors that are emphasized throughout these works.

Sleep Consistency

A substantial body of research has investigated sleep consistency by capturing within-person fluctuations or changes in sleep duration and timing across days. Greater fluctuations or variability in day-to-day sleep has been thought to reflect circadian disruption (Bei et al., 2016; Becker et al., 2017). The terms 'sleep consistency' or 'consistency of sleep' are used specifically in these works to broadly describe regularity of sleep-wake patterns, including daytime and nighttime sleep. Varying metrics have been used to capture sleep consistency (described in detail below) and require that researchers take careful consideration of theoretical and data-specific properties (Fischer et al., 2021). First, Fischer et al. describe *overall metrics* which capture the amount of variability in sleep across days during a study period. Overall metrics within the extant literature include "sleep intra-individual variability," or sleep IIV, which reflects the day-to-day fluctuations in sleep duration or timing within an individual (see Becker et al., 2017). Another overall metric often used is social jetlag (SJ), which is the discrepancy between sleep patterns on days with school or work obligations (e.g., considered days with social obligations) and sleep patterns on “free” days without obligations (Wittmann et al., 2006). SJ captures weekly, rather than daily changes in sleep duration or timing. Both measures propose that higher IIV or SJ reflect less consistent sleep. Second, Fischer et al (2021) describe *consecutive metrics* that capture changes in sleep from one day to the next. One such metric is the sleep regularity index (SRI) which captures the likelihood of being asleep and awake across two sequential 24-hour periods (Phillips et al., 2017).

A central premise of the present works is that studies should consider a developmentally appropriate metric of sleep consistency that appropriately captures the range of sleep patterns that are common during a particular stage of development. Specifically, there are several advantages to using the consecutive SRI metric during adolescence and emerging adulthood. First, reports suggest that between 40 – 70% of adolescents and/or emerging adults reported engaging in daytime sleep (i.e., napping) at some point across a week (Thorleifsdottier et al., 2002; Nicholson et al., 2020). Because the SRI includes multiple parameters of sleep (e.g., bedtime, waketime, nap start time, nap end time) and creates an index score, it can capture both daytime and nighttime sleep. In comparison, overall metrics like sleep IIV and SJ can only include one aspect of sleep (e.g., sleep duration, midpoint of sleep) within the calculation and therefore makes them less apt to capture the complex sleep patterns that might be present among adolescents and emerging adults. In addition, college students may have alternating class schedules and therefore metrics that can capture changes in sleep from one day to the following day are valuable given these unique contextual factors. Finally, a metric that can account for consecutive changes may also best capture circadian disruptions (Fischer et al., 2021). Despite these benefits, a relatively small number of studies have investigated the SRI, let alone among adolescents and emerging adults, which marks a critical gap in the literature. Further, prior systematic reviews have noted that using a developmental lens for sleep consistency is an important next step of the literature (Becker et al., 2017).

Executive Functions (EF)

EF are a set of cognitive skills that involve conscious control and the ability to monitor automatic responses to engage in goal directed behavior (Best & Miller, 2010; Gioia et al., 2001; Miyake et al., 2001; Zhou et al., 2012). Three independent neurocognitive functions are typically subsumed under the construct EF due to their interrelated processes (Best & Miller, 2010; Miyake et al., 2001). First, updating of working memory (WM) involves mentally holding and manipulating information to direct behavior or accomplish goals. Second, inhibition involves suppressing automatic or prepotent responses to seek information or rewards. The third component of EF, shifting, involves the ability to flexibly shift between sets of rules, tasks, or mental states (Miyake et al., 2001; Best & Miller, 2010). Prior studies report that participants engaging in EF tasks also experience activation within specific regions of the brain (i.e., prefrontal cortex [PFC]) as well as interconnectivity across brain regions (Stuss & Alexander, 2000; Eslinger & Grattan, 1993; Morton, 2010; Zelazo & Muller, 2011). These regions and networks continue to develop into emerging adulthood (Galvan et al., 2006; Gogtay et al., 2004; Sowell et al., 2004; Dosenbach et al., 2011; Fair et al., 2009; Zelazo & Müller, 2011).

Theoretical models have proposed that EF may be closely related to the construct of self-regulation (SR) since both rely on similar components. SR components, such as self-control or inhibitory control, allow individuals to manage or change emotions, thoughts, or actions to achieve a goal or adapt to situations (Nigg, 2017). Although some components may be similar across EF and SR (i.e., inhibition vs inhibitory control), a review of the literature emphasizes that self-regulatory capacities are reinforced by EF. However, self-regulatory capacities do not necessarily underly EF (Nigg, 2017). For example, Nigg explains that solving a math problem requires the use of EF skills however it is not considered a self-regulating task. Although objective measures may be able to target specific components of EF and SR specifically, parent or self-report measures of daily EF (e.g., Behavior rating inventory of executive function [BRIEF]; Gioia et al., 2015) often include items and composites that are more related to SR (e.g., emotion regulation, behavioral regulation). Despite these differences, components of SR and EF are particularly important to investigate among adolescents and emerging adults. One study found that adolescents and emerging adults demonstrated poorer decision making, especially during emotionally salient contexts, as compared to children or adults (Cohen et al., 2016).

EF and Sleep

Although different components of SR and EF may be used across tasks, both SR and EF are similar in that they likely have limited energy reserves that are influenced by sleep. This idea is based on the self-regulatory strength model. Baumeister and colleagues propose that SR is a limited energy resource that requires replenishment in order to sustain self-regulatory processes (Baumeister & Vohs, 2016; Muraven & Baumeister, 2000; Vohs & Heatherton, 2000). Similarly, studies of EF suggest that sleep deprivation is associated with worsened EF performance, specifically on tasks of inhibition (Alhola & Polo-Kantola, 2007; Anderson & Platten, 2011; Drummond et al., 2006). It is likely that depletion of cognitive resources may coincide with sleep homeostasis, such that the longer an individual is awake the less cognitive resources are readily available. Barber et al. (2010a) extends this argument to propose that sleep may be a foundational resource of SR, noting that sufficient sleep *restores* SR capacities whereas consistent sleep *strengthens* SR capacities over time. This may be due to bidirectional processes, such that consistent sleep from night to night may support optimal circadian timing whereas maintaining a consistent sleep schedule may involve monitoring timing and suppressing the urge to alter sleep in response to external demands or desires.

The two biological sleep processes, circadian rhythms, and homeostatic sleep pressure, have additive and unique contributions to cognitive functioning. Wright et al (2012) demonstrate that components of EF (e.g., working memory) exhibit a circadian pattern such that performance is optimized during circadian periods of arousal and that performance declines in line with homeostatic sleep drive (e.g., when individuals stay awake past their habitual bedtime). This is further illustrated in a small study by Burke et al (2015) where they observe that higher-order cognitive performance varied with homeostatic sleep pressure, such that optimal performance was observed several hours after waking but progressively worsened the closer to bedtime (Burke et al., 2015). Notably, this study also found that inhibitory control performance exhibited a circadian variation, independent of homeostatic sleep pressure, across a 24-hour period (Burke et al., 2015). Taken together, inconsistent sleep may contribute to circadian misalignment and alter homeostatic sleep pressure, thereby impacting cognitive functioning.

In addition, sleep allows for restoration of optimal neuronal performance (Engle-Friedman, 2014). Indeed, brain imaging studies suggest that sleep inconsistency is related to altered brain functioning among adolescents and emerging adults (Hasler et al., 2012; Telzer et al., 2015; Lunsford-Avery et al., 2020). Specifically, greater SJ during early adolescence (11-13 years old) was associated with lower activation in the medial prefrontal cortex and striatum during a reward-based task, suggesting that greater shifts in sleep from weekdays to weekends (SJ) was related to altered neural responses in the context of rewards (Hasler et al., 2012). Given the cross-sectional nature of these findings, it may be that youth who experience altered neural responses seek out more stimulating (or rewarding) late-night activities which may be more accessible on weekends in the absence of school schedules. Another cross-sectional study by Lunsford-Avery et al. (2020) found that emerging adults who reported less consistent sleep patterns using the SRI evidenced less connectivity in the DMN. In a longitudinal study, greater sleep IIV over a two-week period in adolescents (14-15 years old) corresponded with altered white matter integrity 1.5 years later even after accounting for sleep duration (Telzer et al., 2015). Interestingly, concurrent associations between sleep IIV and white matter integrity were not observed (Telzer et al., 2015). The authors inferred that sleep consistency may alter brain development and they proposed that the white matter tracts implicated in this study were essential in managing impulsive actions and top-down cognitive processes, related to EF (Telzer et al., 2015; Jacobus et al., 2013). These studies present initial evidence that sleep consistency may be associated with altered neural function which may then impact cognitive function, with the potential for long term consequences.

Although the studies above suggest that sleep consistency is associated with brain activity and connectivity, few studies have investigated relations between sleep consistency and components of EF. One study of school-age youth found that children’s working memory was adversely impacted by nights that deviated either more or less from their average sleep across the week (Könen et al., 2015). However, few studies exist that have investigated these relations among adolescents and emerging adults. These are particularly important developmental periods to consider, since adolescence through emerging adulthood are marked by variable sleep-wake patterns and dramatic brain reorganization and maturation (Becker et al., 2017; De Lorme et al., 2013; Crone & Dahl, 2012; Nelson et al., 2016; Piekarski et al., 2017; van den Bos, 2013). Therefore, the present study sought to investigate relations between sleep consistency and EF within adolescent and emerging adulthood samples.

At-Risk Populations

This paper includes two studies that investigate links between EF and sleep consistency among two at-risk samples: emerging adults and adolescents. First, emerging adults continue to experience maturation of inhibition, making them vulnerable to resisting prominent urges. Emerging adults attending college may also face unique challenges such as learning to live independently, attending classes that alternate from day to day, and balancing academic and social demands. These factors may disrupt sleep and further tax their EF and SR capacities. Second, adolescence is a critical developmental period to investigate due to the major bioregulatory shifts in sleep that disrupt sleep patterns and likely create inconsistent sleep patterns. Further, adolescents with a congenital condition, spina bifida (SB), may be particularly at risk for poor sleep compared to typically developing (TD) adolescents (Murray et al., 2016, 2018). Preliminary work also suggests that individuals with SB have altered circadian timing compared to controls that may explain later sleep timing (Edelstein et al., 2012). In addition, adolescents with SB often experience neuropsychological deficits in the areas of attention and EF (Rose & Holmbeck, 2007) emphasizing the need for research that investigates relations between sleep consistency and cognitive functioning in this sample.

The Present Studies

By investigating relations between sleep consistency and EF during at-risk developmental periods, the current studies address key gaps in the literature. The present work begins by emphasizing the key individual (e.g., biological, cognitive, and social) and contextual (e.g., home, school, sociocultural) factors that may be present during distinct developmental periods that may contribute to sleep consistency. This narrative review, “A developmental perspective on sleep consistency: Preschool age through emerging adulthood,” is the first study in this collection of works. Next, two papers explored relations between sleep consistency and EF using already existing datasets. The second study, “Consistency of sleep and inhibition among female college students” uses two different metrics of sleep consistency to examine if inconsistent sleep is associated with performance-based measures of inhibition as measured in a lab. The third study “Sleep consistency among adolescents with spina bifida: Cross-sectional and longitudinal associations with cognitive function” investigates (a) if sleep consistency differs among SB or TD adolescents and (b) if sleep consistency is associated with multi-informant ratings of attention and EF among adolescents with SB. Across these studies, the collective aims of the present works are to consider: (1) factors throughout development that shape sleep consistency, and (2) relations between sleep consistency and EF among at-risk populations.

CHAPTER TWO

A DEVELOPMENTAL PERSPECTIVE ON SLEEP CONSISTENCY: PRESCHOOL AGE THROUGH EMERGING ADULTHOOD

Sleep is a restorative behavior that is essential for optimal physical and emotional development as well as daily functioning. Although sleep duration has been studied extensively, recent work has identified sleep consistency, or regularity in sleep timing and duration, as a critical marker of sleep health (Bei et al., 2016; Becker et al., 2017). Sleep consistency is characterized using different dimensions of sleep including regular nightly (e.g., bedtimes, wake times, sleep durations) and, we argue, daily (e.g., naps) sleep-wake patterns. Unlike average sleep duration, sleep consistency captures the regularity of sleep timing and/or duration from day to day or across the week. Similar to short sleep durations, less consistent sleep is associated with worsened physical, psychological, cognitive, and behavioral outcomes among children and adolescents (Becker et al., 2017; Henderson et al., 2019). Indeed, sleep inconsistency is a unique predictor of adverse outcomes above and beyond the amount of sleep (Becker et al., 2017). Notable researchers in this area have applied a biopsychosocial lens using a contextual model to describe contributors to insufficient sleep, particularly during adolescence (Becker et al., 2015; Carskadon, 2011; Crowley et al., 2018; Beebe, 2011). To date, however, little attention has been paid to normative factors that may contribute to the *consistency* or *inconsistency* of sleep throughout other periods of development.

Sleep is influenced by a complex interplay of individual and contextual influences. Borbély (1982) proposed that two bioregulatory systems regulate sleep timing and duration, including the (1) homeostatic sleep process (Process S) and (2) circadian process (Process C), together comprising the Two-Process Model of sleep regulation. The homeostatic sleep process is the accumulation and dissipation of sleep pressure an individual experiences with waking and sleep, whereas the circadian process, centered within the suprachiasmatic nucleus of the hypothalamus, regulates approximate 24-hour rhythms, including sleeping and waking behavior (Van Gelder, 2004). Prior work proposes that brain maturation influences the dynamics of these two processes across development, leading to the consolidation of naps (during early childhood) and the shift towards later sleep timing, particularly during adolescence (Carskadon, 2011; Crowley et al., 2018; Dionne et al., 2011; Iglowstein et al., 2003; Jenni & LeBourgeois, 2006; Kurth et al., 2016; Lam et al., 2011). Sleep patterns, such as bedtime, may shift later as youth gradually develop more autonomy over their discretionary time and make room for additional responsibilities (e.g., academic, extracurricular, or employment). Environmental factors such as neighborhood noise and streetlights as well as exposure to electronic devices can be alerting and further delay bedtimes (Cajochen et al., 2011; Wood et al., 2013; van der Lely et al., 2015; Hunter & Hayden, 2018). At the same time, youth continue to wake up early to attend school. Using an ecological lens, the current narrative review considers various individual factors (e.g., biological, cognitive, and social) and contextual influences (e.g., home, school, sociocultural) that collectively contribute to sleep consistency from preschool age through emerging adulthood to inform developmental processes and trajectories relevant to sleep consistency (Lerner, 2012; Bronfenbrenner, 1986).

The extant literature offers several mechanisms by which sleep consistency may contribute to adverse biological, psychological, and functional outcomes among youth (Becker et al., 2017). One theory posits that sleep irregularity increases an individual's risk of sleeping and waking at the "wrong" circadian time (one form of circadian misalignment), and therefore gives the circadian system and downstream or peripheral systems inconsistent daily inputs (e.g., light and dark, feeding and fasting). Circadian misalignment is associated with adverse changes in dietary intake (due to appetite regulating hormones), glucose metabolism, affect regulation, mood, and cognitive performance (Baron & Reid, 2014; Chellappa et al., 2018). Albeit a less popular mechanism, the "resource-replenishment enhancement" theory expands upon Muraven and Baumeister's (2000) theory, which suggests that self-regulation is a limited energy resource that requires replenishment in order for an individual to cope with stress, regulate mood, and resist temptations (Barber et al., 2010a). Barber et al. (2010a) proposes that sleep duration may replenish self-regulatory capacities whereas sleep consistency enhances these capacities. However, this theory has not been rigorously examined and requires more exploration as to how circadian rhythm disruption may play a role (Anderson, 2010; Wright, 2010; Barber, et al., 2010b). For example, Barber et al (2010b) posits that an individual with consistent, but insufficient sleep will be resource deficient, whereas an individual with sufficient but inconsistent sleep may still experience the adverse effects of circadian misalignment. Overall, these theories propose that the effects of inconsistent sleep may contribute to adverse physical and mental health outcomes, even above and beyond sleep duration.

Defining Sleep Consistency

Variability of sleep over time is captured in a variety of ways, including weekend oversleeping and bedtime delays (e.g., Wolfson et al., 2007). The most widely utilized indices to quantify sleep consistency are listed in Table 1. First, *social jetlag* (SJ) is defined by measuring the difference in the timing of nocturnal sleep that occurs on work or school days as compared to days with fewer social constraints that do not require an alarm clock to wake up (e.g., weekends or vacations; Wittmann et al., 2006). Second, *intra-individual variability* (IIV) is captured by measuring day-to-day changes in sleep timing or duration within an individual, and again usually focuses on nocturnal sleep episodes (Bei et al., 2016; Becker et al., 2017). Of note, day to day variability is also summarized across a specific study period using average standard deviation or analyzed using multilevel modeling to capture within-person changes in sleep across a specific study period. Third, the *sleep regularity index* (SRI) measures both day-to-day changes in nighttime and daytime sleep (e.g., napping) timing by calculating the degree to which sleep and awake periods occur at the same time across 24-hours (Phillips et al., 2017; Lunsford-Avery et al., 2018). In addition, we argue that *napping* is a major contributor to inconsistent sleep patterns among youth since it may delay bedtimes (described below) and therefore alter consistent sleep routines, with greater relevance during particular points of development (e.g., preschool age). The goal of this narrative review is to offer a guiding framework for understanding the relevance of and contributors to sleep consistency at various points in development. Articles were selected using search terms related to sleep consistency definitions (described above) using various search engines, including PubMed, EBSCO, and Google Scholar, and included studies conducted across the world over the past several decades. We review literature beginning in preschool when sleep patterns become relatively more entrenched, through emerging adulthood, and recognize that our framework offers a comprehensive, although not exhaustive approach, to delineating the factors that influence sleep consistency across development.

Table 1. Widely Utilized Metrics of Sleep Consistency

Sleep Consistency Construct	Description	Example Formula[a]	Article(s) to Reference
Social Jetlag (SJ)	The absolute value of the difference between an individual's sleep on "socially enforced" days (A), such as school or workdays and "free days" (B) such as when a person wakes spontaneously [b]	= |(sleep midpoint A) – (sleep midpoint B)|	(Wittmann et al., 2006)
Sleep Intraindividual Variability (IIV)	Day to day fluctuations in sleep duration or timing within an individual across days to weeks.	= ([within-person standard deviation of sleep outcome] / [average of sleep outcome]) * 100	(Bei et al., 2016; Becker et al., 2017)
Sleep Regularity Index (SRI)	Captures both sleep and awake periods epoch-by-epoch (or minute-by-minute) across an assessment period and then determines the likelihood that any two time points 24-hours apart were the same. Given the 24-hour nature, this includes both daytime and nighttime sleep. Formula used provides a number from 0-100, with higher scores reflecting more regular sleep.[c]	= (200 * [number of epochs that are the same 24-hours apart within the assessment period / number of epochs in the assessment period] – 100).	(Phillips et al., 2017; Lunsford-Avery et al., 2018)

a. Examples of formulas that can be used for each construct. Each construct may include several different formulas that capture different elements of sleep consistency and may use different aspects of a sleep outcome (e.g., duration, sleep midpoint, bedtime, wake time). Sleep IIV may be captured using a formula to summarize data across a time period or may be captured statistically using multilevel modeling with nested data.

b. Reported via questionnaire (i.e., Munich Chronotype Questionnaire [Roenneberg et al., 2003]), diary, and/or Actigraphy.

c. Reported via sleep diary or actigraphy.

Sleep Consistency Across Development

Preschool Age

Individual Factors

Defined as roughly 3-5 years of age, the preschool age marks a period when sleep patterns become relatively more stable compared to infancy but continue to mature and change. Biologically, young children exhibited a transition from biphasic to monophasic sleep between the ages of 3-5 years, with 91-94% of children eliminating regular naps by age 5 (Staton et al., 2019; Komada et al., 2011). This transition occurs earlier in some cultures (Thorleifsdottir et al., 2002). The transition from napping to consolidating sleep at night has been thought to align with maturational changes in sleep regulation (Akacem et al., 2015; Jenni & LeBourgeois, 2006; LeBourgeois et al., 2013) and the developing brain (Iglowstein et al., 2003; Lam et al., 2011; Dionne et al., 2011). Specifically, as children grow older, homeostatic sleep pressure accumulates at a slower rate across waking hours thereby eliminating the need for taking a nap during the daytime (Jenni & LeBourgeois, 2006). In addition, this age group exhibits “morningness” (as opposed to “eveningness”) preference in terms of circadian sleep phase tendency compared to later developmental groups (Randler et al., 2017); however, individual variability in chronotype occurs even at this young age (Simpkin et al., 2014). It is possible that morningness preference could be protective in maintaining a consistent sleep schedule, especially if children awaken without caregivers needing to disrupt natural wake up times.

Socially, young children require extensive supervision and support to adhere to consistent sleep schedules during preschool (e.g., napping, bedtimes, and wake times). However, difficulties with attachment (e.g., separation anxiety) or the emerging drive for autonomy has been shown to contribute to bedtime or naptime resistance or bed sharing (Jenni & Carskadon, 2012). Indeed, prior studies of sleep consistency report that sleep varies 44 minutes (bedtime IIV) to 62 minutes (sleep duration IIV) from day to day (Bates et al., 2002) and over 60 minutes (bedtime SJ) from weekdays to weekends among low-income preschoolers (Miller et al., 2014). In this age group, less consistent sleep across time is associated with worse emotional self-regulation and increased obesity risk (Anderson et al., 2017; Miller et al., 2014). In addition, concurrent associations exist between less consistent sleep and poor nighttime sleep parameters (Mindell et al., 2015), socioemotional problems (Yokomaku et al., 2008) aggression, inattention (Komada et al., 2011), behavioral regulation (Vaughn et al., 2015), poor school adjustment, and family stress (Bates et al., 2002). Of note, several of these studies assessed sleep consistency using questionnaires (e.g., number of days with an enforced bedtime routine) rather than using daily diary or actigraphy (Anderson et al., 2017; Mindell et al., 2015; Komada et al., 2011).

Contextual Factors

Ecological models of development suggest that the home environment is one of the most influential contexts for younger children (Bronfenbrenner, 1986). Caregivers are primarily responsible for creating and enforcing bedtime, wake time, and napping routines for their young children. Therefore, sleep routines may be influenced by the caregiver's daily schedule. For example, the later a parent leaves and returns home is related to more irregular bedtimes among Japanese children (Komada et al., 2011). Young children also influence their caregivers' sleep and functioning (Meltzer & Westin, 2011; Martin et al., 2007), highlighting reciprocal and transactional processes between children and their environments. In terms of bedtime routines, although 73-74% of parents report regular bedtimes five-days per week, only 45% of parents report a regular bedtime seven-days per week suggesting sleep routines fluctuate across the week among families (Schlieber & Han, 2018; Mindell et al., 2015). Families with fewer bedtime routines and more bedtime resistant behavior in young children also report higher levels of household chaos (Larsen & Jordan, 2019). Cultural practices or parental preferences may also influence sleep consistency; bed sharing with a parent is associated with a less regular bedtime (Hayes et al., 2001). Alternative caregivers of young children may also contribute to changes in sleep timing, thereby contributing to differences in sleep consistency. Namely, a longitudinal study conducted in China demonstrates that 68-79% of grandparents were involved in childcare, and when grandparents were the primary caregiver, they tended to have a higher incidence of co-sleeping and bedtime resistance from age 3 to age 6 (Li et al., 2021). It should be noted that socioeconomic factors likely impact caregiver employment and reliance on alternative caregivers. In addition, napping, sleep timing, and consistency may differ depending on racial identity. In the U.S., Black children take more frequent and longer naps, have shorter sleep durations on weeknights, have less consistent bedtime routines, and more SJ, than White children (Lavigne et al., 1999; Crosby et al., 2005; Smith et al., 2019). Crosby et al. (2005) indicate that children are more likely to nap if they are an only child or have younger mothers, but that race is a stronger predictor of napping than these factors. This finding highlights complex systemic factors that increase harm for Black youth and families that could impact sleep patterns (see Smith et al., 2019). One study proposes that the differences in sleep patterns between Black and White preschool children (e.g., delayed bedtimes, inconsistent bedtime routines) are mediated by parenting factors (e.g., confidence in managing sleep) as opposed to socioeconomic variables (Patrick et al., 2016). However, this study notes that a parent's rating of their confidence in managing sleep was higher among two-parent households which was more commonly reportedly among White families as compared to Black families (Patrick et al., 2016). Therefore, family SES, parent employment, reliance on alternative caregivers, and family structure may collectively influence parenting around sleep routines.

A large percentage of children (80%) enter early childhood education centers (ECEC; Thorpe et al., 2015), and it is likely that caregivers may need to shift their child's morning or bedtime routines on these days. A longitudinal study by Cairns and Harsh (2014) reports that 5-year-old children shifted to earlier sleep bedtimes and waketimes during the week when they attended preschool or childcare. Further, many ECEC offer regularly scheduled napping periods during school even though many preschoolers transition out of this napping phase. Researchers argue that enforced napping for nonhabitual nappers may affect nightly sleep durations and delay sleep timing (Staton et al., 2015). Therefore, a scheduled nap opportunity at ECEC for children who already phased out of napping may contribute to inconsistent sleep routines, including delayed bedtimes during the week or late and unplanned naps on the weekends (see Iwata et al., 2012). However, other studies report that habitual nappers benefit the most from napping in terms of memory consolidation and learning (Kurdziel et al., 2013). Reviews investigating napping and cognition are inconsistent which may be due to individual differences in brain maturity, cognitive development, and/or patterns of napping duration and frequency (Horváth & Plunkett, 2018). Therefore, nonhabitual nappers attending ECEC and having the opportunity to nap could negatively impact their sleep consistency.

School-Age Children

Individual Factors

The transition into school-age years is marked by sleep consolidation and sleep timing that conform to school schedules. School age youth demonstrate a slower buildup of homeostatic sleep pressure compared to preschoolers which may explain why youth stop napping (Jenni & LeBourgeois, 2006). Further, studies have shown that youth continue to exhibit individual differences in circadian sleep phase preference, with an overall developmental shift towards eveningness beginning at age 9 or 10 (Jenni & Carskadon, 2012; Ronnenberg et al., 2003; Randler et al., 2017; Werner et al., 2009). Variability in morningness/eveningness preference may be, in part, due to some school-age children beginning pubertal development, which has been demonstrated to alter bioregulatory systems and delay sleep timing (described in more detail in the "Adolescent" section). Prior work suggests that there are biological sex differences in the shift towards eveningness, such that females shift earlier than males, likely due to earlier pubertal timing (Randler et al., 2017). A developmental shift towards eveningness may contribute to later bedtimes, however school-age youth still need to wake up to attend school thereby shortening their sleep duration during the weekday. Studies demonstrate that youth delay their wake time on weekends to "catch up" for any lost sleep during the week (Wolfson et al., 2007; Crowley et al., 2018), thereby increasing their SJ. In one study, greater SJ was observed among females who were later in pubertal development, regardless of whether they were observed at 8.5 years or 11.5 years (Foley et al., 2018). Generally speaking, older age is associated with greater sleep IIV and SJ among children within 6-12 years of age (Buckhalt, et al., 2007; Stewart, 2014). Studies report that sleep timing fluctuates 45 minutes (bedtime) to 60 minutes (bedtime and wake time) from weekdays to weekends (Biggs et al., 2011; Blader et al., 1997).

Cognitive and social changes may also contribute to changes in sleep. Children are expected to stay awake throughout the school day to learn and to develop emerging self-care skills. While still needing parental guidance and care, school age youth may desire more autonomy and prefer to engage in alternative activities that interfere with sleep, such as watching television. Indeed, bedtime resistance is reportedly common among school age youth (27%) and associated with inconsistent bedtimes (Blader et al., 1997). Prior reports suggest that sleep duration varies 25 min (sleep duration IIV) among Danish youth (Kjeldsen et al., 2014) whereas sleep timing varies 60 minutes (wake time IIV) to 70 minutes (bedtime IIV) from day to day among Australian youth (Biggs et al., 2011). Longitudinal studies find that less consistent bedtimes (reported using a Likert scale) predict later problems with behavior, cognitive, and academic functioning (Kelly et al., 2013a; Kelly et al., 2013b). Cross-sectional studies find associations between lower sleep consistency and worsened sleep parameters, diet (Kjeldsen et al., 2014), obesity risk (Stoner et al., 2018), cognitive performance (Könen et al., 2015), hyperactivity (Biggs et al., 2011), and internalizing problems (Pesonen et al., 2010).

Contextual Factors

The home environment continues to be a primary context during middle childhood that affects sleep routines. Permissive family rules and less parental monitoring may allow youth to engage in other activities before bed, which may delay bedtimes and create inconsistent sleep schedules. Caregivers who report their child receives less regular sleep also report their children are more likely to have other unfavorable routines at home, such as skipping breakfast or watching more than three hours of TV (Kelly et al., 2013b). Spilsbury and colleagues (2017) demonstrate that sleep rules (e.g., parent-set bedtimes, restricting cell phone use at bedtime) benefit sleep in school-age youth, such that they are more likely to report “nothing” disturbed their sleep, whereas other family members’ nighttime activities (e.g., watching TV, talking on the phone) disrupts youth-reported sleep. This may explain why more crowded sleeping environments (e.g., greater person ratio in a bedroom) are associated with greater bedtime and waketime IIV (Buckhalt et al., 2007). In addition to the home environment, family relations may also influence sleep patterns. A two-year longitudinal study examining racial (Black vs White) and socioeconomic (high vs low) differences in sleep consistency reports that marital conflict predicts greater variation in bedtime IIV (and vice-a-versa) and these associations are stronger for Black families and low SES families (Kelly & El-Sheikh, 2011). Parents’ work schedules may also continue to disrupt sleep among school-age youth. Stewart (2014) compares bedtimes and wake times of children with employed and non-employed mothers and find that children of working mothers awoke about 15 minutes earlier during the school year and 45 minutes earlier in summertime as compared to children of non-working mothers. Kelly et al. (2013b) note that children with less regular bedtimes also tend to be from lower SES backgrounds, have caregivers with less education, and have mothers with higher rates of mental health problems. These findings demonstrate that parent-level factors, such as parenting style and employment, continue to exert influence on sleep consistency among school-age youth.

Sleep timing may also be influenced by attending school regularly during the weekdays. We hypothesize that school-age youth may experience more consistent sleep from day to day during the school week but vary their sleep more on the weekends or during school vacation. In a study of school-age youth, Stewart and colleagues (2014) find that average bedtimes are similar across weekdays, weekends, and summertime, whereas waketimes are delayed about 45 minutes on non-school days (i.e., weekends, summertime) as compared to school days. Similarly, a report by Crowley and colleagues (2006) compares sleep among school-age children (9-12 years old) to adolescents (13-16 years old) across summer and the schoolyear, with findings suggesting that school age youth experience a greater delay in bedtimes (64 minutes) in the summer months than the adolescents (32 minutes). Regarding daytime sleep, opportunities for napping are limited as sleep schedules adjust to academic schedules (6-7 hours per day, five days per week). As with preschool youth, racial or ethnic differences in napping continue to exist among school age youth as 40% of Black children in the U.S. continue to take naps till the age of eight years (Crosby et al., 2005). Sleep consistency may differ across cultures due to different school schedules or expectations. One study notes that sleep timing is earlier among Chinese school age youth compared to children in the U.S. due to earlier school start times and greater homework load (Liu et al., 2005), potentially leading to "catch-up" sleep on weekends or vacation days (and therefore increased SJ). Countries also differ in how much time off from school children have, with some countries offering several months off (e.g., U.S.) and others offering shorter vacation periods multiple times throughout the year (e.g., Australia), providing greater or fewer opportunities for inconsistent sleep when students transition to vacation periods.

Adolescence

Individual Factors

Adolescence is characterized by an increase in autonomy and focus towards extrafamilial activities and relationships (Steinberg & Silverberg, 1986; McElhaney et al., 2009). These new developmental tasks converge with biological, cognitive, and social changes that occur with the onset of puberty to create the “perfect storm” of short and irregular sleep timing (Carskadon, 2011; Crowley et al., 2018). As described earlier, a circadian shift towards eveningness and a slower accumulation of sleep pressure both delay sleep timing, particularly among adolescents. Along with normative changes in bioregulatory systems, structural and functional changes in the brain occur during puberty (Piekarski et al., 2017) and correspond to increased sensation seeking and reorientation of attention and motivation towards peers (Crone & Dahl, 2012; Nelson et al., 2016; De Lorme et al., 2013). This change in social orientation may contribute to adolescents communicating with peers in excess (in person or via electronic devices) which may delay sleep timing throughout the week. Changes in sleep are also seen across the week, as one study demonstrates that a majority (88%) of adolescents attempt to “catch up” on sleep over the weekends (Carskadon et al., 2006), thereby increasing SJ. Across studies, sleep duration and timing shifts 1.3 to 3.7 hours from weekdays to weekends (Crowley et al., 2007; Díaz-Morales & Escribano, 2015; Garmy & Ward, 2018; Malone et al., 2016). 44% of high school students report their bedtimes shift at least two hours later on weekends than on weekdays (Carskadon et al., 2006). In addition, studies demonstrate that many adolescents (41%) nap at some point across the week, likely to compensate for shortened weekday sleep (Malone et al., 2016). However, napping contributes to later bedtimes that night (Fuligni & Hardway, 2006). Therefore, we propose that napping likely contributes to day-to-day differences in sleep timing and duration in adolescents.

Across studies, sleep IIV fluctuates between 1.2 to more than 1.5 hours (He et al., 2015; Telzer et al., 2015; Malone et al., 2016). In a longitudinal study, Telzer et al. (2015) reports that greater sleep duration IIV is associated with white matter integrity one year later, but not concurrently among adolescents. Cross-sectional associations suggest that less consistent sleep is associated with worsened sleep parameters, poorer mental health (Fuligni & Hardway, 2006; McHale et al., 2011), altered brain function and connectivity (Hasler et al., 2012; Lunsford-Avery et al., 2020), poor diet and weight parameters (Feliciano et al., 2019; He et al., 2015a; He et al., 2015b; Malone et al., 2016), as well as physical health, risk-taking behavior, and family conflict (Sally et al., 2015). It should be noted that there are relatively more studies of sleep consistency during this developmental period than among preschool or school age youth.

Contextual Factors

Studies suggest that families continue to influence sleep routines among adolescents despite increases in self-directed activities. Despite fewer sleep rules with age (Short et al., 2011), parent-set rules around bedtime and daytime activities continue to be beneficial for adolescents and are associated with earlier bedtimes and longer sleep durations during the weekdays (Short et al., 2011; Adam et al., 2007). Parent rules and monitoring of adolescent activities are impacted by the family structure, such as number of parents in the home. For example, bedtime IIV is greater among adolescents within single-parent homes as compared to adolescents in two-parent homes and researchers hypothesize that single parents have fewer resources to frequently monitor and enforce sleep rules, particularly for teens (Troxel et al., 2014). Further, a recent study also observes that more household-related stressors (e.g., lower SES, higher caregiver stress) are associated with greater sleep duration IIV, but these influences have less of an effect on average sleep duration (Schmeer et al., 2019). Although adolescents may have fewer sleep rules imposed by parents, these studies show that the home environment may still exert influence over sleep patterns and consistency.

Similar to school-age children, school schedules and the academic calendar continue to influence sleep routines during adolescence. As discussed, the early start time of school is related to adolescents "catching up" on sleep over the weekends (Crowley et al., 2018). Day to day fluctuations in bedtimes may also result from changes in academic demands and school pressure. Specifically, a longitudinal study using multi-level modeling suggests that time spent studying for a test or quiz is associated with shorter sleep that night (Gillen-O'Neel et al., 2013). Further, these associations strengthen with age, as high schoolers moved from 9th to 12th grade, suggesting that bedtimes and sleep consistency may worsen throughout high school (Gillen-O'Neel et al., 2013). Sleep patterns change dramatically during non-school periods, as illustrated by studies that follow youth across the school and vacation periods. During vacation periods, high school students experience greater bedtime and wake time IIV showing a 67-175% increase when compared to during the schoolyear (Bei et al., 2014). In sum, transitions between school and non-school periods as well as variations in academic demands contribute to changing sleep schedules and lower sleep consistency.

The influence of non-academic activities on sleep is relevant across ages, but it is particularly important to consider during adolescence, when there is greater independence in engaging in preferred discretionary activities. This may include using electronic media (e.g., watching TV, using portable phones), participating in after school activities (e.g., sports), and securing employment. Reviews suggest that media use displaces sleep, delays bedtime, and increases physiological arousal before bed (Cain & Gradisar, 2010; Harbard et al., 2016).

Despite these consequences, nearly half of high school students in the US report using TV to assist them in falling asleep (Noland et al., 2009). Poorer sleep environment (e.g., TV in bedroom, light exposure) is associated with greater sleep duration IIV (Strofer-Isser et al., 2013). Further, social media usage before bed is a likely culprit for inconsistent sleep; one study of Swedish adolescents (15–17-year-old) observes that those who regularly text before bed have significantly greater SJ (50-minute delay in sleep timing on weekends) than those who state they texted less often (Garmy & Ward, 2018). Outside of media use, problematic peer activities (e.g., delinquency, substance use, risk-taking) during adolescence are also associated with greater SJ (Pasch et al., 2010; O'Brien & Mindell, 2005). It is also possible that positive activities, such as sports, may alter sleep consistency. For example, adolescents that are in sports that require high-demand facilities (e.g., pools, ice rinks) sometimes practice or hold events at early or late hours (Copenhaver & Diamond, 2017). In terms of employment, adolescents with long part-time hours (~16 hour/week) demonstrate delayed bedtimes, shorter sleep durations, and poor sleep habits when compared to those who worked fewer hours or no hours (Carskadon, 1989; Laberge et al., 2014). Although not explicitly investigated, later bedtimes and shorter sleep durations on workdays as compared to non-workdays could introduce more day-to-day variability in sleep across a week among adolescents who work. Taken together, discretionary activities are an important contextual consideration when examining sleep consistency during adolescence.

Emerging Adulthood

Individual Factors

Emerging adulthood is referred to as a time of major social change and a distinct developmental period due to major transitions (Arnett, 2000). These changes may involve moving out of the family home, attending college, and/or entering the work force to live relatively more independent and self-directed lifestyles. Biologically, emerging adults continue to show a circadian tendency towards eveningness (Randler et al., 2017). However, sex differences have been observed, such that females shift back to morningness sooner than males (Randler et al., 2017). Along with these biological shifts in sleep, emerging adults are in the final stages of neural development (Taber-Thomas & Perez-Edgar, 2015), refining executive functions and social cognition (Taylor et al., 2015). Underdeveloped executive functions and entry to new environments with novel academic and social demands may contribute to adopting irregular lifestyle behaviors, such as opting to stay up late studying or socializing. Although circadian preferences start to shift earlier during emerging adulthood, adolescents followed longitudinally from 16 to 20 years demonstrated that sleep duration IIV increases over time (Park et al., 2019). A study of first-year college students notes that students experience one-to-two-hour fluctuations in sleep duration and timing from day to day and from weekdays to weekends (Nicholson et al., 2020). Similarly, Veeramachaneni et al. (2019) observes that sleep duration IIV varies by 82 minutes from day to day using actigraphy-measured sleep. Similar to adolescents, a substantial number of college students (43-63%) report engaging in daytime napping at least once per week (Ye et al., 2015; Duggan et al., 2018). Both longitudinal and cross-sectional studies observe that sleep consistency is associated with adverse health outcomes, including higher weight parameters (Bailey et al., 2014; Nicholson et al., 2020; Roane et al., 2015), poorer psychological functioning (Doane et al., 2015; Bernert et al., 2017), and stress (Veeramachaneni et al., 2019). In addition, cross-sectional studies find associations between sleep consistency using the SRI metric and academic performance (Phillips et al., 2017).

Contextual Factors

Many emerging adults enter new environments, such as post-secondary education, that may require living independently for the first time. Reports suggest that a significant number of youth attend a 2- or 4-year college (67%) and/or move out of their family home (35-50%) following high school (NCES, 2018; Dey & Pierret, 2014). For those who attend college, class schedules may fluctuate from day to day which may affect sleep schedules. In line with this, one study reveals that students experience greater wake time IIV, but not bedtime IIV, when they transition from high school to college (Doane et al., 2015). In addition, residential status may also influence sleep consistency. Students living off-campus or at home may need to wake up earlier to commute to in-person college classes, possibly contributing to more irregular sleep timing and duration across a week. A study of emerging adults in Croatia demonstrates that many youth continue to live with their parents following high school and that these students experience earlier waketimes and bedtimes during the week, but experience greater SJ due to sleeping later on weekends (Bakotić et al., 2006). However, inconsistent sleep routines may exist even for emerging adults who do not attend college. For example, a recent study did not detect differences in sleep duration IIV when comparing college- and non-college samples (Park et al., 2019).

Either as an alternative or in addition to college, emerging adults may enter the work force after high school. Recent reports suggest that around half (45-60%) of college students are employed (USDL, 2019; Chiang et al., 2020). This may include jobs with typical business hours (i.e., Monday to Friday, 9 AM to 5 PM) or shift work. In fact, half of employed college students hold shift work positions, many of which are in service industry jobs (Chiang et al., 2020). Shift work contributes to irregular sleep and circadian disruption. As mentioned, studies identify that circadian disruption or living “against” the clock, as is the case in shift work, leads to various adverse health consequences (Kecklund & Axelsson, 2016). In addition to employment, some students may also have volunteer positions to gain additional experience or to bolster their resume. To accommodate these additional activities or work schedules, class schedules may shift to the evenings or early mornings and inadvertently change sleep timing and duration on some nights, but not others.

Trends of Sleep Consistency Across Age Groups

Large cross-sectional cohort studies that investigate sleep consistency observe different sleep patterns across developmental periods. In a large sample (n=4032) of Australian children aged 9-18 years old, sleep-wake patterns differ from weekdays to weekends, and this became more pronounced in older age groups (Olds et al., 2010). Indeed, one study finds that younger children (5-7 years) in Germany exhibit earlier sleep timing and lower levels of SJ as compared to older children (8-20 years; Randler et al., 2019). In a cohort study of Icelandic youth (n = 668; 1-20 years), weekend sleep durations are longer than weekday durations among older youth, evident at age 9, suggesting that SJ emerges during the school-age years (Thorleifsdottir et al., 2002). Across several cohort studies, SJ increases until the end of adolescence (17-19 years old; Randler et al., 2019; Whittmann et al., 2006). Although wake times are reportedly stable from ages 9 to 18 years, bedtimes progressively shift later on school days across studies (Randler et al., 2019; Thorleifsdottir et al., 2002; Olds et al., 2010). Regarding daytime sleep, Thorleifsdottir et al (2002) show that napping is prevalent in preschool age youth, rare (4%) among younger school-age children (7-9 years), and then is more common again during late adolescence and emerging adulthood. Specifically, 40% of 15–20-year-olds engage in weekday napping, and these nappers experience significantly shorter nighttime sleep when compared to non-nappers (Thorleifsdottier et al., 2002).

Few longitudinal studies capture trends of sleep patterns across developmental periods. Crowley and colleagues (2014) measured sleep behavior in two cohorts (starting at 9-10 years and 15-16 years) using actigraphy. Similar to the cohort studies above, findings indicate a delay in wake times (on weekends only) and bedtimes as well as an increase in SJ with age (Crowley et al., 2014). No studies have considered sleep timing or sleep duration IIV using a cohort or longitudinal study design to investigate changes across developmental periods.

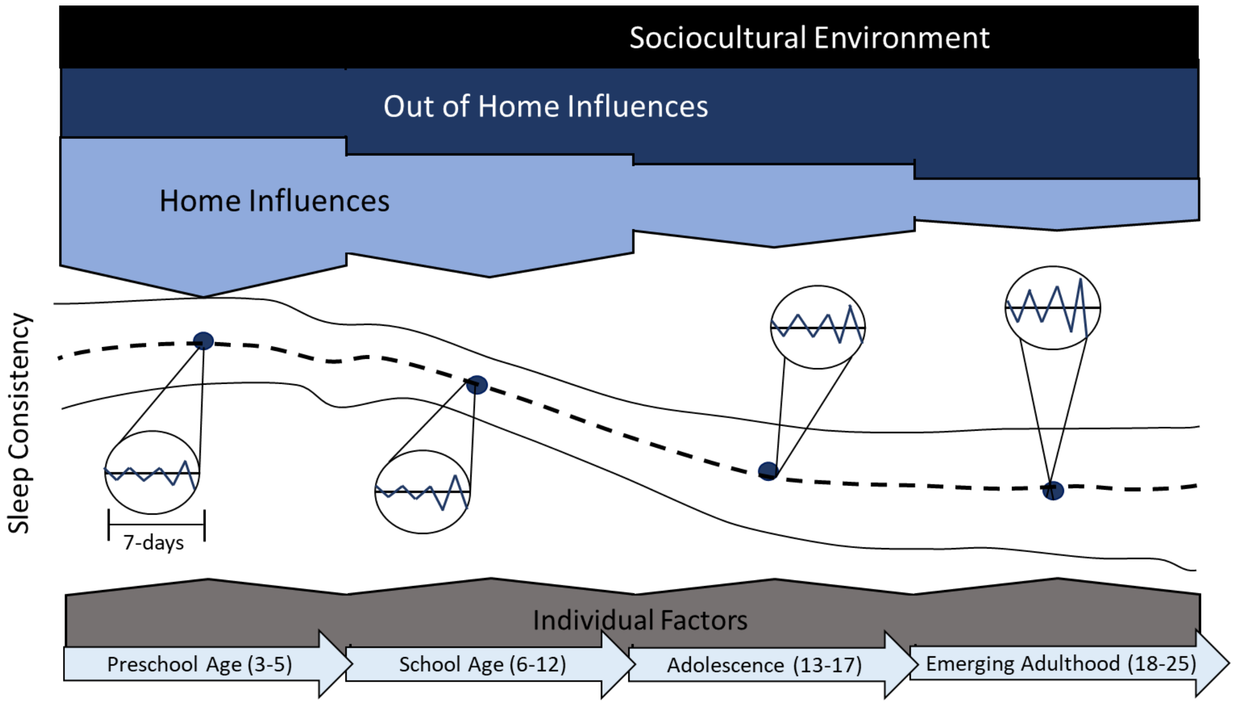
Considerations for Future Research

A central premise of this paper is the importance of applying a developmental perspective when examining sleep consistency, considering individual and contextual influences relevant to specific developmental periods (summarized in Table 2). This perspective may guide future study methods. A conceptual model (shown in Figure 1) articulates keyways in which a developmental perspective can be applied in future work. Based on the literature included in this narrative review, this model not only captures variability in sleep consistency throughout development, but also the factors that impinge on sleep/wake behavior and contribute more or less to sleep consistency at different developmental stages. In addition, there are numerous gaps in our collective understanding about sleep consistency across development, and in this final section, we propose recommendations for researchers to build on in their future work.

Table 2. Summary of Major Individual and Contextual Factors

Individual Factors	Home Influences	Out of Home Influences	Sociocultural Environment
Circadian phase	Caregiver demographics	ECEC/School/College	Cultural practices/norms
Sleep/wake homeostasis	Family structure (single parent)	School start times	Racial/ethnic identity
Brain development	Caregiver schedules	Academic demands	Socioeconomic status
Puberty	Household chaos	Sports/extracurriculars	
Biological sex	Parenting rules and monitoring	Risky peer behavior	
Dependence on caregiver(s)	Caregiver stress/mental health	Employment/shift work	
Developing independence/autonomy	Marital conflict	Post-secondary education	
	Sleeping environment	Residential status	
	Media/electronic usage at night		

The specific method for capturing sleep consistency should bear in mind the developmental period and respective sleep patterns that may be present. Relatively few studies exist on sleep consistency among infants and toddlers, likely due to challenges in capturing multiple sleep episodes (e.g., naps) over 24-hour periods. This marks a limitation of the current review and the need for future studies to explore how 24-hour metrics (e.g., SRI) could be used in studies of infants and young children. Researchers who aim to capture sleep consistency during preschool should go beyond evaluating bedtime routines by adding measures of sleep consistency (examples described in Table 1) to capture fluctuations in sleep duration and timing as well as nap duration and timing. In addition to exploring napping behaviors among preschoolers, studies should follow youth as they enter the school-age years to investigate how nap duration, frequency, and timing changes once youth enter school and how this change impacts sleep consistency across a school-week.



Note: Similar to Bronfenbrenner's ecological model (1986), this conceptual model aims to describe factors influencing sleep consistency and the levels of measurement to capture sleep consistency using a developmental perspective. The figure does not depict actual data, but rather illustrates the developmental trajectory of sleep consistency across four distinct developmental periods (see bottom arrows). Moving from the top of the figure to bottom, various factors influence sleep consistency to varying degrees, including sociocultural (e.g., SES), out of home influences (e.g., school, employment), home influences (e.g., parenting), and individual level factors (e.g., biological, cognitive, and social). We propose that these factors must be accounted for when studying sleep consistency across development. The dotted line represents an example of a single individual, with an overall decrease in sleep consistency (or increased in variability) observed over their development. The thin lines above and below the dotted line reflect hypothetical between-person differences among youth. Finally, four snapshots of sleep consistency are included to magnify how the sleep midpoint may change during a week-long period (starting on Monday and ending on Sunday during the school year). Within these dissections, the black horizontal line reflects an individual's "average" sleep midpoint whereas the blue jagged line represents the variability in sleep midpoint.

Figure 1. Conceptual model that illustrates how individual factors and contextual factors influence sleep consistency across development

Further, studies should investigate multiple parameters of sleep consistency, including timing (bedtime, wake time) and duration to provide clarity on whether variability in sleep duration or timing have differing impacts on study outcomes. This may be important for developing recommendations or policies to promote consistent sleep. For instance, school timing may exert greater influence on wake times, whereas family environment and social activities may contribute more to bedtimes.

Future studies should focus on aspects of the home environment, including the sleep environment (e.g., TV in bedroom), family or caregiver factors (e.g., employment status, family conflict, chaos) and caregiver-child level factors (e.g., sleep rules) that may influence consistent sleep duration and timing. This may be especially relevant for younger children who require additional childcare from adults (e.g., daycare, before-school care), but these factors still play an important role in supporting consistent sleep among adolescents.

Youth develop more autonomy over discretionary activities as they get older which may affect sleep routines. Investigators are encouraged to continue exploring within-person changes in sleep patterns in response to educational, employment, extracurricular demands as well as how youth spend their discretionary time (e.g., time with peers, social media use). In addition, there is a need to investigate between-person differences as some individuals may have lifestyle choices that lead to markedly less consistent sleep schedules (e.g., shiftwork, athletes, high achieving youth) than others. Lifestyle choices may include substance usage (e.g., alcohol, marijuana, caffeine), particularly among adolescents and emerging adults. Bidirectional associations exist between drinking alcohol and SJ (Haynie et al., 2018) and a systematic review demonstrates associations between caffeine usage and shorter sleep durations (Bonnar & Gradisar, 2015). More studies, however, are needed to understand the bidirectional associations between substance use and sleep consistency across development.

Additionally, studies should capture sleep consistency as youth transition into new contexts or shift between contexts that differ in amount of structure or routine. Academic breaks, vacations, or even self-isolation due to a global pandemic may impose less structure and alter sleep consistency. For example, Moreno et al. (2021) find that the midpoint of sleep was more variable during the summer months compared to the school year and highlight that greater variability in sleep timing is associated with excess weight gain. By definition, SJ differentiates "free" from "work/school" days, but it will be important to ask parents or youth whether their schedule is constrained or not instead of defaulting to weekends or vacation periods as "free" days. For example, factors such as employment, sports/extracurriculars, or even religious obligations may alter wake timing on non-school days.

Clinical problems may also impact sleep consistency. Indeed, behavioral insomnia is characterized by a difficulty falling asleep and/or early awakenings (American Psychiatric Association, 2013), and therefore could easily affect the consistency of sleep duration and timing. Studies should also consider other aspects of sleep health, such as sleep quality, arousals, disorders, chronotype, etc. and examine whether these factors are associated with sleep consistency. Similarly, studies should assess psychosocial functioning, including the presence of psychopathology (e.g., depression), that coincide with changes or disruptions in sleep. Indeed, Becker and colleagues propose that studies should account for mood symptoms, such as depression, as a covariate in analyses (Becker et al., 2017). Future studies may want to account for mood or observe the unique impact of mood on sleep consistency, or vice versa. This raises the question of directionality in existing research, as some clinical sleep problems or psychological concerns may contribute to inconsistent sleep patterns, whereas inconsistent sleep may increase risk for mood and behavioral problems.

Methodological approaches to capturing sleep consistency within studies are essential considerations for future work. Researchers should consider the appropriateness of commonly used indices or metrics of sleep consistency. A recent study by Fischer et al (2021) uses simulations to consider which metrics are more or less susceptible to factors like study length or sample size as well as considers a study's available sleep parameters (e.g., daytime and nighttime sleep). In addition, sophisticated methodological approaches and longitudinal designs may address limitations of previous studies. For example, multilevel modeling may allow researchers to explore within- and between-person differences in sleep consistency and explore associations with different risk factors or outcomes of interest. Further, long-term longitudinal studies are needed to understand the normative trends that occur throughout development, possibly using growth curve modeling. Interestingly, some studies do not find that sleep IIV at one developmental period predicts sleep IIV at a later period (Erath & El-Sheikh, 2015; Park et al., 2019). Therefore, more work is needed to explore how biological, cognitive, and social factors as well as transitions to new contexts (e.g., college) may influence sleep IIV within youth over time.

Researchers are encouraged to consider covariates, mediators, or moderators to develop a nuanced understanding of how sleep consistency is correlated with target outcomes. Accounting for sleep duration has been recommended to understand the unique contribution of sleep consistency, especially since lower sleep consistency has been associated with shorter sleep durations (Becker et al., 2017). In addition, experimental studies that can manipulate aspects of sleep, such as sleep duration, are needed to explore the unique effects of sleep consistency. For example, a study found that sleep consistency was associated with perceived difficulties awakening and daytime sleepiness, even after methodologically accounting for sleep duration (Van Dyk et al., 2019). Further, relatively few studies that capture sleep consistency consider sleep duration as a moderator (or vice versa) and this marks a critical area for future research. It may be the case that sleep consistency is more problematic when it occurs in the context of restricted sleep than in the context of excessive sleep (see Barber et al., 2010). Overall, more work is needed to parse apart the unique and combined effects of sleep duration and sleep consistency.

Consistent with using a developmental perspective, there is a need to further investigate the ecological systems and larger sociocultural context in which youth are embedded (Jenni & O'Connor, 2005). In particular, studies find that minority status and low SES confer risk for low sleep consistency (e.g., Marco et al., 2012; Buckhalt et al., 2007; El-Sheikh et al., 2013; Spilsbury et al., 2004; McHale et al., 2011; Moore et al., 2011), whereas others do not (El-Sheikh et al., 2013; Erath & El-Sheikh, 2015). Studies report that Black youth tend to experience greater levels of sleep variability (e.g., Spilsbury et al., 2004), as well as poorer bedtime routines and increases in napping when compared to White samples (Milan et al., 2007; Adam et al., 2007; Crosby et al., 2005; Spilsbury et al., 2004). One explanation may experience discrimination which is associated with day-to-day changes in sleep (Fuller-Rowell et al., 2017) Hale et al. (2009) observes that being White, educated, and higher SES is associated with greater adherence to bedtimes and bedtime routines. Families with higher SES evidence lower levels of chaos, more routines, and live in less distressed environments, factors that are associated with better sleep consistency (Bates et al., 2019; Philbrook et al., 2020; Moore et al., 2011). Even after accounting for SES, studies note that cultural differences in parenting practices or perceived confidence in adhering to sleep routines between Black parents and White parents may explain differences in sleep routines (Milan et al., 2007; Patrick et al., 2016). Further, cultural factors, such as the practice of co-sleeping, may be normative in certain demographic groups or in specific countries (Cortesi et al., 2004; Latz et al., 1999; Welles-Nystrom, 2005), but co-sleeping is also associated with more challenges adhering to a regular bedtime (Hayes et al., 2001). Further, napping among older children and emerging adults may be normative among certain cultures or racial/ethnic groups (Becker et al., 2015; Crosby et al., 2005), however these differences are largely tied to other sociocultural factors (see Smith et al., 2019). Although studies focus on risk factors, more work is needed to consider the protective factors (e.g., Conway et al., 2021) that may support better sleep routines in children across racial identities or cultural groups.

Academic calendars and schedules may differ across countries and differentially influence sleep timing. As one study by Košćec and colleagues (2013) in Croatia pointed out, youth attend school in the afternoon to accommodate work schedules or shift weekly between morning (8 AM-1 PM) and afternoon (2 PM-7 PM) schedules due to overcrowded classrooms. Findings from this study suggest that elementary and high school students experience more variable sleep schedules across morning and afternoon schooling, as students delay sleep timing in the context of afternoon school schedules as well as on weekends, particularly for those identified as evening types (Košćec et al., 2013). Societal expectations or events may also disrupt school schedules and therefore sleep patterns. COVID-19 is a pivotal example of a societal event that influenced academic, work, and extracurricular schedules. Work suggests that sleep schedules changed when restricted to at-home learning and working (Altena et al., 2020). Therefore, hybrid learning where students' transition in and out of the classroom may influence sleep routines among youth of all ages, though additional work in this area is still underway.

Overall, there is a need to explore racial, socioeconomic, cultural, and societal expectations and events as possible risk and protective factors for sleep consistency. These and other factors may help researchers understand normative and non-normative pathways and identify targets for intervention.

Conclusion

The present narrative review uses a developmental perspective to consider individual (e.g., biological, cognitive, social) and contextual (e.g., home, school, discretionary activities) influences of *sleep consistency*, a term used to describe various constructs within the literature that assess regularity of sleep duration, timing, and daytime sleep (e.g., sleep IIV, SJ, SRI). During preschool, sleep consistency is likely affected by the biological transition from napping to consolidating sleep as well as the role of the family environment and ECEC, though more research is needed to explore sleep consistency within this developmental period. School-age youth experience greater SJ as they align their sleep with school schedules and the family environment continues to protect or disrupt sleep patterns. During adolescence, changes in bioregulatory systems and reorganization of cognitive processes converge with school timing to increase risk for inconsistent sleep patterns. In addition, academic (e.g., homework) and discretionary (e.g., social media) activities serve to displace sleep and delay bedtimes during adolescence as well as into emerging adulthood. As youth transition into emerging adulthood, variability in educational, residential, employment, and housing makes this an ideal time to consider how various ecological factors may influence sleep patterns. Napping behaviors reemerge during adolescence and emerging adulthood and may further increase risk for inconsistent sleep. Overall, this narrative review of the literature suggests that bedtimes delay with age while schools continue to enforce early wake times and familial factors and discretionary time may combine to create irregular sleep routines with advancing age. This review demonstrates that more work is needed, using objective measures of sleep, longitudinal methods, and advanced statistical techniques to explore age-relevant factors that may disrupt sleep consistency and the implications of inconsistent sleep throughout development.

CHAPTER THREE

CONSISTENCY OF SLEEP AND INHIBITION AMONG FEMALE COLLEGE STUDENTS

In making the transition to college, emerging adults encounter a relatively less structured environment, with alternating class start times and increased social, academic, and employment responsibilities. Combined with learning to live a relatively more independent lifestyle, entry to this new environment may result in changes to health behaviors, such as eating and sleep routines. Although sleep durations may lengthen from high school to college, sleep-wake patterns become less consistent (Doane et al., 2015). Even after accounting for sleep duration, inconsistent sleep routines are associated with worsened dietary patterns, academics, and physical and mental health (Phillips et al., 2017; Becker et al., 2017; Bei et al., 2016; Kjeldsen et al., 2014; Lemola et al., 2013; Fuligni & Hardway, 2006). It may be that executive functions (EF), such as inhibition or the ability to resist prominent urges, underly these associations (Zhou et al., 2012; Diamond, 2006). Investigating the relation between EF and sleep patterns is particularly important to consider, as sleep and EF may impact and compromise the other across development (Turnbull et al., 2013; Williams et al., 2017). College is an ideal time to consider this question from a developmental perspective, as students are on the cusp of brain maturation and enter a sleep disrupting environment. However, few studies have explored sleep routines and EF during this developmental period and context. Drawing on a larger study examining the influence of food marketing on female college students, the present paper explores relations between sleep consistency and a prominent component of EF (i.e., inhibition) through the use of daily diary data and laboratory-based design.

Drawing on theoretical models, inhibition is a feature of EF that is also considered a hallmark feature of self-regulation (SR; Hofmann et al., 2012; Zhou et al., 2012; Roebers, 2017). Similar to inhibition, SR involves the ability to suppress urges or actions in service of a larger goal or task (Baumeister & Heatherton, 1996). Researchers have proposed that SR is a limited energy resource that requires replenishing to sustain self-regulatory processes, termed the self-regulatory strength model (Baumeister & Vohs, 2016; Muraven & Baumeister, 2000; Vohs & Heatherton, 2000). Health behaviors, such as sleep, may assist in replenishing self-regulatory capacities. In fact, Barber et al. (2010) proposed that SR is replenished by obtaining enough sleep at night and then further enhanced when sleep is consistent from night to night. SR continues to develop throughout adolescence and emerging adulthood and certain environmental factors (e.g., emotional stimuli, rewards) may be more challenging to resist during these developmental stages than during childhood or adulthood (Casey & Caudle, 2013; Casey et al., 2016). In a college environment, SR may be further taxed when students are required to self-direct their daily activities as well as balance their academic demands with new temptations. Therefore, a central premise of this study is that both sufficient and consistent sleep may contribute to SR. However few studies have investigated this among college students.

Emerging adults are in the final stages of cognitive development and do not have fully matured inhibition skills (Zhou et al., 2012; Diamond, 2006). In brain imaging studies, the lateral prefrontal cortex is often implicated during tasks related to inhibition and cognitive flexibility (Aron et al., 2003) and these regions are reported to be the last to fully mature structurally and functionally (Morton et al., 2009; Shaw et al., 2008; Sowell et al., 2001; Giedd et al., 1999; Huttenlocher & Dabholkar, 1997). Indeed, a study found that performance on inhibition tasks are significantly worse among emerging adults (<25 years) as compared to adults (Knežević & Marinković, 2017) and therefore suggest that this skill may not be fully matured. While there are developmental changes in inhibition, between person differences further explain why some individuals may be more likely to engage in risky behaviors, develop psychopathology, and have poor psychosocial adjustment (Harnishfeger & Bjorklund, 1994).

Along with changes in brain development, adolescence marks changes in bioregulatory systems that alter sleep patterns. Specifically, adolescents experience reduced buildup of homeostatic sleep pressure (less desire to sleep in the evening) and evidence a circadian phase delay (Crowley et al., 2018). These changes may lead to later bedtimes and wake times, as well as shorter sleep durations during the school week. As a result, adolescents tend to oversleep on the weekends and therefore sleep timing and duration become less consistent across the week. Sleep consistency worsens across development, due to various individual and contextual factors (Nicholson et al., 2022). Indeed, a longitudinal study from 10th grade to three years post-high school graduation observed that sleep became more variable and that sleep duration shortened with age (Park et al., 2019). Therefore, emerging adults are at greater risk for insufficient and less consistent sleep, both of which are associated with adverse consequences to psychological, physical, and cognitive functioning (Short et al., 2011; Becker et al., 2017; Bei et al., 2016).

Studies propose that sleep patterns and brain maturation are intrinsically related across development (Fontanellaz-Castiglione et al., 2020; Cirelli & Tononi, 2015). A study by Jalbrzikowski et al. (2021) utilized cross-sectional data to observe changes in sleep patterns and brain structures across a wide age range of participants (childhood through emerging adulthood). Findings of this study suggest that certain aspects of sleep, including sleep duration, later bedtimes, and greater WASO, were associated with a thinner cortex and differences in the volume of various subcortical structures (Jalbrzikowski et al., 2021). In addition, these authors observed differences by self-reported sex in these associations, with some findings suggesting larger or smaller volumes of subcortical structures in relation to sleep depending on sex (Jalbrzikowski et al., 2021). Although it is unlikely that sex differences are simply "hardwired" in the brain (see Jordan-Young & Rumiati, 2012), past studies have identified that males and females experience differences in brain development (Sowell et al., 2002; Koolschijn & Crone, 2013; Giedd et al., 1997) and in their sleep patterns (Santhi et al., 2016). Regarding sleep, prior studies report that females tend to have less consistent sleep than their male counterparts (Dillion et al., 2015; Knutson et al., 2007; Mezick et al., 2009; Nicholson et al., 2020; Tsai & Li, 2004) which may be related to higher stress among female college students which can impact sleep patterns (Lee et al., 2013). Therefore, sleep patterns may affect brain development and females may be at particular risk as they exhibit more variable sleep patterns.

In addition to changes in the brain, poor sleep behaviors may also reduce the ability to inhibit behavioral responses or impulses. Studies have found that restricting sleep in a laboratory-based setting adversely impacts performance-based measures of inhibition among college-age youth. Specifically, Drummond and colleagues (2006) restricted sleep for two nights among emerging adults and observed that these participants had greater difficulties in withholding inappropriate responses (e.g., increase in false positive rates) on a Go/No Go task across both nights of sleep loss with a return to baseline after one night of recovery sleep

(Drummond et al., 2006). Similarly, another study of emerging adults found that one night of sleep deprivation resulted in reduced response accuracy and more impulsive responding to negative stimuli on a Go/No Go inhibition task (Anderson & Platten, 2011). Another study used a Go/No Go inhibition task and compared differences in performance across two sleep conditions groups, one group that was sleep restricted for three days (five hours vs. eight hours of sleep) and the other group got 8 hours of sleep (Alhola & Polo-Kantola, 2007). Aligned with other studies, those in the partial sleep deprivation group showed reduced response accuracy, however, participants did not demonstrate impulsive responding (van Peer et al., 2019). These studies suggest that inhibition may be compromised in some way, even after one night of restricted sleep. Studies reported that college youth often experience restricted sleep (Lund et al., 2010) which may have inadvertent consequences on EF and their ability to successfully self-regulate.

Naturalistic studies of sleep speak to how inconsistent sleep may influence aspects of EF and SR. Könen and colleagues (2015) investigated school-age youth's performance on working memory, a component of EF, and observed that when a child's sleep deviated from their average sleep, by either substantially more or less, their performance was impaired. Another study explored response inhibition and delayed discounting (a component of SR) among college students. This study observed that inconsistent sleep was associated with a higher body mass index and that these associations were stronger among students with worse response inhibition performance and delayed discounting (Chan, 2017). Work by Kjeldsen et al. (2014) proposes that inconsistent sleep, even after accounting for sleep duration, was associated with greater consumption of sugar-sweetened beverages among children. Albeit limited, these studies offer preliminary evidence that inconsistent sleep relates to components of EF and SR. However, few of these studies accounted for sleep duration in their analyses, a factor that also relates to EF and SR.

Sleep patterns during college are markedly variable, requiring thoughtful consideration of how to capture sleep consistency in a developmentally appropriate way. A large body of work has measured sleep consistency using sleep IIV or the degree of variability in nightly sleep (for reviews, see Becker et al., 2017; Bei et al., 2016). Studies using standard metrics of sleep IIV (e.g., within person standard deviation) have found that college students vary their sleep duration and timing between 1-2 hours from day to day (Nicholson et al., 2020; Bailey et al., 2014; Chan, 2017). In addition to variable sleep, many college students (43-63%) also nap during the week (Ye et al., 2015; Duggan et al., 2018; Lovato et al., 2014). However, many traditional metrics of sleep consistency do not include multiple parameters of sleep, such as daytime and nighttime sleep, that are essential for capturing the complexity of sleep patterns among college students. Phillips and colleagues (2017) addressed this limitation by creating the 'Sleep Regularity Index' (SRI) to capture the degree of consistency across sleep-wake periods in both nighttime and daytime sleep across 24-hour periods. The SRI offers a value from 0 – 100 to estimate the likelihood that sleep-wake periods are the same 24-hours apart over a period of time (e.g., a week), with higher scores reflecting more consistent sleep (Phillips et al., 2017). This index allows researchers to capture multiple indices of sleep (i.e., bedtime, wake time, nap start time, nap end time). Further, Phillips et al. propose that the SRI is associated with delayed circadian timing and endogenous rhythms (e.g., melatonin). In addition, given that deviations in typical sleep could affect cognitive performance (Könen et al., 2015), the present study also sought to capture how a student’s sleep the night before coming into a lab may deviate from their “typical sleep.”

Drawing on a sample of female college students, the present study will consider sleep patterns, particularly sleep consistency, as it relates to performance-based measures of inhibition. This multi-method study uses both daily diary reports and a repeated measures lab-based procedure to assess inhibition (one task being food related and the other being non-food related). For the purposes of the present study, both the SRI and deviations from “typical” sleep are conceptualized as features of sleep consistency. It was hypothesized that individuals with lower SRI (suggesting less consistent sleep) will exhibit poorer performances on both the food and non-food related inhibition tasks, above and beyond their reported sleep duration. The second hypothesis was that individuals who report greater deviations in sleep duration the night before the experiment as compared to their “typical” sleep (suggesting less consistent sleep) will demonstrate worse performance on both inhibition tasks.

Method

Participants

Participants included undergraduate females enrolled in a psychology course as part of a larger study that aimed to understand the effects of television food commercials among individuals at risk for disordered eating. Study recruitment occurred in two phases. During Phase 1, 708 participants completed an initial screener and daily diary for up to seven days. In Phase 2, participants were invited to participate in a laboratory-based assessment over two visits, depending on whether they reported either high (>75th percentile) or low (<25th percentile) reports of disordered eating measured by the Eating Disorder Examination-Questionnaire (EDE-

Q; Fairburn & Beglin, 1994). Although males were recruited within Phase 1 of the study, they were not invited to Phase 2 due to the larger study's interest in eating disorders among women (Hudson et al., 2007). Of the 44 females who participated in the lab-based portion of the study, three participants did not complete at least four consecutive days of sleep daily dairies and two did not have complete inhibition data due to study equipment malfunction.

The final analytic sample of the present study included 39 females, ages 18-22 (*M* = 19.27, *SD* = .98). Participants identified as White/Caucasian (51%), Asian (33%), Multi-racial, (10%), Hispanic (15%), Black/African American (3%), and Other (3%). A majority of participants were first-year students (64%); the next largest groups were sophomores (23%), juniors (8%), and seniors (5%).

Procedure

In Phase 1 of the study, the initial screener asked about demographics, disordered eating, psychological symptoms and then daily diary measures on mood, sleep, and other health behaviors. If participants completed the screener, they were invited to complete the daily diary measure for up to seven days. Participants were emailed the screener/daily diary at 8:00 PM, starting on Monday and then were sent reminder emails at 11:00 PM each night if responses were incomplete. Participation in the present study occurred in waves over two academic years (fall 2017 through spring 2019) and during weeks that did not overlap with academic breaks (e.g., fall break, holidays) or academically rigorous periods (i.e., finals week).

Phase 2 of the study involved two visits to the laboratory at the university. Visits were scheduled at least one week apart (*M*=11 days, *SD*=6 days) and during discrete times (i.e., 10am-1pm, 1-5pm). Since the experiment included food-based measures, participants were instructed to eat breakfast or lunch prior to arrival. In addition, a single item of hunger was discretely embedded within a mood survey presented at the start of the experiment. If participants endorsed high levels of hunger, they were offered a granola bar. Participants were randomized at the first visit to either engage in the unhealthy food advertisement condition (e.g., candy, fast food) or the control advertisements unrelated to food (e.g., feminine hygiene products, cars). Participants completed the other condition during their second visit. Following exposure to the commercials, participants were asked to write a response about the persuasive tactics used within the commercials. Next, participants were set up for EEG and completed several performance-based tasks of inhibition, including a neuropsychological assessment and a computer-based task. This study pre-registered the aims, hypotheses, and analytic procedure (https://osf.io/64wyg/).

Measures

Demographics

Demographic variables, including age, gender, and race/ethnicity were assessed during the daily dairy data collection.

Inhibition

Two tasks were utilized to assess inhibition. First, the Color-Word Interference Task (CWIT), a subtest from The Delis-Kaplan Executive Function System (D-KEFS; Delis et al., 2001) was used to assess inhibition. This subtest is a Stroop- task and asks participants to read a printed word and instead name the color print of the word, thereby suppressing an automatic desire to read the word in order to complete the task requirements. Two scores were used to capture inhibition, (1) time to complete the inhibition trial and (2) number of errors made during the inhibition trial (Delis et al., 2004).

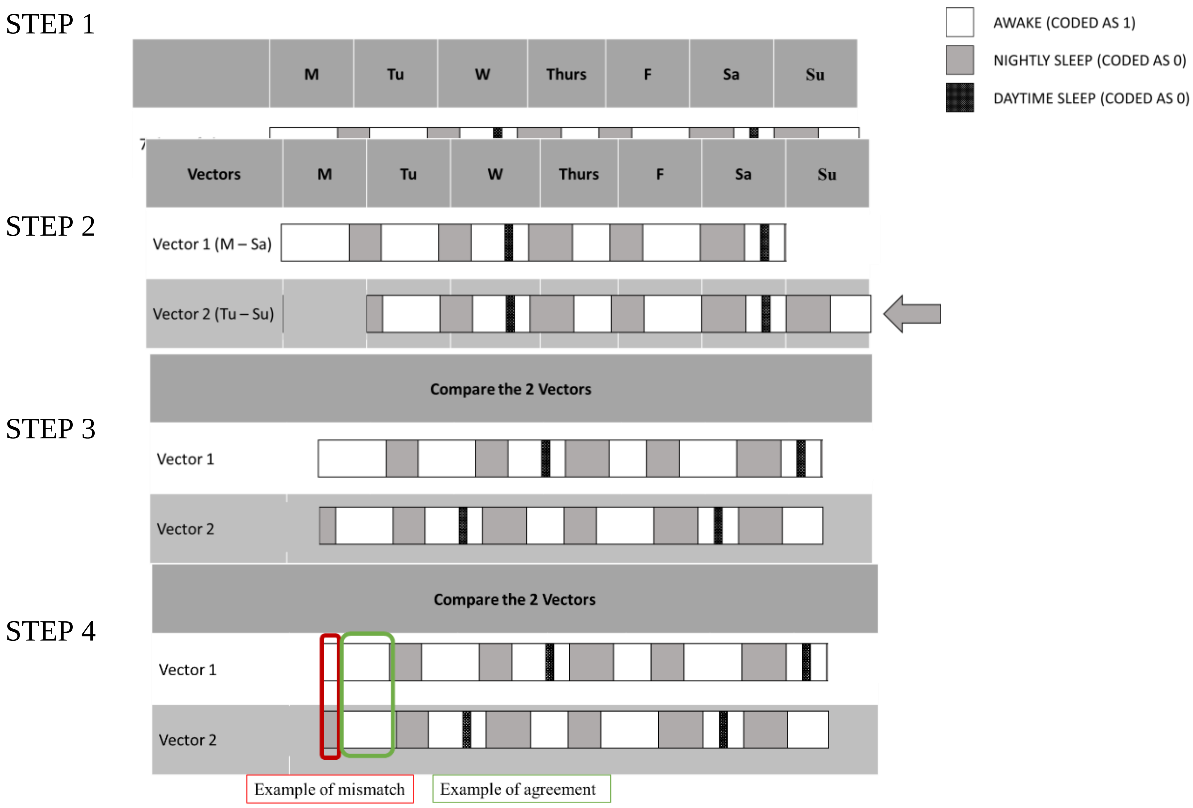
A second inhibition task consisted of a computer-based Go/No Go stop-signal task (SST) that used E-Prime 2.0. In line with the aims of the larger study, images of healthy (*n* = 52) and unhealthy foods (*n* = 52) were taken from an open-sourced database (Blechert et al., 2014) and were prescreened to match based on valence and arousal (see appendix in Egbert et al., 2020). Participants were instructed to quickly decide if foods were either healthy or unhealthy by pressing two button response options (*go trial*), but participants were simultaneously asked to withhold their response if the image was surrounded by a black and white striped box (*stop trials*). In both trials, images were displayed for 1 second and responses needed to occur within that time frame. In *stop trials*, the stop signal box was displayed 100ms following the food stimulus. Using recommended protocols, timing of the food image and presence of the stop signal box were adjusted (200-500ms) based on prior performance to ensure sufficient difficulty across participants (Sagaspe et al., 2011). Healthy and unhealthy foods, as well as the *go trials* and *stop trials* were randomized during each testing administration. Trained experimenters (including LN and AE) administered instructions to participants and offered two practice trials to familiarize participants with the task (20 images for each trial) and to support understanding of the task. During the recorded test administration, participants completed 720 trials, divided into 12 blocks with 20 second breaks between blocks. From this task, inhibition was captured using scores from *stop trails*, including both the stop-signal accuracy (SSA) and the stop-signal delay (SSD). SSA is the proportion of correct responses during stop-signal trials and two variables were created for healthy and unhealthy food stimuli. Higher scores reflect better accuracy in responding. SSD is the amount of time between when the stimulus and stop signal were presented. As individuals successfully progress through the task, the latency of the stop signal box lengthens during the presentation of the food stimulus to maintain difficulty level. Therefore, individuals with longer average SSD have better inhibition than individuals who have shorter average SSD.

Sleep Consistency

Participants' sleep consistency was captured using two indices (1) the sleep regularity index (SRI) and (2) deviation from "typical" sleep prior to the lab-based paradigm.

SRI. This variable captures the regularity of being asleep and awake across 24-hour periods with higher scores (0-100) representing more consistent sleep (Phillips et al., 2017). The present study utilized self-report daily diary data, including bedtime, wake time, nap time, nap duration to determine sleep-wake periods. These times were converted to minute-by-minute epoch data and used the same formula to calculate the SRI, as done in previous works (Phillips et al., 2017). Figure 2 depicts a visual demonstration of how the SRI was calculated using seven days of daily diary.

Deviation from "Typical" Sleep. During Phase 2, at both visits to the laboratory, participants were asked to recall their sleep duration the previous night as well as how long their sleep duration is "typically" or on average. A difference score was created to capture deviation from "typical" sleep by subtracting the difference between these two variables. For example, if a participant reported getting six hours of sleep the night before the experiment, but report they get 8 hours of sleep typically, then their deviation from "typical" sleep was -2 hours. If this participant instead reported getting 10 hours of sleep, but typically get 8 hours, then their deviation from "typical sleep was +2.



STEP 5 SRI = 200* (agreement / cases) - 100

Note. The figure shows a visual schematic to depict how SRI was calculated. The key presented at the top right denotes awake periods (white) and asleep periods (grey, dark grey). In this visual example, seven days of data would produce a six-day vector reflecting 8,640 minutes (1440 minutes per day times 6 days). In step 1, two vectors are created, vector 1 being Monday through Saturday and vector 2 being Tuesday through Sunday. Step 2 demonstrates that two vectors are created and then step 3 shows how these two vectors are aligned to compare awake and asleep periods across 24-hours. In step 4, asleep and awake periods are compared minute-by-minute, 24-hours apart. If an individual is awake or asleep at the same minute, 24-hours apart, then this minute reflects an "agreement." If an individual is awake and then asleep 24-hours later, then this minute reflects a "mismatch." The number of cases reflects the length of the vector in minutes (or the sum of minutes in agreement and mismatched).

Figure 2. Calculating the Sleep Regularity Index (SRI)

Data Analytic Plan

Psychometric properties of all study variables were examined for normality. Reliability of the inhibition measures across visits to the lab were investigated within the present sample. Paired samples correlations demonstrated that D-KEFS Inhibition completion time (r = .716) SSA healthy (r = .942), SSA unhealthy (r = .936), and SSD (r = .678) were highly correlated across time points, however K-KEFS Inhibition total errors was not (r = .038). Descriptive analyses and correlations were run to describe study variables and their relations. Five repeated measures analysis of covariance were used to assess the main effects of the SRI on the four inhibition scores, including (1) D-KEFS Inhibition completion time, (2) D-KEFS Inhibition total errors, (3) SSA, and (4) SSD. The inhibition variables in the food and nonfood conditions were added as the within-subject factor. The SRI variable was added as a between-subject factor and therefore was dichotomized since ANOVAs require categorical predictors. The EDE-Q global score was used as a covariate since scoring either high or low was a criterion for recruitment to the second phase of the study. In addition to the EDE-Q global score, the time between Phase 1 (daily diary) and Phase 2 (lab visits) recruitment was used as a covariate as the delay between visits varied across participants (*M*= 65days; *SD*= 88 days). Finally, average sleep duration (measured by the daily diary) was added as a covariate since it was highly correlated with the SRI (rs = .61, p < .01).

Next, five multiple linear regressions were performed to investigate relations between deviation from “typical” sleep and inhibition scores (i.e., D-KEFS Inhibition completion time, D-KEFS Inhibition total errors, SSA, and SSD). Only variables collected at the first visit were used in analyses. Therefore, study condition (e.g., food or non-food) at the first visit was included as covariates on step 1 along with EDE-Q global score. In addition, high correlations were observed for sleep duration last night and deviation in "typical" sleep (*rs* = .58, p < .01), thus, sleep duration last night was included as covariate given its proximity in time to the experimental visit and it was added on the step 2. The predictor, deviation from "typical" sleep, was added to step 3.

Power analyses suggested that a sample of 39, power of .80, and an alpha of .05 yielded enough power to detect large effects (F^2 = .46) within a repeated measures ANOVA with 2 groups and 3 covariates (Faul et al., 2007). Using the same sample and parameters, regression analyses were powered to detect a medium to large effect size with 3 predictors (f^2 = .33) (Faul et al., 2007).

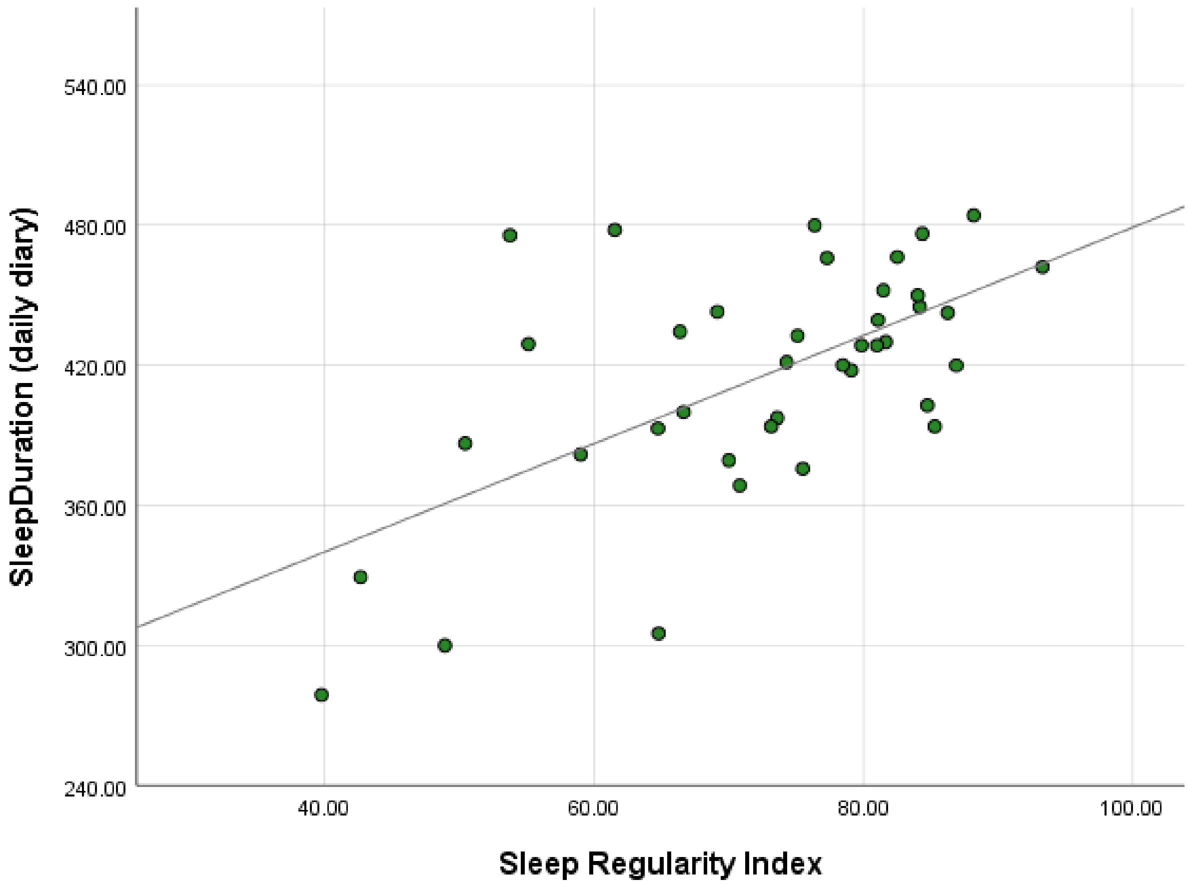
Results

Basic descriptive data on key study variables are reported in Table 3. Regarding sleep collected through daily diary, participants in the study reported getting 6.93 hours (six hours and 56 minutes) of sleep on average across the week. The D-KEFS inhibition completion time was, on average, 40-43 minutes across times points (scaled score = 12; Average range for age). There were no significant differences on the basis of race/ethnicity among key study variables. In comparison, age was significantly associated with SSA of healthy images across food and nonfood conditions (*rs*= -.38, p=.018), such that older participants were less accurate in appropriately selecting healthy images. As shown in Figure 3, longer sleep duration (measured via daily diary) was associated with more regular sleep as captured via the SRI.

Table 3. Descriptive Information on Key Study Variables

	M	*SD*
Sleep Variables		
Sleep Regularity Index (Daily Diary)	72.62	13.14
Sleep Duration in hours (Daily Dairy)	6.93	0.35
Sleep Duration Last Night (T1)	7.05	1.13
Typical Sleep Duration in hours (T1)	6.42	1.12
Deviation from Typical Sleep (T1)	0.63	1.29
D-KEFS		
Food Condition		
Inhibition Trial Raw Time (Food)	43.10	6.18
Errors	1.00	1.38
Non-Food Condition		
Inhibition Trial Raw Time (Non-food)	40.46	6.47
Errors	1.31	1.51
First Visit (T1)		
Inhibition Trial Raw Time (T1)	40.31	7.29
Errors	1.36	1.65
Stop Signal Task		
Food Condition		
Stop-signal accuracy: Healthy	0.84	0.12
Stop-signal accuracy: Unhealthy	0.83	0.13
Stop-signal delay	489.79	22.36
Non-Food Condition		
Stop-signal accuracy: Healthy	0.83	0.12
Stop-signal accuracy: Unhealthy	0.84	0.11
Stop-signal delay	490.40	14.26
First Visit (T1)		
Stop-signal accuracy: Healthy	0.83	0.11
Stop-signal accuracy: Unhealthy	0.84	0.11
Stop-signal delay	488.00	21.97

Note: The sleep duration variable is calculated in minutes but was converted to hours to maintain consistency across reporting sleep duration.



Note: Higher SRI scores reflect more consistent sleep.

Figure 3. Relations between sleep duration and the SRI

Regarding variables captured during the first visit to the lab, participants estimated that they “typically” get 6.42 (six hours and 25 minutes) of sleep. On average participants reported getting 7.05 hours (seven hours and three minutes) of sleep the night before the experiment. Therefore, participants reported getting longer sleep the night before the experiment (.63 hours or roughly 38 minutes) than they “typically” do. As shown in Figure 4, relations between sleep duration the night before the experiment and deviations from “typical” sleep suggested a positive linear relationship, such that more sleep the night before the experiment was associated with a greater positive discrepancy (e.g., participants reported getting more sleep than “typical”) whereas less sleep the night before was associated with a greater negative discrepancy (e.g., participants reported getting less sleep than “typical”). This suggested that getting less sleep the night before tended to be related to a negative discrepancy score whereas getting more sleep the night before tended to be related to a positive discrepancy score.

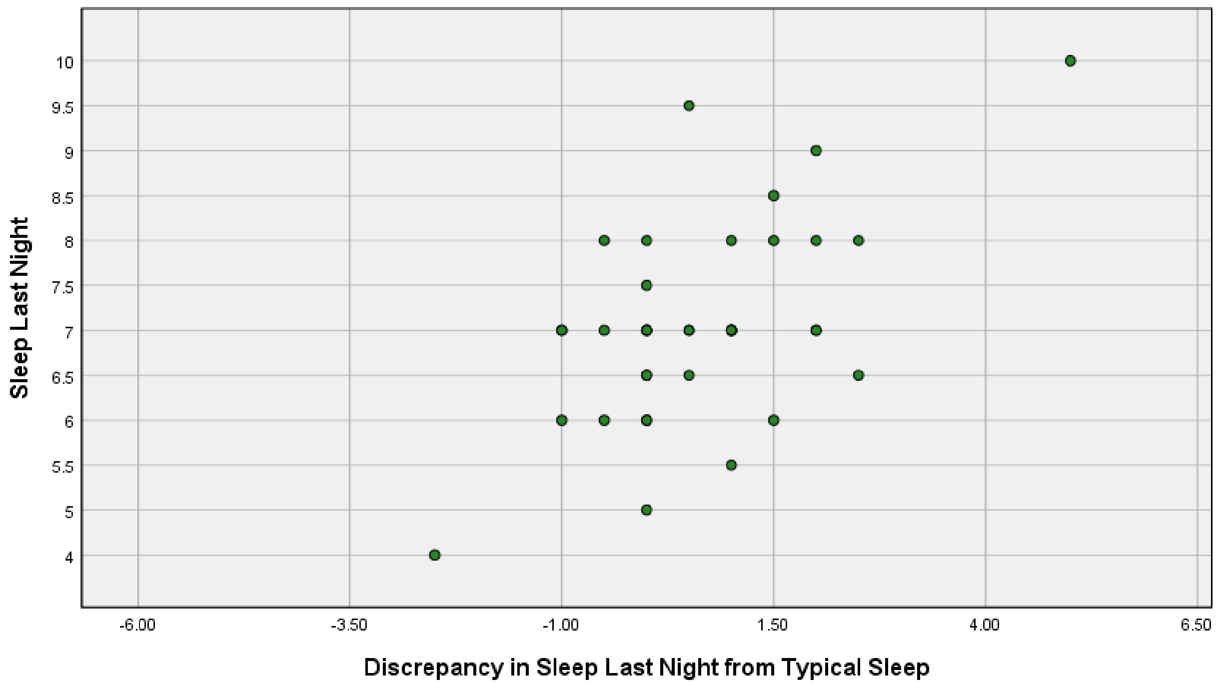


Figure 4. Relations between sleep last night and discrepancy in sleep

Table 4. Basic Correlations among the Sleep Variables Related to the SRI

Variable	1	2	3	4	5	6	7	8	9	10	11	12
1. EDE-Q	-											
2. Sleep Duration	-.07	-										
3. SRI	-.24	.61**	-									
4. F-DK IN raw time	-.39*	-.00	.16	-								
5. F-DK_IN errors	-.29	-.03	-.06	.28	-							
6. NF-DK IN raw time	-.28	-.29	.00	.44*	.27	-						
7. NF-DK IN errors	-.03	.04	-.04	-.29	.03	.24	-					
8. F-SST SSA Healthy	-.03	-.03	-.20	-.11	-.01	-.18	.11	-				
9. F-SST SSA Unhealthy	.03	-.09	-.19	-.16	-.04	-.23	.10	.93**	-			
10. NF-SST SSA Healthy	-.03	-.01	-.19	-.03	-.14	-.17	.09	.88**	.82**	-		
11. NF-SST SSA Unhealthy	-.08	-.11	-.25	-.04	-.09	-.23	-.02	.80**	.84**	.90**	-	
12. F-SSD	-.03	-.21	-.26	-.07	-.12	.05	.12	.77**	.75**	.74**	.66**	-
13. NF-SSD	.10	-.17	-.23	-.12	-.20	-.28	.04	.64**	.72**	.73**	.83**	.67**

Table 5. Basic Correlations among Sleep Variables and the SST

	1	2	3	4	5	6	7	8
1. EDE-Q	-							
2. T1-Typical Sleep Duration	-.15	-						
3. T1-Sleep Duration Last Night	-.13	.35*	-					
4. T1-Discrepancy in Sleep	.02	-.56**	.58**	-				
5. T1-DK IN raw time	-.44**	.18	-.01	-.17	-			
6. T1-DK IN errors	-.11	.20	.14	-.05	.11	-		
7. T1-SST SSA Healthy	.12	-.32*	.15	.41**	-.18	-.02	-	
8. T1-SST SSA Unhealthy	.01	-.36*	.14	.44**	-.18	-.07	.92**	-
9. T1-SSD	.14	-.30	.07	.32*	-.14	-.11	.77**	.79**

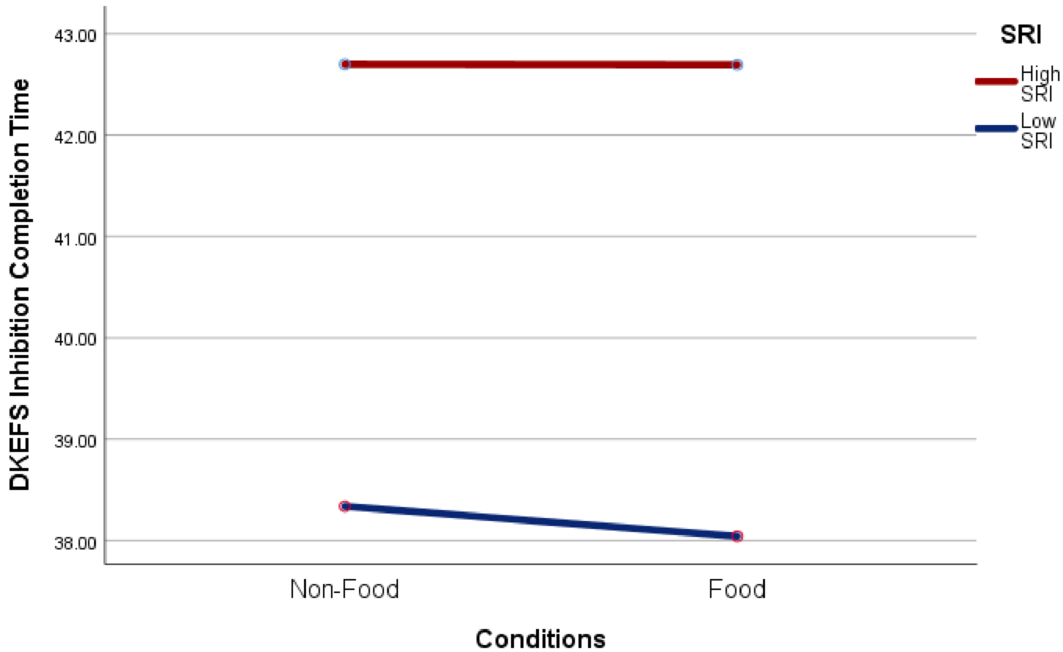
Note: Higher values for "discrepancy in sleep" suggests that individuals reported getting more sleep than they "typically" get.

Associations between the SRI and Measures of Inhibition

Repeated measures ANCOVA were performed to assess the main effects of the SRI (between-person effects) across within-subject measures of inhibition (food and nonfood conditions) while controlling for (1) EDE-Q, (2) time between Phase 1 and Phase 2 visits, and (3) average sleep duration.

D-KEFS

Regarding inhibition completion time, results suggested that there were no within-subject effects of condition (food vs nonfood) on inhibition completion time, but there were significant between-subject effects of the SRI, such that those with lower SRI (e.g., less sleep regularity) had faster inhibition completion times than those with higher SRI (e.g., more sleep regularity) (F[1, 37]=5.33, $p < .05$; see Figure 5). There were no within subject effects of condition or between-subject effects of the SRI on D-KEFS inhibition errors ($p > .05$).



Note: D-KEFS inhibition completion time is measured in seconds. The SRI cut point is the median, with high SRI being above 75 and low SRI being $\leq$ 75.

Figure 5. Relation between D-KEFS inhibition completion time across study conditions with SRI as a between-subject factor

SST

For SST SSA of healthy food images, there were no significant within-subject effects of the conditions or between-subject effects of the SRI. Similarly, no significant within- or between-subject effects were observed for the SST SSD. In contrast, there was a between-subject effect of the SRI on SST SSA of unhealthy food images, such that lower SRI (e.g., less regular sleep) was associated with better accuracy in stopping oneself from making a selection when looking at unhealthy food images ($F[1, 37] = 4.25$, $p < .05$; see Figure 6). Thus, individuals who had less regular sleep demonstrated better inhibition in the context of unhealthy food images.

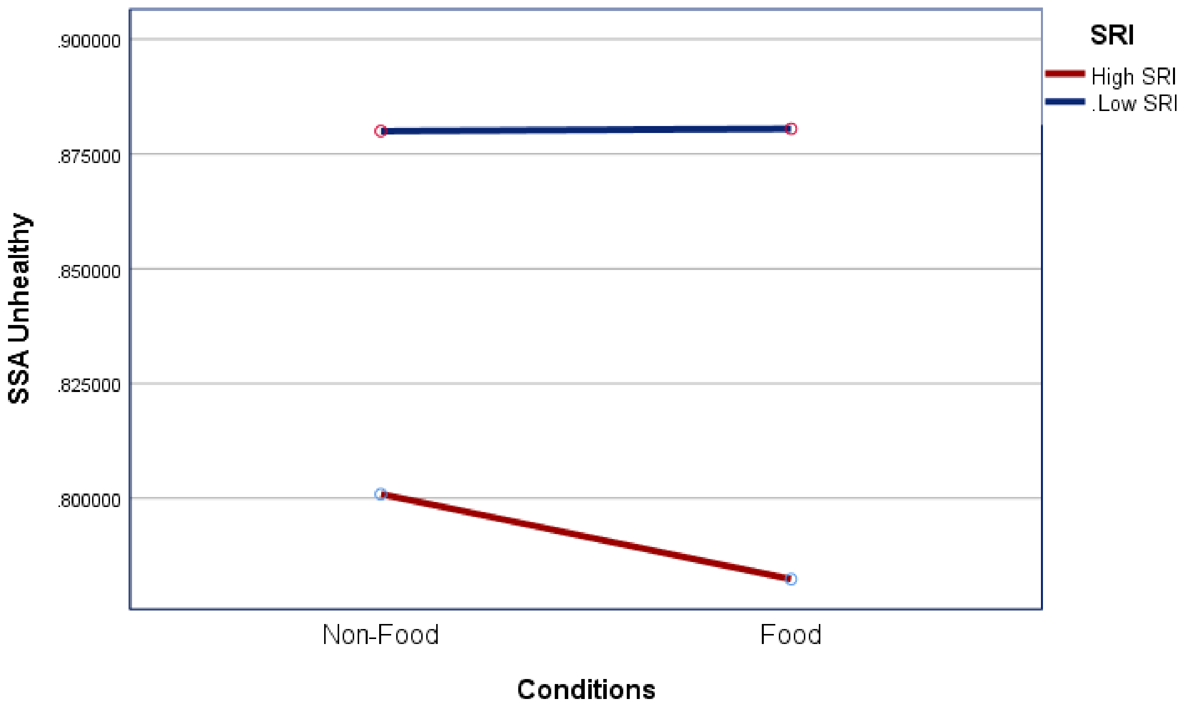


Figure 6. Relation between SST SSA unhealthy images across study conditions with SRI as a between-subjects factor

Associations between Deviations in "Typical" Sleep and Measures of Inhibition

D-KEFS

Multiple regressions (using Time 1 data) revealed no significant associations between deviations from "typical" sleep and D-KEFS inhibition completion time or D-KEFS inhibition errors (p > .05). However, one covariate (EDE-Q global score) was significantly associated with D-KEFS inhibition completion time (R^2=4.31, F(2, 36)=4.31, p < .05), such that individuals with more disordered eating exhibited longer inhibition completion times (b = -.43, p < .01).

SST

Multiple regressions (using Time 1 data) demonstrated that greater deviations from "typical" sleep were positively associated with higher SSA of healthy images (b = .45, $R^2\Delta$=.12,

F[1, 34]=5.24, $p < .05$) and unhealthy images ($b = .54$, $R^2\Delta$=.18, F[1, 34]=7.65, $p < .01$). In other words, getting more sleep than "typical" was associated with better accuracy in correctly selecting food images. For SSD, greater deviations in "typical" sleep were positively associated with longer SSD or better inhibition performance ($b = .41$, $R^2\Delta$=.11, F[1, 34]=4.17, $p < .05$). Therefore, getting more sleep than "typical" was associated with better inhibition performance on the stop signal task.

Discussion

Utilizing multiple methods of measurement (i.e., daily diary, lab-based protocols), the present study investigated relations between sleep consistency and performance-based measures of inhibition. This study hypothesized that individuals who report less consistent sleep would also report poorer inhibition across various tasks, even when accounting for average or "typical" sleep. However, findings demonstrated that individuals who reported lower SRI (or less regular sleep) were quicker on the D-KEFS inhibition trial and had better accuracy in resisting the impulse to select unhealthy images during a SST. At the same time, these results also demonstrated that getting more sleep than "typical" the night before an experiment may benefit inhibition performance. Although counter-intuitive, one possible explanation may be that getting more sleep than usual may support inhibition performance. College students do not meet the standard recommendations for sleep duration (7-9 hours) as recommended by the National Sleep Foundation (Hirshkowitz et al., 2015; Lund et al., 2010). Indeed, in the present study, the average sleep duration reported was 6.93 hours (via daily diary) or 6.42 hours (via self-report survey in the lab) indicating that the present sample was under-slept. Taken another way, these findings also suggest that getting less sleep than usual was associated with worsened performance. Past studies report that one night of sleep restriction worsens inhibition performance, but performance may improve after just one day of sleep recovery (Drummond et al., 2006). These findings suggest that researchers investigating sleep consistency and inhibition should consider if changes in sleep are positive (getting more sleep than usual) or negative (getting less sleep than usual).

With regards to the first finding, that lower SRI was associated with faster D-KEFS completion times, there are several factors to consider that may explain this outcome. First, D-KEFS inhibition completion time may not be an ideal measure of inhibition since it does not account for the number of errors participants make while completing the task. For example, it may be that individuals respond faster, but sacrifice speed for accuracy by making many errors (van Maanen et al., 2019). This response style would reflect poor self-monitoring and poor inhibitory control. However, the current study captured the number of errors made during this task and did not find significant relations with the SRI, however this variable did not demonstrate good reliability across visits to the lab in the present sample. Future studies may benefit from calculating variables that account for multiple aspects of performance within a specific measure (e.g., contrast scores that include response speed and error distribution) so as to draw inferences about inhibition (see van Maanen et al., 2019). Even if this specific contrast score was offered by the D-KEFS, the currently available contrast scores are not considered reliable and it is argued that they are uninterpretable (Crawford et al., 2008). Second, future studies should consider adding self-report measures alongside behavioral measures of inhibition. Recent work has proposed that laboratory-based inhibition tasks are not predictive of day-to-day life outcomes (Von Gunten et al., 2020). One explanation may be that performance-based inhibition may not reflect the construct of inhibition, or rather the real-world management of impulses that individuals confront in everyday life (Von Gunten et al., 2020). Further, it is possible that self-report measures of day-to-day inhibition and the SRI would be more likely to co-occur together as opposed to the present study's approach of capturing the SRI (via daily diary) and then asking participants to come to the lab for a single assessment. Further, this lab visit occurred often a month after participants completed the daily diary survey. Instead, studies should capitalize on multi-level-modeling to capture how daily changes in sleep patterns affects both daily self-reports as well as performance-based measures of inhibition.

Additional findings demonstrated that lower SRI was associated with higher accuracy in inhibiting unhealthy images of food. Contrary to these findings, the extant literature offers evidence that short and inconsistent sleep are both related to increased dietary intake of unhealthy foods as well as increased obesity risk among adolescents and emerging adults (Beebe et al., 2013; Dashti et al., 2015; Fenton et al., 2020; He et al., 2015a; He et al., 2015b). Although the present study investigated inhibiting unhealthy food images, this task cannot directly translate to a participant's ability to resist eating unhealthy foods in the real world. It is important to consider that lab-based experimental designs are known to have lower external validity compared to real-world behavior (Cozby & Bates, 2020). One possible explanation may be that there is a third variable that was not measured or accounted for within analyses, unrelated to food or dieting patterns. For example, it may be that high achieving students or students that want to perform well may also be students who sacrifice sleep and stay up late studying for an exam or completing an assignment (Edens, 2006). Gillen-O'Neel et al. (2013) observed that time spent studying for a test or quiz was related to shorter sleep that night and this type of tendency in a high achieving student could contribute to low sleep consistency and high motivation to perform well on SST.

Another possibility that may have influenced findings in the present study was the role of napping behaviors as well as unusual sleep patterns. First, the literature proposes that napping may benefit cognitive performance because it dissipates homeostatic sleep pressure (Ji et al., 2019; Lo et al., 2020; Lovato & Lack, 2010). Considering Barber's (2010) proposal that sleep may replenish self-regulatory capacities, it is possible that napping behaviors may alleviate fatigue or daytime sleepiness and therefore improve self-regulation and inhibition. The present study used the SRI metric which is sensitive to napping behaviors (Fischer et al., 2021), such that those who nap also exhibit lower sleep consistency scores. However, it is unclear if napping benefited students in the present study since students were not asked if they napped the day of the experiment. Future experimental studies should inquire about napping behavior to determine if this may alter cognitive performance during lab tasks. Secondly, studies should further investigate sleep patterns that may be consistent but contribute to circadian misalignment and therefore cognitive impairment. It could be argued that the SRI is an indicator of overall circadian dysregulation since if an individual's sleep timing is irregular then it would suggest that their light exposure and daily living patterns (e.g., eating) may be subsequently altered. On the other hand, individuals may have consistent sleep timing, but sleep at unusual times (e.g., shift work) and also be in a state of circadian misalignment. Past work has found that circadian misalignment corresponded with impairments in aspects of cognitive functioning, even though participants maintained consistent sleep timing from day to day (Chellappa et al., 2018). Although participants in the present study did not exhibit shift work sleep schedules, future studies should consider the timing of sleep as well as the regularity of sleep as factors that could impact cognitive functioning.

Strengths and Limitations

The present study offers several strengths, including utilizing both a daily diary and a lab-based experimental design to capture study variables. However, a limitation was the time between the daily diary or SRI measurement (Phase 1) and inhibition performance or the lab experiment (Phase 2). On average, the difference was nearly two months. Although time between Phase 1 and 2 recruitment was used as a covariate, sleep consistency may have changed by the time participants entered Phase 2. Indeed, work by Park et al. (2019) reported that sleep consistency (measured using sleep IIV) became less consistent over the course of semesters and years within adolescents/emerging adults (Park et al., 2019). However, studies have not yet been conducted to assess sleep consistency over shorter time frames (e.g., weeks, months). Although a strength of the SRI was that it was considered a developmentally appropriate metric to capture the spectrum of sleep patterns evident among college youth (e.g., bedtime, wake time, nap start time, nap end time), a limitation is that napping reduces SRI scores despite napping being a factor that improves cognitive outcomes. Another limitation of the SRI metric was that the study used daily diary methods as opposed to actigraphy-measured sleep. Although daily diary has been used to calculate the SRI metric (Phillips et al., 2017), sleep diaries collect less complete sleep information (e.g., nighttime awakenings) that could alter scores (Fischer et al., 2021) and diaries are more subjective, and therefore less accurate estimates of sleep timing (Carney et al., 2004; Lockley et al., 1999) despite moderate associations between self-reported and actigraphy-measured sleep (Lauderdale et al., 2008). It is possible that someone who experienced more sleepiness or fatigue the day of the experiment may estimate that they got less sleep the night before and therefore report that they got less sleep than "typical.' Additional studies are needed that use actigraphy to capture sleep, specifically how changes in sleep may influence cognitive performance. Finally, as mentioned, performance-based measures of inhibition may not fully or accurately represent inhibition or translate to real life behavior.

Another strength of the present study was that sleep duration or sleep duration the night before the experiment were covariates in analyses. This was particularly important to understand the unique impact of sleep consistency as it relates to cognitive functions. Interestingly, neither sleep duration nor sleep duration the night before the experiment were significant predictors within the analytic models. Some studies have found that inconsistent sleep, but not sleep duration, was associated with worse white matter integrity (Telzer et al., 2015) whereas other studies have reported that sleep duration, but not sleep consistency, was associated with differences in brain cortex and subcortical structures across development (Jalbrzikowski et al., 2020). Therefore, more research is needed before making recommendations on whether consistent sleep or sufficient sleep is more important. Future experimental studies may consider randomizing individuals to either short or long sleep duration conditions and then changing the amount of sleep the night prior to an experiment to capture proximal effects of inconsistent sleep. Studies should also account for napping behaviors prior to an experiment or add napping as an independent variable. Taken together, additional studies are needed to collectively explore the unique role of sleep consistency, sleep duration, and napping as they relate to cognitive performance.

A major limitation of the present study was the small sample size which only included female college students. Using simulated data, Fischer et al. (2021) observed that the SRI measure required larger samples to achieve the same statistical power as other sleep metrics (e.g., sleep IIV), however this metric was more advantageous when there were fewer days of daily diary (<7 days) as was true for the present study. Although the larger study recruited this sample with repeated measures analysis in mind for lab-based analyses, the present study was a secondary data analysis and therefore repeated measures were not possible for all analyses. For example, deviation in typical sleep had to use data from the first visit to the lab which reduced the statistical power to detect significant effects. In addition, the present study observed that the average scaled score on the D-KEFS for inhibition completion time was 12, which is considered the high end of the Average range compared to sample norms (Delis et al., 2001). Therefore, future studies may want to consider samples who might demonstrate more variability in performance to identify individuals particularly at risk for cognitive dysfunction. Finally, the recruitment of only females limits generalizability to male samples.

Conclusion

College is a risky time for poor sleep, including getting inconsistent sleep. Although studies propose that inconsistent sleep corresponds with worsened brain function, few studies have investigated relations between sleep consistency and components of EF (i.e., inhibition). Utilizing both daily diary measures of sleep and a lab-based paradigm, the present study observed that less consistent sleep as measured by the SRI was associated with better inhibition performance on a SST. However, results also demonstrate that getting more sleep than usual the night before the experiment was associated with better SST performance. Overall, these findings suggest that the relations between sleep consistency and inhibition may depend on how sleep consistency is captured and how sleep patterns deviate from typical patterns.

CHAPTER FOUR

CROSS-SECTIONAL AND LONGITUDINAL ASSOCIATIONS OF SLEEP CONSISTENCY AND EXECUTIVE FUNCTIONING AMONG ADOLESCENTS WITH SPINA BIFIDA

Adolescents with complex medical and neurodevelopmental conditions are at heightened risk for poor sleep patterns and sleep disorders (Beebe, 2012; Lewandowski et al., 2011). Youth with chronic illness may experience poor sleep due to various biopsychosocial stressors, such as illness-related symptoms and management (i.e., episodes of pain, use of medication) and psychosocial stressors and events that may impact sleep schedules (e.g., hospitalizations, missing school; Lewandowski et al., 2011). Further, youth with neurodevelopmental disorders (e.g., attention deficit hyperactivity disorder [ADHD]) have high rates of sleep problems, likely due to various genetic, neurobiological, and environmental factors (Robinson-Shelton & Marlow, 2016). Poor sleep patterns contribute to worsened physical, cognitive, and psychological outcomes among typically developing (TD) youth (Becker et al., 2017; Chaput et al., 2016; Shochat et al., 2014), thereby increasing the risk for negative outcomes among youth with chronic illnesses and/or neurodevelopmental conditions. Investigations of sleep to date have largely focused on the amount of sleep at night rather than other aspects of sleep, such as sleep consistency which is also associated with adverse health consequences (Becker et al., 2017). Therefore, the present study has two aims: (1) to investigate if sleep consistency differs among adolescents with spina bifida (SB) and TD adolescents and (2) to examine how sleep consistency is associated with important cognitive outcomes among adolescents with SB.

SB is a complex congenital condition resulting from a failure of the neural tube to completely close during gestation (Mahmood et al., 2011). Depending on the quality and location of the spinal lesion, those with SB face varying motor, orthopedic, bladder/bowel, and neurological complications, often requiring a lifelong and strict medical regimen (Copp et al., 2015; O'Hara & Holmbeck, 2013). Youth with SB commonly experience difficulties with attention and executive functioning. In terms of attention, studies propose that youth with SB experience difficulties with focusing and shifting attention as compared to TD youth (Burmeister et al., 2005; Rose & Holmbeck, 2007). This may present as inattentive as opposed to hyperactive features of ADHD (Burmeister et al., 2005). With respect to executive functioning, parent-report of youth with SB indicate poorer cognitive control (e.g., working memory, organization, planning, and initiation) but not necessarily behavioral regulation (e.g., inhibition, shifting, and emotional control) when compared to TD youth (Brown et al., 2008). Over time, youth with SB may experience increased risk for executive dysfunction. A longitudinal study of TD youth and youth with SB found that multi-informant ratings of executive functioning among the SB group did not change from childhood through adolescence, whereas the TD group saw age-related improvements in behavioral regulation (Tarazi et al., 2008). Such dysfunction has implications for adolescents' development of autonomy over their medical regimen needed to manage the complexities of their condition (Stern et al., 2018).

Another factor essential for psychosocial functioning and illness management is receiving adequate sleep. However, sleep becomes more disrupted during adolescence. During puberty, bioregulatory changes in the homeostatic and circadian systems delay sleep timing while early school start times create the "perfect storm" for short and ill-timed sleep (Carskadon et al., 2011;

Crowley et al., 2018). Also using a biopsychosocial framework, Daniel et al (2016) considered illness-specific pathways that confer risk for poor sleep, particularly in pediatric populations. Specifically, biological (e.g., medication use, neurological abnormalities, pain), psychosocial (e.g., depression), and environmental risk-factors (e.g., nighttime medical management) are also common among youth with SB (Copp et al., 2015) and may further contribute to poor sleep during adolescence. Therefore, adolescents with SB may be at even heightened risk for sleep problems when considering unique medical biopsychosocial factors.

Although limited, studies suggest that adolescents with SB demonstrate poorer sleep-wake patterns as compared to TD youth. A multi-method examination (e.g., actigraphy, multi-informant report) of sleep revealed that adolescents with SB evidenced poorer sleep quality and sleep maintenance (staying asleep at night) and higher levels of fatigue as compared to TD youth (Murray et al., 2018). Although Murray et al. notes that mean sleep duration was not significantly different between SB and TD subsamples, a significantly greater proportion of adolescents with SB (43.2%) received less than six hours of sleep per night as compared to TD youth (21.6%). These findings suggest that many adolescents with SB fall well-below age-based recommendations for sleep (Hirshkowitz et al., 2015). Indeed, longitudinal examinations find that youth with SB report poor subjective sleep starting in adolescence, which persists into early adulthood when compared to TD youth followed over a 10-year period (Murray et al., 2016). Overall, these studies suggest that youth with SB are at differential risk for sleep problems.

Individual (e.g., sleep regulation) and contextual factors (e.g., school schedules) that influence sleep duration and timing also have the potential to create inconsistent sleep routines. Regarding individual factors, a prior study has reported that TD and SB samples differed in circadian timing (Edelstein et al., 2012). Specifically, this study measured the midpoint of sleep on “free days” (or in the absence of school/work) across both samples and found that the midpoint of sleep timing was similar across groups from childhood through adolescence, but diverged in emerging adulthood (Edelstein et al., 2012); sleep timing was latest at 23 years of age among TD adults as compared to 29 years for adults with SB. In terms of contextual factors, school schedules may impact sleep patterns across a week. Adolescents may choose to sleep in on the weekends to “catch up” on weekday sleep and therefore experience social jetlag (SJ) in their sleep patterns (Wittmann et al., 2006). Indeed, large cohort studies of TD youth report that the discrepancy in sleep duration from weekday to weekend widens with age (Randler et al., 2019; Wittmann et al., 2006). Differences in sleep consistency between TD adolescents and those with SB have not been examined, nor have any studies investigated inconsistent sleep patterns among individuals with SB. Therefore, the first aim of the study is to explore sleep consistency in adolescents with SB and compare to TD adolescents.

Investigations of sleep consistency among adolescents requires thoughtful consideration for how to capture the distinctive sleep patterns during this developmental period. Along with shifts in sleep timing across the week, napping behaviors reemerge in adolescence (Thorleifsdottir et al., 2002). Although naps may alleviate fatigue for under slept adolescents, other work proposes that napping delays bedtimes at night (Fukuda & Ishihara, 2002) and could contribute to inconsistent sleep patterns. Prior work has traditionally captured sleep consistency by focusing on variations in nightly sleep from day to day (e.g., sleep intraindividual variability; Becker et al., 2017) and from weekdays to weekends (e.g., SJ; Wittmann et al., 2006). However, these strategies do not account for napping patterns. Phillips et al. (2017) addressed this issue of daytime sleep by creating the sleep regularity index (SRI), which captures the likelihood of being asleep and awake across two 24-hour periods. This index is calculated on a scale from 0 (random) to 100 (perfect sleep regularity), with higher scores representing more consistent sleep routines (Phillips et al., 2017). Although a relatively new measure, existing studies demonstrate that this index correlates significantly with other aspects of sleep health, such as sleep quality and daytime sleepiness (Phillips et al., 2017; Murray et al., 2019; Lunsford-Avery et al., 2018). The present study will capture sleep consistency using the SRI and investigate associations between the SRI and other aspects of sleep health among adolescents with SB and TD adolescents.

Sleep consistency may also contribute to attention and executive functioning deficits. In brain imaging studies, adolescents experience altered neural functioning and connectivity when exhibiting inconsistent sleep routines (Hasler et al., 2012; Lunsford-Avery et al., 2020). A longitudinal study observed that greater sleep variability from day to day was associated with altered white matter integrity more than one year later, even after accounting for sleep duration (Telzer et al., 2015). Such neurobiological consequences likely relate to functional outcomes in higher-order cognitive skills, such as attention and executive functioning. In addition, other studies suggest that cognitive functioning may be directly impacted by immediate changes in sleep routines. For example, Könen and colleagues (2015) assessed daily measures of sleep and working memory in children over several weeks and found that children’s working memory (in the morning) was adversely impacted by nights that deviated either more or less from their average sleep across the week. Such associations were particularly strong for youth with lower intellectual functioning, highlighting those deviations in sleep may have their greatest impact in youth with neurocognitive vulnerabilities (Könen et al., 2015). Therefore, a second aim of the current study is to investigate concurrent and longitudinal associations between consistent sleep and inattention and executive functioning problems among adolescents with SB.

In summary, although adolescents with SB typically have more impaired sleep compared to TD adolescents (Murray et al., 2018), past studies have not yet explored if sleep is less consistent among adolescents with SB as compared to TD youth. Thus, the first aim of the present study was to investigate if the SRI differs between adolescents with SB and TD adolescents using actigraphy-derived measures of sleep timing. It was hypothesized that youth with SB are at greater risk for inconsistent sleep patterns compared to TD youth given that they may face unique biopsychosocial and environmental factors that disrupt sleep timing (Daniel et al., 2016). As part of this aim, the study evaluated if the SRI was associated with self-report measures of sleep health (e.g., sleep hygiene, quality, sleep arousal) and examined if such associations differed between adolescents with SB versus TD adolescents. It was hypothesized that lower SRI would be significantly associated with poorer subjective ratings of sleep hygiene, quality, and sleep arousal for both study groups. The second aim of the study capitalized on additional data available for adolescents with SB and tested concurrent and longitudinal relations between the SRI and multi-informant ratings of attention and executive functioning. It was hypothesized that lower SRI (e.g., less consistent sleep) would be related to attention and executive functioning concurrently and several years later in youth with SB.

Method

Participants

Adolescents (*n*=74) between the ages of 12-18 years old, who were either TD (*n* = 37) or had a diagnosis of SB (*n* = 37) were participants in this study. Study sample, procedures, and analyses varied depending on the study aims. For the first aim, comparisons of the SRI and associations with other measures of sleep health included both TD and SB samples. For the second aim, relations between sleep consistency and attention and executive functioning were only assessed used data from participants with SB. The present study capitalized on concurrent and longitudinal data collected as part of a larger study that captured the adolescent transition to adulthood among youth with SB (e.g., Devine et al., 2012; Murray et al., 2018; Stern et al., 2018; Wasserman & Holmbeck, 2016). Descriptions of the samples and procedures from each study are detailed below.

The SB sample was recruited from a larger longitudinal study during the 3rd, 4th, or 5th wave home visits (2012-2015) to participate in a more intensive actigraphy study to compare sleep-wake patterns of youth with and without SB (see Murray et al., 2018; Palermo et al., 2012). For the purposes of the present study, the initial wave at which the sleep data were collected will be referred to as Time 1 (T1) regardless of the data collection wave (see Figure 7). To meet the inclusion criteria of the longitudinal study, participants were required to: (a) have a diagnosis of myelomeningocele, lipomeningocele, or myelocystocele, (b) be within 8-15 years of age at the first time point, (c) be proficient in reading and speaking English or Spanish, (d) have parent permission and parent involvement, (e) cognitive ability necessary to comprehend and complete surveys, and (f) live within 300 miles of the research laboratory located in the Midwest to enable research assistant travel for home visits. Further inclusion criteria were applied to the intensive actigraphy subsample, including: (g) being 12-18 years old, and (h) being demographically matched (e.g., age, gender, ethnicity, income level) to a participant in a sample of TD youth (described below).

The sample of TD adolescents was recruited in another study prior to the recruitment of the SB sample (Palermo et al., 2012; Palermo et al., 2011). The TD comparison group was recruited from the Pacific Northwest and inclusion criteria required participants to be: (1) 12 to 18 years old, (2) proficient in reading and speaking English, (3) without serious co-morbid health conditions, development delays, or psychiatric diagnoses. Prior results reported that participants who declined participation did not differ based on age and gender (Palermo et al., 2011).

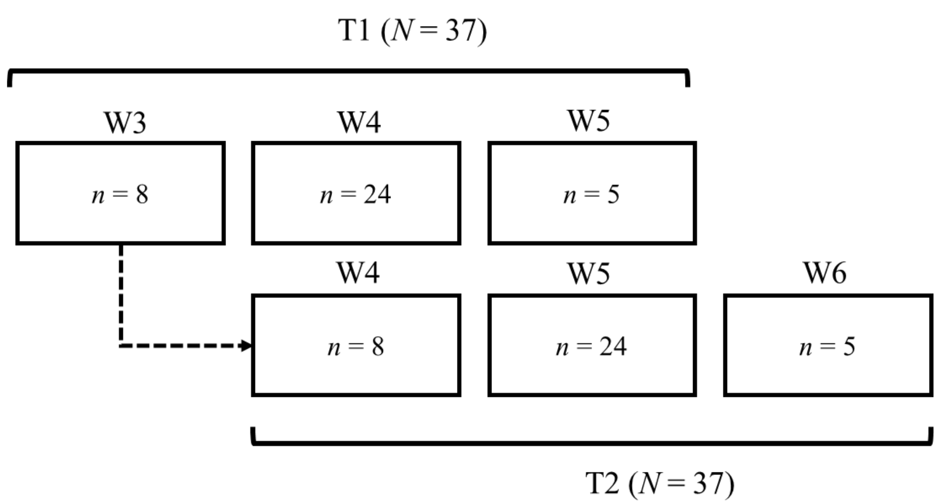


Figure 7. Correspondence of the waves of the longitudinal study and the time points in the present study

The final analytic sample included adolescents (*n* = 74; M_{age}=16) who were majority female and White/Caucasian (see Table 6 for demographic characteristics of the SB and TD analytic samples). Participants in the two analytic samples did not differ from the larger full samples with respect to age, gender, race, ethnicity, as well as SB type and shunt status for those with SB (Murray et al., 2018; Palermo et al., 2011). Medical characteristics of the SB sample are described in Table 7. By T2, 65% of participants had turned 18 years old and caregivers and teachers were no longer given surveys of attention and executive functioning; instead, participants completed self-report measures.

Table 6. Demographic Characteristics of the SB and TD Samples

	SB (*n*=37)	TD (*n*=37)
Adolescent Characteristics		
	M (SD)	*M (SD)*
Age	16.1 (1.4)	16.0 (1.5)
	n (%)	*n (%)*
Gender		
Male	16 (43.2%)	15 (40.5%)
Female	21 (56.8%)	22 (59.5%)
Race		
Caucasian	26 (70.3%)	26 (70.3%)
Other	11 (29.7%)	11 (29.7%)
Ethnicity		
Hispanic	8 (21.6%)	7 (18.9%)
Non-Hispanic	29 (78.4%)	28 (75.7%)
Missing	0 (0%)	2 (5.4%)
Pubertal Status		
Early pubertal	1 (2.9%)	4 (10.8%)
Mid pubertal	2 (5.7%)	3 (8.1%)
Late pubertal	19 (54.3%)	19 (51.4%)
Post pubertal	13 (37.1%)	11 (29.7%)
	M (SD)	*M (SD)*
Total Score	3.3 (0.5)	3.2 (0.7)

Caregiver Characteristics		
	n (%)	*n (%)*
Median Income		
<$29,000	10 (29.4%)	4 (10.8%)
$30,000 - 49,000	6 (17.6%)	8 (21.6%)
$50,000 - 69,000	3 (8.8%)	9 (24.3%)
>$70,000	15 (44.1%)	16 (43.2%)
Marital Status		
Two-parent intact	25 (71.4%)	27 (73.0%)
Not intact	10 (28.6%)	10 (27.0%)
Caregiver Report		
Mother	29 (78.4%)	30 (81.1%)
Father	16 (43.2%)	3 (8.1%)
Adoptive Mother	0	3 (8.1%)
Other	0	1 (2.7%)

Note. Pubertal status was calculated using the combined gender norms on the Pubertal Development Scale (ranging 1-4). Marital status was collapsed to reflect either intact or not intact, including families with one parent households and separated or divorced status. Youth with SB could have multiple caregiver reports.

Table 7. Medical Characteristics of the SB Sample

	n (%)
SB Type	
Myelomeningocele	34 (91.9%)
Other	3 (8.1%)
Lesion Level	
Sacral	6 (16.2%)
Lumbar	27 (73.0%)
Thoracic	4 (10.8%)
Gros Motor Functioning	
Level I	5 (13.9%)
Level II	9 (25%)
Level III	10 (27.8%)
Level IV	12 (33.3%)
Unknown	1 (2.7%)
Prescription Medications	
Antispasmodics	18 (24.3%)
Antidepressants	3 (8.1%)
Anticonvulsants	3 (8.1%)
Stimulants	3 (8.1%)
Shunt Status	
Yes	28 (75.7%)
No	9 (24.3%)
	M (SD)
Shunt Revisions	
	2.2 (2.2)
Surgeries and Hospitalizations	
	0.7 (0.0)

Note. SB type was collapsed to either myelomeningocele and other, including lipomeningocele and lipoma. Average shunt revisions since birth was only calculated among those with a shunt.

Attrition Analysis

The majority of participants participated at both time points (n = 33; 89%). Youth who did not participate in the second time point did not significantly differ (p > .05) from youth who participated in the sleep assessment time point with respect to age, gender, race, SES, lesion level, SB type, shunt status, attention problems (parent- and teacher-report), or executive functioning problems (parent-report). However, those who did not participate at T2 had significantly higher teacher-reports of executive functioning problems at the first time point, $t(29) = 3.17$, $p < .01$.

Procedure

For youth with SB, adolescents and their parents participated in a larger longitudinal study that included a home visit by the research team, where they completed various measures, including those presented in the present study. Parents and teachers across study samples were also given self-report questionnaires related to sleep health (described below). Questionnaires were offered in English or Spanish. Parents consented to a medical chart review for their child. Data collection across each wave of data collection occurred between two to three years apart.

For both the SB sample and TD comparison group, Actiwatch and sleep diaries were mailed to participant homes (TD group) or provided during home visits (SB group). Participants were instructed on how to use the Actiwatch64 (AW64) and how to complete accompanying daily diaries to cross-reference sleep-wake patterns. Youth underwent 10 days of actigraphy monitoring. In terms of matching procedures, 78 TD adolescents (Palermo et al., 2012) were matched based on age, gender, ethnicity, and socioeconomic status (SES) for adolescents in the SB group (see Murray et al., 2018 for more information).

Measures

Demographics

Parents of TD adolescents and those with SB reported on their child's demographic characteristics (e.g., age, gender, race, ethnicity) as well as their own characteristics (e.g., median income, marital status).

Pubertal Status

Pubertal status was measured by using parent-report of the Pubertal Development Scale (PDS), with higher ratings indicating more advanced pubertal status (Petersen et al., 1988). Both parents of TD adolescents and youth with SB reported on pubertal status.

Objective Sleep

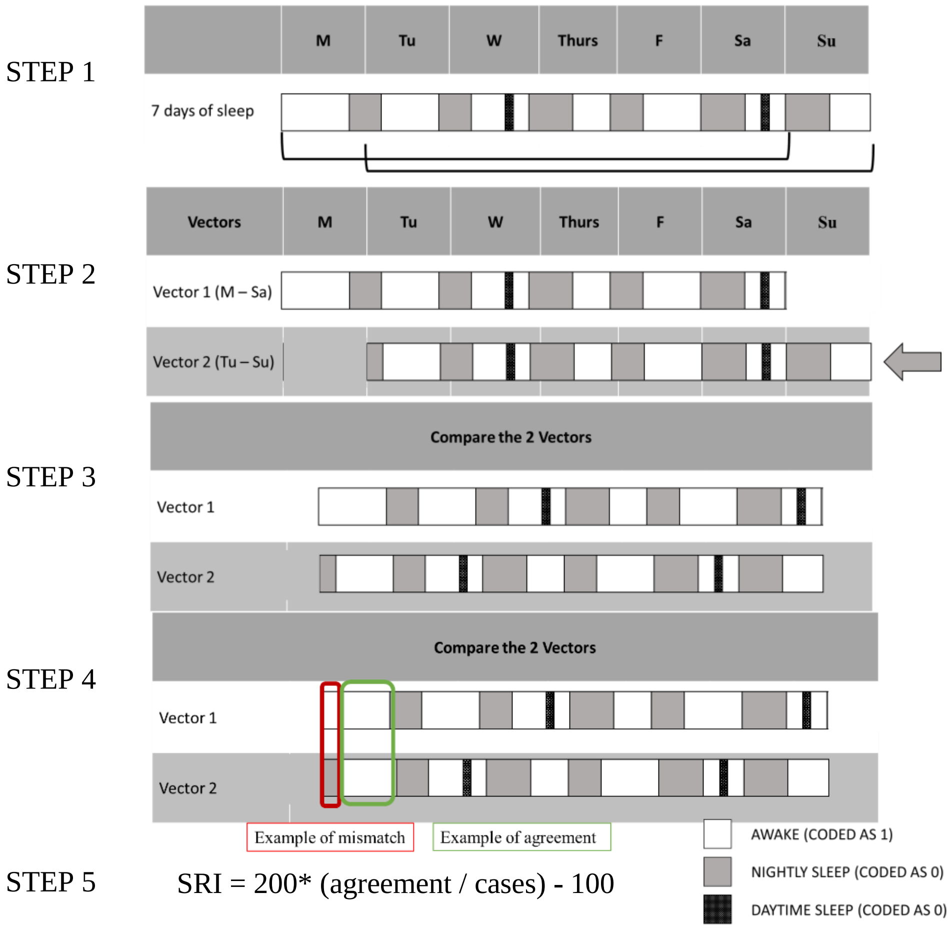
Sleep-wake patterns of participants (both adolescents with SB and TD youth) were assessed using the Actiwatch 64 (AW64; Phillips Respironics/MiniMitter Company Inc., Bend, OR). Participants wore a small wrist actiwatch that monitors sleep and wake behaviors by detecting amount of movement minute-by-minute for 10 days. Participants were asked to press an event marker at bedtime and wake time. In addition to event markers, participants maintained daily diary reports to facilitate coding sleep patterns and confirm daytime napping (see Murray et al., 2018). Sleep-wake patterns were analyzed and created using Actiware Sleep version 5.5 (Webster et al., 1982) and a standard coding procedure. Actigraphy-derived measures of sleep included sleep onset (referred to as "bedtime"), wake after sleep onset (WASO referred to as "wake time"), and sleep duration. Using common scoring protocols, sleep onset and WASO were determined after 10 consecutive minutes of epoch data were scored as sleep or awake, respectively (Meltzer et al., 2012). Similar procedures were applied to napping. Actigraphy is a valid assessment tool (Gruber & Sadeh, 2004), even among youth with neurological disorders and those with impaired mobility (Scheer et al., 2006; Zollman et al., 2010).

Sleep Regularity Index

Using the scored actigraphy measures, the SRI was calculated using sleep onset, sleep offset, and napping onset and offset times (see Figure 8 for a step-by-step visual calculation). Sleep-wake periods were converted to either 0 = asleep or 1 = awake, then two vectors are compared to examine degree of agreement across 24-hour periods.

Subjective Sleep Health

Various self-reported and subjective measures of sleep were captured in the SB and TD youth samples, including perceived sleep quality using three measures. First, the Adolescent Sleep Wake Scale (ASWS) assesses quality of sleep-in terms of going to bed, falling asleep, staying asleep, and waking up using 32 items (LeBourgeois et al., 2005). Items were rated along a 6-point scale (1 = never to 6 = always) and then averaged, with higher scores indicating better sleep quality. Second, sleep arousal before bed was assessed using the Pre-Sleep Arousal Scale (PSAS; Nicassio et al., 1985). This measure consisted of 16 items rated along a 5-point scale (1 = not at all to 5 = extremely). Responses were averaged with higher scores indicating greater arousal before falling sleep. Third, sleep habits were rated using the Adolescent Sleep Hygiene Scale (ASHS) which consisted of 24 items (LeBourgeois et al., 2005). Responses were rated along a 6-point scale (1 = always to 6 = never), then averaged, with higher scores reflecting better sleep habits or sleep hygiene. Adolescents' self-reports across measures demonstrated good internal consistency (a= .87-.91).



Note: The key presented at the bottom left denotes awake periods (white) and asleep periods (grey, dark grey). The figure shows a visual schematic to depict how SRI was calculated. In step 1, two vectors are created, vector 1 being Monday through Saturday and vector 2 being Tuesday through Sunday. Step 2 demonstrates that two vectors are created and then step 3 shows how these two vectors are aligned to compare awake and asleep periods across 24-hours. In step 4, asleep and awake periods are compared minute-by-minute, 24-hours apart. If an individual is awake or asleep at the same times 24-hours apart, then this minute reflects an “agreement.” If an individual is awake and then asleep 24-hours later, then this minute reflects a “mismatch.” The number of cases reflects the length of the vector in minutes (or the sum of minutes in agreement and mismatched). In this visual example, seven days of data would produce a six-day vector reflecting 8,640 minutes (1440 minutes per day times 6 days).

Figure 8. Calculation of the Sleep Regularity Index (SRI)

Medical Information

Medical information was obtained for the SB sample using medical records or, in the case of missing records, parent report. The following variables were collected: SB type, lesion level, and shunt status. In addition, parents completed a medical form that indicated the number of shunt revisions (since birth), surgeries and hospitalizations (within the past two years), prescription medications, and current gross motor functioning. Gross Motor functioning was captured using The Gross Motor Function Classification System Expanded and Revised (GMFCS-E&R) to classify youth along the following scale: Level I (unassisted walking), Level II (uses braces, crutches, or walker), Level III (some wheelchair use, but can walk with braces >50% of the time), and Level IV (uses wheelchair, and may walk short distances with walker <50% of time; Palisano et al., 1997). For the current study, only lesion level was used as a covariate to indicate illness severity to conserve power.

Attention

Parents and teachers of adolescents with SB reported on levels of attention and this was measured using the attention subscale (11 items) from the Child Behavior Checklist (CBCL; Achenbach & Rescorla, 2001). The CBCL measures socioemotional and behavioral problems as well as problems with attention; subscale scores are normed based on age and gender of the participant and converted to T-scores. Internal consistency of the attention problems subscale (a= .92-.94) demonstrated adequate reliability across parents and teachers in the present sample. Regarding longitudinal analyses, participants who turned 18 years old in the subsequent wave completed the Achenbach System of Empirically Based Assessment (ASEBA) Adult Self-Report for Ages 18-59, and the attention problems scale was used in analyses for these participants. Therefore, at T2, this variable included either self-reported attention problems (for participants > 18 years old) or parent- or teacher-reported attention problems (for participants < 18 years old). Higher scores reflect more attention problems.

Executive Functioning

Among those with SB, multi-informant (i.e., parent, teacher) ratings of executive functioning were captured using the Brief Rating Inventory of Executive Function (BRIEF; Gioia et al., 2000). The BRIEF measures children's executive functioning in everyday tasks (e.g., home, school). The Global Executive Composite (GEC) consists of all subscales, including inhibition, shifting, emotional control, initiation, working memory, planning/organizing, organization of materials, and monitoring. This subscale demonstrated good internal consistency (*a*=.97-.98). In longitudinal analyses, when participants turned 18 years of age, they were given a self-report version of the BRIEF. Therefore, the T2 variable included either self-reported executive functioning problems (for participants > 18 years old) or parent- or teacher-reported executive functioning problems (for participants < 18 years old). Higher scores reflect more executive functioning problems.

Data Analytic Plan

Composites

To minimize the number of analyses performed, composites were created if the scores across multiple informants (i.e., mother, father, teacher) are moderately correlated (*rs*>.40); see Holmbeck, 2002). Mother and father reports on the CBCL attention problems scale were significantly correlated (*rs* = .72) and combined, but teacher reports were not significantly correlated with parent report (*rs* = .35). Similarly, the BRIEF GEC was significantly correlated among mother and fathers (*rs*= .79) but not significantly correlated with teacher report (*rs*=.29). Therefore, parent and teacher reports of attention and executive functioning were utilized for the primary analyses. When youth turned 18 and completed self-report measures, the overall means between parent-report and teacher-report (T1) did not significantly differ from self-report (T2). However, correlational findings only found that teacher-reported executive functioning was correlated with self-report executive functioning later ($p < .01$), which suggested some stability in this variable over time.

Covariates

The inclusion of various covariates in the present study differed depending on study aim. For the first aim where relations between the SRI and self-reported sleep health across TD and SB groups were assessed, sleep duration was used as a covariate. For the second aim, which involved the examination of associations between the SRI and several outcome variables (i.e., executive functioning, attention), covariates were considered across three levels: (1) demographic factors, (2) illness severity, and (3) theoretically driven variables**.** There were no significant associations between the demographic factors (e.g., race, age, family income) and the primary outcomes. However, pubertal status was significantly correlated with executive functioning (teacher report) and attention (parent report) and therefore was included as a covariate across all analyses. Despite significant gender differences in attention, gender was not used as a covariate since the normed t-scores already accounted for gender differences in scores. To account for illness severity, lesion level was used as a covariate. A dummy variable was created to account for season of sleep assessments (i.e., summer vs. schoolyear), but there were no significant associations between season of sleep assessments and the outcome variables; thus, season of sleep assessment was not used as a covariate. Finally, all analyses used sleep duration as a covariate given its theoretical importance and potential contribution to key outcomes.

Statistical Analysis

Data were analyzed using statistical software (IBM SPSS software, Version 25). Descriptive analyses of napping, nighttime sleep duration, and the SRI were calculated among TD adolescents and those with SB. Analyses of covariance (ANCOVA) were performed to examine how the SRI differed between TD adolescents and those with SB, using sleep duration as a covariate. Next, moderation analyses were conducted to investigate relations between the SRI and other self-report indices of sleep health, including the ASHS, PSAS, and ASWS, and if associations differed by group status (TD or SB; see Figure 9). In these analyses, sleep duration was entered on the first step. To account for the main effects of the proposed moderator variable, group status was entered on the second step. To test for the main effects of the SRI on sleep health measures, the SRI was entered on the third step. On the fourth step, an interaction term (e.g., group status x SRI) was included. Continuous variables were centered prior to such analyses and significant interactions were probed using simple slope analyses as recommended by Aiken & West (1991). A total of three regressions were performed for each sleep health variable (i.e., ASHS, PSAS, ASWS).

For analyses investigating differences between youth with SB and TD youth, a sample of 74, power of .80, and an alpha of .05 would yield enough power to detect medium effects (f^2 = .17; Faul et al., 2007; Cohen et al., 2016). For the SB-only analyses, with a sample of 37, power of .80, and an alpha of .05, we would be able to detect large effect sizes with either 4 predictors (f^2 = .37) or 5 predictors (f^2 = .41; Faul et al., 2007). Therefore, for the SB-only analyses, the present study had enough power to detect large effects across concurrent analyses (4 predictors) and longitudinal analyses (5 predictors).

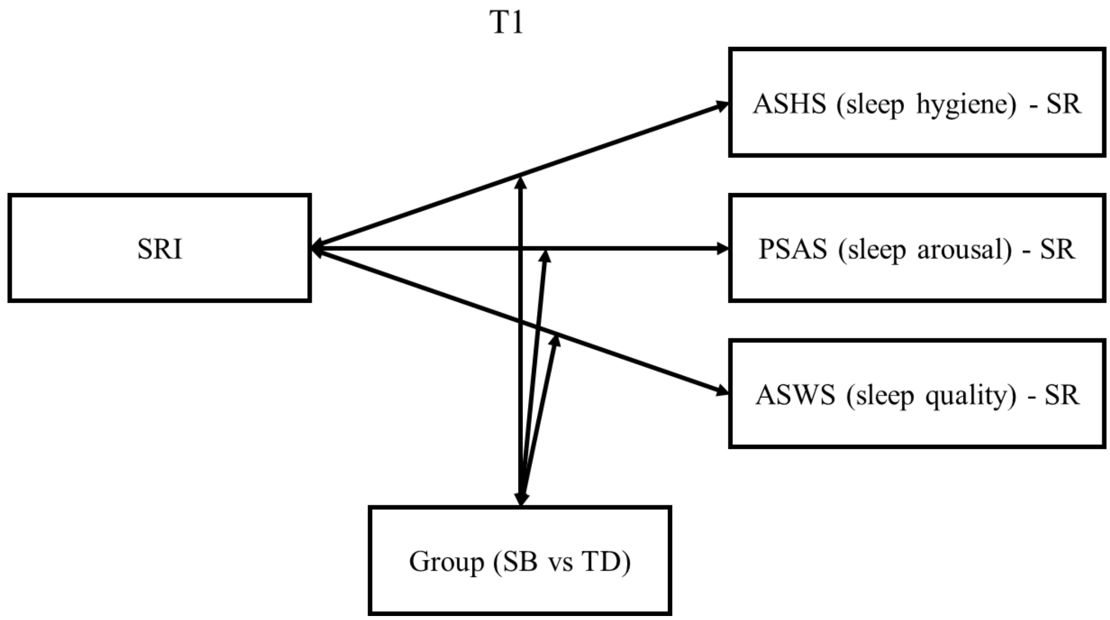


Figure 9. Relations between the SRI and other self-report (SR) sleep health measures across the TD and SB adolescent sample

Hierarchical linear regression analyses were conducted to examine concurrent and longitudinal associations between the SRI and attention and executive functioning in youth with SB (see Figure 10). Four regressions were performed to assess attention (parent, teacher) and executive functioning (parent, teacher) concurrently (T1 only) and four regressions were performed to assess these outcomes longitudinally (T1 → T2). For concurrent analyses, lesion level was entered on the first step and pubertal status was entered on the second step. Finally, sleep duration was entered on the third step. To test the main effect of sleep consistency, SRI was entered on the fourth and final step. For longitudinal analyses, the same covariates were entered on step 1-3, and then either attention or executive functioning at the previous timepoint (T1) was included on the fourth step to account for prior levels of attention or executive functioning. For example, parent reports of attention at T1 were included on the fourth step and then the SRI was entered on the fifth step in attention analyses. As discussed, 65% of participants turned 18 years old by the second timepoint and therefore their self-report was used as the T2 variable.

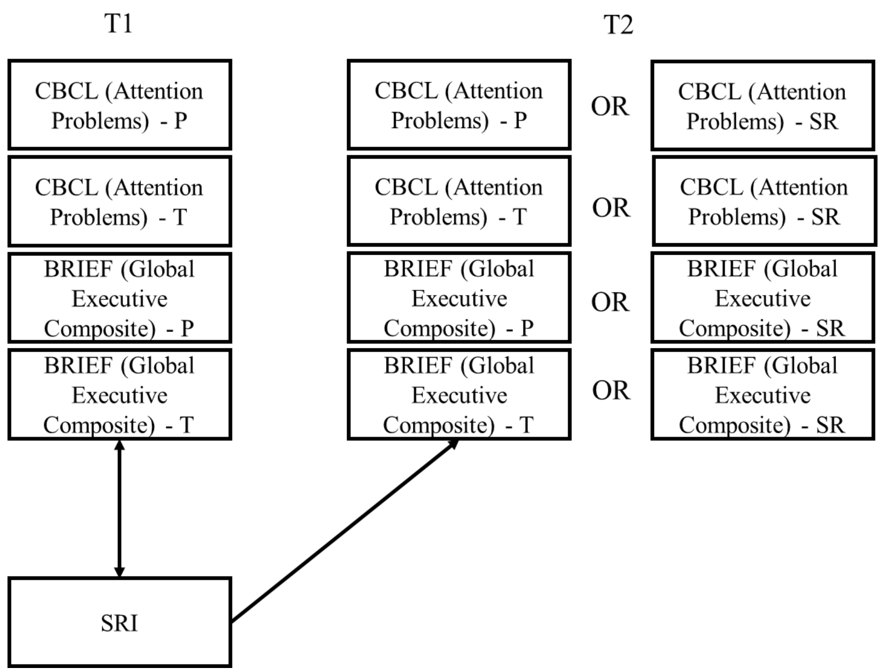


Figure 10. Model of concurrent and longitudinal associations between the SRI and attention/executive functioning among adolescents with SB

Results

Preliminary Analyses

Basic descriptive statistics of study variables for both the TD and SB groups are displayed in Table 8. Correlational findings demonstrate relations between older age and lower sleep regularity and lower reports of sleep hygiene (i.e., ASHS). Further, lower sleep regularity was associated with longer nap durations. Sleep duration and sleep regularity measured via Actigraphy were not significantly correlated, however shorter sleep duration was significantly associated with lower reports of sleep quality (ASWS) and lower sleep regularity was associated with lower reports of sleep hygiene (ASHS).

Table 8. Basic Correlations and Descriptive Data Collapsed across the TD and SB Groups

Variable	1	2	3	4	5	6	7	8	9
1. Age	-								
2. Puberty	.35**	-							
3. SES	.01	.14	-						
4. SRI	-.39**	-.10	.08	-					
5. Sleep Duration	-.13	.08	-.14	.05	-				
6. Nap Duration	.15	-.00	.07	-.36**	-.20	-			
7. ASWS	.00	-.02	.16	.15	.29*	-.19	-		
8. ASHS	-.25*	-.19	.03	.26*	.21	-.09	.53**	-	
9. PSAS	.02	.02	-.19	-.10	-.17	-.00	-.65**	-.53**	-
Mean	16.04	3.28	5.89	78.22	382.81	44.36	4.24	4.78	27.19
SD	1.43	0.59	2.26	10.23	59.59	61.10	0.70	0.68	9.98

Descriptive statistics of study variables for youth with SB are displayed in Table 9. In addition, significant associations were observed between pubertal status and teacher reports of executive functioning problems (T1), parent reports of attention problems (T1), and self- or teacher-reports of attention problems (T2). Sleep duration was also significantly correlated with teacher reports of executive functioning problems (T1).

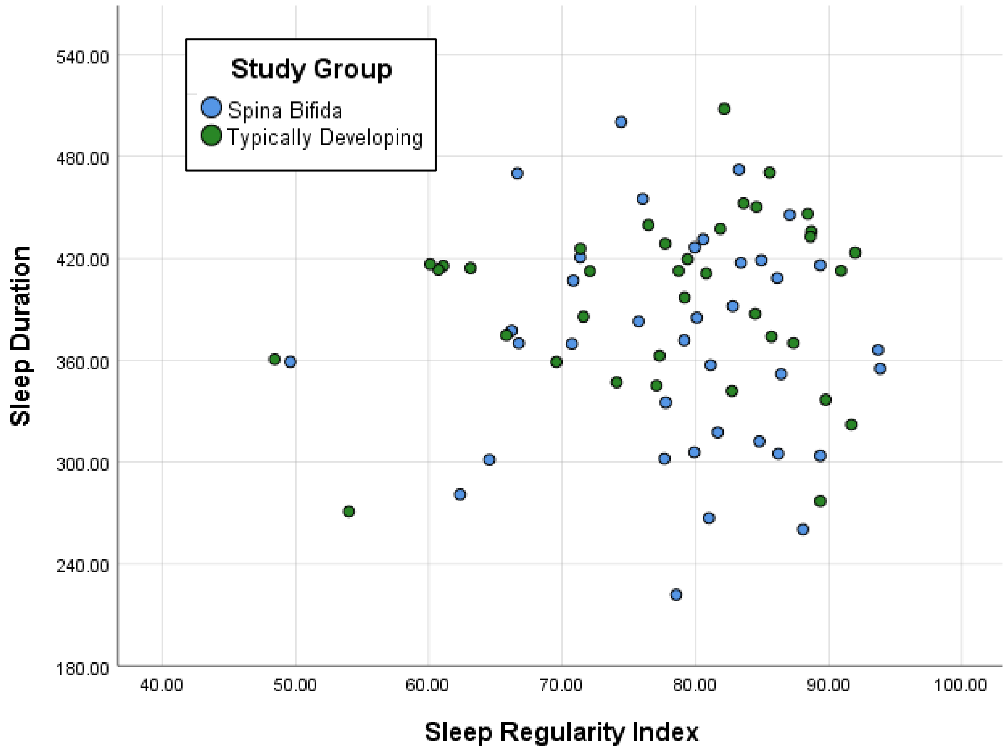
Table 9. Basic Correlations and Descriptive Data among the SB Sample

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. Age	-													
2. Pubertal Status	.55**	-												
3. Lesion Level	.11	-.04	-											
4. SES	-.04	.21	-.06	-										
5. Sleep Duration	.11	-.07	.07	-.25	-									
6. SRI	-.43**	-.05	-.16	.28	-.03	-								
7. EF_P T1	.20	.07	.08	.09	.17	-.47**	-							
8. EF_C/P T2	.19	.16	.04	-.11	-.09	-.46**	.63**	-						
9. EF_T T1	-.28	-.42*	-.07	-.28	.41*	-.08	.25	-.02	-					
10. EF_C/T T2	.27	.24	.11	-.22	-.01	-.40**	.52**	.87**	-.04	-				
11. ATTN_P T1	-.31	-.42*	.06	-.30	.35	-.17	.18	-.01	.82**	-.06	-			
12. ATTN_C/P T2	.08	.30	.20	-.17	-.08	-.31	.09	.51**	-.34	.67**	-.27	-		
13. ATTN_T T1	.05	.06	.15	.23	-.04	-.16	.58**	.25	.30	.23	.30	-.01	-	
14. ATTN_C/T T2	.17	.36*	.10	-.07	-.26	-.46**	.19	.62**	-.42*	.63**	-.30	.89**	.05	
Mean	16.12	3.33	1.95	5.62	368.61	78.70	1.58	1.65	1.54	1.62	55.97	55.41	55.11	54.97
SD	1.38	0.52	0.52	2.50	65.20	9.35	0.32	0.38	0.37	0.41	5.32	6.14	5.47	5.92

Note: EF = executive functioning; ATTN = attention.

Comparisons between TD Adolescents and Those with SB (Aim 1)

ANCOVA indicated there were no significant differences between the TD and SB sample on the SRI, when controlling for sleep duration (see Figure 11). Results from multiple linear regressions indicated that there were no significant relations between the SRI and the ASWS nor was there a moderating effect of group status (p > .05). However sleep duration explained a significant portion of the variance in ASWS when it was entered on the first step of the regression (b = .29, $t(71) = 2.53$; $R^2 = .08$, $F(1, 71) = 6.38$, $p < .05$), suggesting that shorter sleep duration was associated with lower sleep quality. In addition, group status was significantly associated with ASWS after accounting for sleep duration (b = -.27, $t(71) = -2.39$; $R^2 \Delta = .07$, $F(1, 70) = 5.71$, $p < .05$) suggesting SB youth have lower sleep quality than TD youth even after accounting for sleep duration. Findings suggested that there were no significant relations between sleep duration, group status, and SRI nor was there a moderation effect of group status on the PSAS. Finally, lower sleep regularity was associated with worse sleep hygiene after accounting for sleep duration (b = .23, $t(69) = 2.34$, $p < .05$; $R^2\Delta = .069$, $F(1, 69) = 5.65$, $p < .05$). There was no significant moderating effect of group status and therefore these associations were not significantly different between youth with SB and TD youth.



Note: Sleep duration is averaged over the study period and represented in minutes. Higher SRI suggests more regular sleep patterns.

Figure 11. Visual scatterplot of sleep duration and SRI between SB and TD samples

Associations between Attention and Executive Functioning among Adolescents with SB (Aim 2)

Cross-Sectional Findings

Multiple linear regressions were conducted to examine cross-sectional associations between SRI and executive functioning or attention after accounting for the covariates (i.e., lesion level, pubertal status, sleep duration). Regressions were performed separately for parent and teacher report. There was a significant relation between SRI and parent report of executive functioning, $b = -.47$, $p < .01$, such that lower SRI was associated with more executive functioning problems. Moreover, the SRI explained a significant portion of the variance in executive functioning scores, $R^2\ \Delta = .21$, $F(1, 29) = 8.36$, $p < .01$. Regarding teacher reports of executive functioning, shorter sleep duration was associated with fewer executive functioning problems ($b = .40$, $R^2\Delta = .21$, $F(1, 26) = 6.29$, $p < .05$). However, the SRI was not significantly associated with teacher reports of executive functioning. Multiple regressions were also performed separately for parent and teacher report of attention problems (e.g., CBCL) using the same covariates (i.e., lesion level, pubertal status, sleep duration). There were no significant associations between the SRI and attention problems for either teacher report or parent report ($p > .05$).

Longitudinal Findings

Multiple linear regressions were conducted to examine longitudinal associations between the SRI and executive functioning problems, after accounting for lesion level and pubertal status (both entered on the first step) and sleep duration (entered on the second step) and T1 executive functioning (on the third step). Analyses again were run separately for parents and teachers. For parents, findings demonstrated that there were no significant associations ($p > .05$) between the SRI and T2 executive functioning (parent-reported if under 18 or self-reported if over 18). For teacher reports, findings revealed a significant longitudinal association between the SRI and later executive functioning (teacher-reported if under 18 or self-reported if over 18) such that lower SRI was associated with higher executive functioning problems, $b = -.40$, $R^2\Delta = .15$, $F(1, 22) = 4.50$, $p < .05$. For parent reports, findings revealed significant longitudinal relations between the SRI and T2 attention (parent-reported if under 18 or self-reported if over 18) such that lower SRI was associated with more attention problems later, $b = -.42$, $R^2\Delta = .34$, $F(1, 25) = 5.90$, $p < .05$.

For teacher reports, there were no significant longitudinal relations (p > .05) between the SRI and T2 attention (teacher-reported if under 18 or self-reported if over 18).

Discussion

Although studies report that adolescents with SB report poorer sleep compared to TD adolescents (Murray et al., 2018), the present study is the first to investigate if sleep consistency varies on diagnostic status and if inconsistent sleep may increase risk for attention and executive functioning problems among youth with SB. In addition, the study is among the first to capitalize on a developmentally appropriate measure, the SRI, which is a metric that captures daytime sleep and day-to-day changes in sleep patterns (Fischer et al., 2021), both of which are important elements to investigate during adolescence (Nicholson et al., 2022). Investigating how sleep may confer risk among pediatric populations may provide insights on how to best support long-term illness outcomes.

Findings in the present study demonstrated that there was no significant difference between TD adolescents and adolescents with SB on the SRI. This may be because adolescent sleep is marked by irregular sleep (Nicholson et al., 2022) and therefore TD adolescents and adolescents with SB may be equally likely to experience irregular sleep-wake patterns. This finding was in contrast to the study hypothesis that adolescents with SB might demonstrate less consistent sleep than TD youth, possibly due to illness-related factors (Daniel et al., 2016). These findings are particularly surprising given that previous research suggests that youth with neurodevelopmental disorders (i.e., ADHD) exhibit more irregular sleep compared to TD youth (Gruber et al., 2000; Hvolby et al., 2008; Langberg et al., 2019). Youth with SB often experience hallmark symptoms of ADHD, including deficits in attention and executive functioning (Rose &

Holmbeck, 2007), and nearly a third meet clinical criteria for ADHD (Burmeister et al., 2005). It is possible that differences in sleep consistency might be more apparent during emerging adulthood, when the sleep midpoint is notably later among those with SB compared to TD youth (Edelstein et al., 2012). The transition to adulthood may mark a critical period to investigate sleep and sleep timing for individuals with SB, especially since difficulties transitioning from pediatric to adult care may pose risks for illness management and medical complications that could subsequently impact sleep (Mukherjee & Pasulka, 2017). Future studies should consider how these illness-related factors as well as psychological factors could influence sleep patterns among adolescents and emerging adults with SB. For example, 25% of individuals with SB experience chronic pain (Ohanian et al., 2020), a known factor that affects sleep (Husak & Bair, 2020). Therefore, it may be that poorly managed pain may contribute to irregular sleep patterns.

The present study also hypothesized that the SRI would be associated with subjective measures of sleep, collected in both TD and SB samples. Findings demonstrated that individuals exhibiting less regular sleep measured via actigraphy also reported poorer sleep hygiene, consistent with the study hypothesis. Poor sleep hygiene is often characterized by poor daily habits (e.g., caffeine use, exercise before bed), including having inconsistent sleep schedules (LeBourgeois et al., 2005). Therefore, these findings provide preliminary evidence of convergent validity, such that reports of poorer sleep hygiene coincide with less regular sleep on the SRI. In comparison, there were non-significant relations between the SRI and other measures available related to subjective sleep (i.e., sleep quality, pre-sleep arousal). Prior work has observed associations between the SRI and other sleep quality as measures, including the Pittsburg Sleep Quality Index (PSQI; Buysse et al., 1989) among emerging adults in college (Phillips et al., 2017). However, the PSQI appears to capture global sleep problems, including sleep duration, latency, efficiency, and daytime dysfunction within the calculation of this measure (Buysse et al., 1989). Therefore, future studies interested in exploring how the SRI relates to subjective sleep should use measures that are precise enough to capture sleep quality.

The second aim of the study investigated concurrent and longitudinal attention and executive functioning problems among adolescents with SB. Results demonstrated different associations based on reporter, such that lower SRI (e.g., less sleep regularity) was associated with greater attention problems several years later when reported by either the parent (if under 18 years) or via self-report. In terms of executive functioning problems, less sleep regularity was associated with greater executive functioning problems as reported by parents at the same time point, but not longitudinally. Longitudinal analyses suggested that less sleep regularity was related to greater executive functioning problems several years later as reported by teachers (if under 18) or via self-report, but not parents. These findings are notable given the inclusion of covariates, including illness severity (i.e., SB lesion level), pubertal status, sleep duration, and the previous time point of attention or executive functioning. Indeed, previous work proposed that short sleep is associated with reduced attention and executive functioning deficits among adolescents (Perez-Lloret et al., 2013; Owens & Weiss, 2017). However, this study is among the first to observe relations between less consistent sleep and greater attention and executive functioning problems. These findings have important implications for interventions that are aimed to support functioning in youth with SB, since prior studies have proposed that poorer attention and executive functioning can contribute to adaptive functioning deficits (Winning et al., 2020). In addition, inattention may contribute to reductions in academic fluency in youth with SB and this may negatively affect academic skills across subjects (Cirino et al., 2019).

Findings from the current study also reported relations between less sleep regularity and longer napping duration. The SRI affords the ability to include multiple parameters of sleep unlike other measures of sleep consistency and therefore longer naps have been shown to contribute to lower SRI (Fischer et al., 2021). This is notable since studies report that napping increases during adolescence and can contribute to a cyclical relationship between napping and poor nighttime sleep parameters (Jakubowksi et al., 2017; Rea et al., in preparation) among adolescents and emerging adults. Although only one marker of sleep consistency, taking naps may also be in response to getting poor quality of sleep or feeling fatigued during the daytime. Therefore, these factors should be investigated in future research to further understand associations between sleep consistency and cognitive outcomes (i.e., attention and executive functioning), using subjective sleepiness as a mediator.

Less regular sleep was also associated with increased age in the present study. This may suggest that sleep becomes less regular across development, possibly due to various biological and environmental factors. As mentioned, bioregulatory processes change during adolescence that contribute to circadian phase delay and a slower buildup in homeostatic sleep pressure (Crowley et al., 2018). In terms of environmental factors, increased homework responsibilities may disrupt sleep patterns (Gillen-O'Neel et al., 2013), and students likely need to complete more assignments and study for more tests as they progress through high school. Therefore, future studies investigating sleep consistency should consider the developmental trends in sleep and also investigate contributing factors that may be present during distinct developmental periods (Nicholson et al., 2022).

Strengths and Limitations

Strengths of the study include using actigraphy-derived measures of sleep and using a developmentally appropriate measure of sleep consistency (i.e., SRI) that captured both daytime and nighttime sleep. This was particularly important in this sample, which previously indicated that 45.5% of youth engaged in daytime sleep across the 10-day assessment period (Murray, 2017). However, a major limitation of the SRI is that greater sample sizes are required to detect differences between groups (Fischer et al., 2021). This may explain why the present study did not find significant differences between adolescents with SB and TD adolescents.

A strength of the present study was the ability to use data from multiple sources. Specifically, there was a demographically matched sample of TD youth that could be used to compare for differences in sleep consistency. Further, the adolescents with SB were part of a larger, longitudinal study which enabled concurrent and longitudinal analyses to investigate relations between sleep regularity, attention and executive functioning. These assessments also included multi-informant reports from parents and teachers. From an ecological perspective, the different findings observed for parents and teachers may suggest that challenges with attention and executive functioning may be more apparent to reporters in different contexts (De Los Reyes et al., 2015). In the present study, perhaps parents are aware of executive functioning problems occurring in the home first, whereas teachers notice the effects of these problems over time within the school context. Although more analyses were conducted because of the low correlation across reports, prior research suggests that collapsing multi-informant data may obscure the unique perspectives and how functioning may differ across contexts (Kraemer et al., 2003; Makol et al., 2020).

This study is not without limitations. First, the study investigated analyses using small sample sizes, particularly for the SB-only analyses, which limited the ability to detect large effects. Relatedly, a major drawback of this study is that the TD sample did not have data available on attention and executive functioning. This may have increased the study's power to detect effects as well as provided a method to investigate if sleep consistency disproportionally affected attention and executive functioning among youth with SB as compared to TD youth. In addition, the present study did not collect repeated measures of actigraphy-based measures of sleep to investigate if SRI changed over time. This also limits the ability to determine directionality of effects and cannot rule out that greater executive functioning or attention problems could contribute to reduced ability to complete everyday tasks efficiently and therefore affect sleep patterns (Turnbull et al., 2013). Another limitation of the study design was that many adolescents with SB turned 18 years old by the second time point and parents and teacher-reports of measures were discontinued. Therefore, longitudinal analyses included self-report assessments for some participants and proxy report assessments for other participants. Furthermore, correlational analyses demonstrated that parent- and teacher-reported attention problems (at T1) did not correlate with self-reported attention problems (at T2) nor did parent-reported executive functioning (at T1) correlate with self-reported executive functioning (at T2). This limits interpretations of the longitudinal findings since changes in attention and executive functioning are reported by teachers or parents and via self-report.

Future Directions

Future studies should explore sleep consistency among other pediatric populations who are at heightened risk for sleep problems (Beebe, 2012). Despite no difference in sleep consistency between adolescents with SB and TD adolescents in the present study, prior studies have identified that adolescents with ADHD experienced more variability in sleep patterns than TD adolescents (Langberg et al., 2019). Inconsistent sleep could have detrimental impacts on health outcomes related to their condition. Specifically, one study among adolescents with Type 1 diabetes demonstrated that greater sleep variability was associated with poorer glycemic control and less blood glucose monitoring (Patel et al., 2018). It is possible that executive functioning could mediate relations between sleep consistency and illness management. However, more work is needed in this area.

Interestingly, one finding in the present study indicated there were cross-sectional relations between longer sleep duration and more executive functioning problems as reported by teachers in study three. Previous studies have identified U-shaped relations between total sleep time and self-report measures of executive functioning among adolescents (Momoda et al., 2019). Therefore, future studies may benefit from investigating individuals who get short sleep, adequate sleep, and long sleep, to investigate how this might impact their day-to-day executive functioning skills.

Finally, future studies should explore the SRI as it relates to other important factors that may be impacted by circadian misalignment. The SRI has been correlated with endogenous markers of circadian timing (Phillips et al., 2017) and could be an indicator of general circadian dysregulation. If an individual's sleep timing is irregular from day to day, it would be likely that their daily routines (e.g., eating), light exposure, or other important zeitgebers ("time givers") could also be irregular and indicate circadian dysregulation. Indeed, systematic reviews find the irregular sleep patterns are associated with psychopathology, body weight, and stress and propose that circadian dysregulation may be the underlying mechanism (Bei et al., 2016; Becker et al., 2017). Therefore, studies investigating pediatric populations and adolescents in general, may seek to explore the SRI as a proxy of circadian dysregulation and see if it is associated with key outcomes.

Conclusion

Findings of the present study demonstrate that adolescents with and without SB exhibited similar levels of sleep consistency as measured by the SRI. Lower SRI (e.g., less regularity in sleep) was associated with poorer sleep hygiene among adolescents with SB and TD adolescents. Among adolescents with SB, less regular sleep was associated with and greater executive functioning problems, both concurrently and longitudinally. Further, less regular sleep was associated with greater attention problems longitudinally. Findings differed by reporter, such parents reported concerns for executive functioning problems concurrently, whereas teachers reported greater executive functioning problems several years later. Overall, these results suggest that adolescents with SB may experience adverse cognitive consequences of irregular sleep patterns, which may become evident in different contexts over time.

CHAPTER FIVE

DISCUSSION

The goals of the present series of works were to consider how various factors may disrupt sleep patterns throughout development as well as how sleep consistency may be associated with EF during at-risk periods of development. These studies expanded on the extant literature which reports that short sleep duration and sleep restriction is associated with adverse EF performance (Alhola & Polo-Kantola, 2007; Anderson & Platten, 2011; Bernier et al., 2013; Drummond et al., 2006; Lowe et al., 2017; Turnbull et al., 2013). This study instead considered the impact of inconsistent sleep, known to be associated with aspects of EF and SR (Könen et al., 2015; Barber et al., 2010) as well as neural consequences (Hasler et al., 2012; Lunsford-Avery et al., 2020; Telzer et al., 2015). The first study, “A developmental perspective on sleep consistency: Early childhood through emerging adulthood” begins by emphasizing the individual (e.g., biological, cognitive, social) and contextual factors (e.g., home, school) that increase risk for irregular sleep patterns, identifying adolescence and emerging adulthood as periods of particular risk. This paper highlights the need to use metrics of sleep consistency that can capture the range of sleep patterns that are evident during distinct developmental periods. For example, a large percentage of adolescents and emerging adults start to engage in napping, a sleep pattern that is not captured in standard measures of sleep consistency (e.g., sleep IIV), and therefore require 24-hour metrics such as the SRI (Phillips et al., 2017). The next two papers in this series used the SRI metric, and others, to investigate relations between sleep consistency and EF during at-risk developmental periods for sleep and brain development, the first being with emerging adulthood and the second with adolescence. In addition, these studies consider additional risk factors for sleep and EF, such as attending college and having SB, a congenital condition associated with attention and EF deficits.

The second study, “Consistency of sleep and inhibition among female college students” explores relations between sleep consistency and performance-based measures of inhibition among female college students who participated in a larger experimental study investigating the effects of food advertising. This study used two sleep metrics: (1) the developmentally appropriate SRI metric and (2) a novel measure aimed to capture deviation in “typical” sleep the night before the experiment. When accounting for sleep duration, the results of this study demonstrated that lower SRI (e.g., less consistent sleep) was associated with better inhibition performance (e.g., faster D-KEFS completion, less errors on SSA of unhealthy foods) whereas greater deviation in sleep (e.g., getting more sleep than “typical”) the night before the experiment was associated with better inhibition performance (e.g., less errors on SSA, better SSD). Although seemingly contradictory, these findings magnify the importance of exploring the timing of sleep consistency assessments and inhibition performance. Specifically, there may be immediate benefits of getting more sleep than “typical” on inhibition, even when accounting for sleep duration the night before. Further, third variables, such as desire to succeed and tendency to sacrifice self-care in service of a larger goal (e.g., studying for a test), may also be the characteristics of a student who exhibits less consistent sleep and therefore could explain why lower SRI would coincide with better inhibition performance.

The third study, “Sleep consistency among adolescents with spina bifida; Cross-sectional and longitudinal associations with cognitive functioning” had two aims. First, this study investigated if sleep consistency (measured using the SRI) was different between adolescents with and without SB; results revealed no significant differences between SB and TD groups. Second, this study used additional data available for the SB sample and explored concurrent and longitudinal relations between the SRI and multi-informant ratings of attention and executive functioning, both cognitive abilities that are considered vulnerable among adolescents with SB (Rose & Holmbeck, 2007). Cross-sectionally, lower SRI (e.g., less consistent sleep) was associated with greater executive functioning problems (as reported by parents) above and beyond illness severity, pubertal status, and sleep duration. Longitudinally, lower SRI was associated with greater executive functioning problems (as reported by teachers or self-report) and attention problems (as reported by parents or self-report) using the same covariates. From an ecological perspective, different findings by informants may suggest that challenges with attention and executive functioning may become evident in different contexts at different time points (De Los Reyes et al., 2015). For example, it may be that caregivers notice greater executive functioning problems in the proximal home environment, whereas these problems may become more noticeable to teachers over time within the school context.

Findings across these studies bring to light how and when sleep patterns were assessed. Although study two was limited by a cross-sectional design and self-report measures of sleep, findings suggested that getting more sleep than “typical” the night before an experiment benefited inhibition performance the following day. This coincides with prior research findings, which suggest that sleep restriction, or getting less sleep than typical, is associated with more impulsive responding and/or reduced accuracy on inhibition tasks (Drummond et al., 2006; Anderson & Platten, 2011; Alhola & Polo-Kantola, 2007; van Peer et al., 2019). In comparison, study three utilized objective measures of sleep and then captured multiformat ratings of executive functioning concurrently and then again, several years later. Findings demonstrated cross-sectional (by parent report) and longitudinal relations (by teacher or self-report) between less consistent sleep and more executive functioning problems. This is aligned with previous research which has observed cross-sectional and longitudinal consequences of sleep inconsistency on brain function (Lunsford-Avery et al., 2020; Hasler et al., 2012; Telzer et al., 2015). However, neither the extant literature nor the present study can elucidate directionality. For example, it may be that individuals with deficits in EF engage in alternative activities at night due to lack of planning or challenges with inhibition (e.g., studying last minute, staying late at a party). This could not be determined in the present series of works since sleep was only collected at one time point. Although the present collection of works demonstrated correlational findings between sleep consistency and EF, more work is needed to explore the nuances between these relations.

The present collection of works also highlighted the construct of EF, specifically inhibition, and how this construct may be understood clinically. Study two used performance-based measures of inhibition, one being a food-based SST, requiring inhibiting unhealthy and healthy food images. One major finding was that females reporting lower SRI (e.g., less consistent sleep) exhibited better accuracy in inhibiting responses when unhealthy images were presented. These findings are in contrast to prior studies that reported adolescents with less consistent sleep engaged in greater consumption of sugar sweetened beverages (Kjeldsen et al.,

2014) and snacks after dinner (He et al., 2015), also accounting for sleep duration. It is possible that the ability to accurately inhibit responses to unhealthy food images in the lab does not necessarily translate outside of the lab. In fact, a recent investigation reported that lab-based assessments of inhibition have poor convergent validity with self-reported measures of inhibition (Saunders et al., 2018) and that performance-based measures of inhibition (e.g., Stroop task, go/no-go task) were not consistently correlated in the expected direction with important life outcomes (e.g., finances, health, medical, psychological adjustment, relationships, school, work) among college students (Von Gunten et al., 2020). In comparison, the third study captured executive functioning ratings that aim to investigate the clinical consequences of poor EF. Findings suggested that less consistent sleep was related to worsened executive functioning (BRIEF; Giola et al., 2015). Therefore, researchers should consider the clinical utility of their measures and how they relate to important clinical outcomes.

Another challenge in drawing conclusions across studies is that the second and third studies analyze data among two different developmental periods (emerging adults, adolescents) and neurodiverse populations (e.g., typically developing college students, congenital medical condition). Regarding development, the first study proposes that sleep becomes less consistent over time, based on several longitudinal studies measuring sleep IIV from adolescence to emerging adulthood (Park et al., 2019; Done et al., 2015). Indeed, average SRI across the second and third study suggest that emerging adults evidenced lower SRI as compared to adolescents. This worsening of sleep consistency was in line with the narrative review proposed in study one. Interestingly, the longitudinal associations observed in study three demonstrate that sleep consistency during mid- to late-adolescence may predict attention and executive functioning in during the transition to emerging adulthood. Therefore, if sleep becomes less consistent with age, it may be possible that these associations strengthen with age. Another major difference between studies is that study two analyzes relations among a sample of typically developing females attending college whereas the third study is a sample of male and female adolescents with SB, a congenital condition marked by neurological and orthopedic differences. The third study determined that adolescents with SB and TD adolescents exhibited similar scores on the SRI, which may suggest that adolescents with SB are not at particularly heightened risk for inconsistent sleep patterns. This is in contrast to other pediatric populations (e.g., ADHD) which are reported to be at high risk for inconsistent sleep patterns (Beebe, 2012; Langberg et al., 2019) when compared to TD youth. Furthermore, although sleep consistency was similar across groups in study three, circadian timing appears to differ among emerging adults with SB as compared to TD emerging adults (Edelstein et al., 2012). Therefore, it is possible that these differences may become apparent in emerging adulthood. Longitudinal assessments of sleep and EF are needed among both TD and pediatric populations, starting in adolescence and continuing into emerging adulthood.

Strengths and Limitations

A major strength of the present collection of works is the emphasis on a developmental perspective. A narrative review of the extant literature identified at-risk developmental periods for inconsistent sleep and the specific individual and contextual factors that contribute to increased risk (study one). In addition, this review highlights important gaps in the extant literature to date and proposes considerations for future studies of sleep consistency, one being to consider developmentally appropriate measures of sleep consistency. The second and third studies use such a measure (i.e., SRI) that captures both daytime and nighttime sleep evident among adolescents and emerging adults to investigate relations with EF. One of these studies (study two) capitalized on performance-based measures of inhibition, a feature of EF, and the other (study three) used objective measures of sleep and global measures of executive functioning. In addition, studies two and three use sleep duration as a covariate in analyses to examine the influence of sleep consistency above and beyond average sleep duration, as recommended by study one.

The present collection of works has several limitations, many of which have been previously mentioned across studies. First, although the SRI is developmentally appropriate for adolescents and emerging adults who engage in both nighttime and daytime sleep, there are limitations of this measure as discussed in Fischer et al. (2021). Fischer and colleagues used simulation techniques and identified that although the SRI was less dependent on study length (e.g., number of days) this measure is not ideal when used with small sample sizes. In addition, there are relatively fewer studies that used the SRI in past research. Most of these studies used actigraphy data (Brooks et al., 2020; Lunsford-Avery et al., 2018; Lunsford-Avery et al., 2020; Murray et al., 2019; Zuraikat et al., 2020) while few used self-report (Phillips et al., 2017). Although Fischer et al. (2021) stated that both daily diary and actigraphy can be used to calculate the SRI, the SRI is sensitive to nighttime awakenings and napping which may be captured differently across self-report and actigraphy studies. Neither study included nighttime awakenings, and therefore the SRI scores may be slightly higher than would be typically seen if nighttime awakening were included.

Other limitations include the study methodology. Studies two and three involved secondary data analyses using previously collected data to address these hypotheses. Therefore, there were limits in building upon the previous literature as discussed in study one. For example, studies two and three were not equipped to capture how aspects of the home/dorm environment (i.e., room sharing, sleep rules) or school environment (i.e., class start times) may affect sleep consistency since these data were not captured. The timing of data collection was also not ideal in both studies. For study two, there was a delay in getting females to come to the laboratory following completion of the daily diary. Therefore, measures of sleep consistency using the daily diary may have captured sleep weeks before completing performance-based measures. In addition, the first study emphasized the importance of capturing changes in sleep consistency across transitions, such as summertime, where sleep consistency has been shown to become more variable (Bei et al., 2014). The third study collected sleep data from participants across the schoolyear and summer months. Of note, a dummy code was created to account for summertime or schoolyear data collection, but ultimately it was not used as a covariate given the lack of correlational findings across key study variables. Future studies should consider when sleep data collection occurs during the year and how this could influence findings related to sleep timing.

Finally, a major limitation was the use of small samples which limits generalizability to the broader populations. Specifically, both studies had analyses with samples of less than 40 participants and therefore these studies had less power and could mostly detect large effects. Therefore, there is a risk that these studies perhaps missed smaller effects and therefore increased the likelihood of a type II error (Cozby & Bates, 2020). In addition, the second study of emerging adults utilized an all-female sample, which limits our understanding of how sleep consistency affects inhibition among male college students.

Future Directions

In addition to addressing the limitations above, including using larger samples, objective and subjective measures of sleep, multi-informant ratings and performance-based measures of EF, and longitudinal designs, future studies should investigate potential third or extraneous variables, specifically as they relate to sleep. Indeed, a previous study reported that higher ratings of sleepiness, but not sleep duration, was associated with worsened self-report and performance-based measures of EF among adolescents (Anderson et al., 2009). Similarly, college students reported that short sleep and sleepiness both were associated with EF (Cifre et al., 2020). Further, experimental studies have also reported that creating inconsistent sleep schedules (1 hour difference in sleep timing from day to day) while keeping sleep duration stable was associated with increased sleepiness and difficulties awakening among adolescents (Van Dyk et al., 2019). Subjective ratings of sleepiness might also mark impairment in day-to-day executive functioning. Therefore, future studies investigating sleep consistency and cognitive functioning may want to consider sleepiness as a covariate or mediating variable.

Another recommendation for future research is to explicitly explore the role of napping behaviors as they relate to sleep consistency and cognitive outcomes among adolescents and emerging adults. Past studies have reported that napping was beneficial for cognitive functioning (Short & Chee, 2019; Ji et al., 2019; Lim et al., 2017; Lo et al., 2020). As stated, the SRI metric is sensitive to napping behavior, which is relatively common among both adolescents and emerging adults (Nicholson et al., 2020). This may offer one explanation as to why lower SRI was associated with better inhibition performance among female college students in the second study. One study by Lo et al. (2020) used an experimental procedure to examine the effects on adolescents either receiving 6.5 hours of nocturnal sleep and 1.5 hours of napping or eight-hours of nocturnal sleep with no napping. Findings demonstrated that students' cognitive performance (e.g., processing speed, working memory, psychomotor vigilance) is maintained so long as they receive adequate sleep (i.e., eight hours) throughout the day (Lo et al., 2020). Therefore, future studies are needed to parse apart the effects of napping in the context of adequate or inadequate sleep and how this may influence our understanding of sleep consistency metrics such as the SRI.

Lastly, the first study within this collection of works emphasized the need for studies to account for sleep duration within analyses, as recommended by previous researchers (Becker et al., 2017). Both the second and third study accounted for the effects of sleep duration within analyses to examine the unique contribution of sleep consistency. Interestingly, shorter sleep duration was associated with less consistent sleep in study two, but no significant relations between these two variables were identified in study three. As stated previously, Barber (2010) proposes that self-regulation is replenished by sufficient sleep whereas it is enhanced by consistent sleep. Therefore, future research is needed to investigate the combined effects of sleep duration and sleep consistency, perhaps using either variable as a moderating factor.

Conclusion

Overall, these papers argue that developmental factors should be considered in exploring sleep consistency, and that sleep consistency is associated with aspects of EF above and beyond sleep duration during key developmental periods. The first study makes the case for using developmentally appropriate measures that capture sleep behaviors that are evident during distinct developmental periods. The second and third studies use such a measure (i.e., SRI) and observe differing relations to EF above and beyond sleep duration. Findings broadly suggest that immediate changes in sleep consistency, such as getting more sleep than typical, may be associated with better inhibition as measured in a lab (study two). In comparison, less consistent sleep over time may be associated with worsened executive functioning as measured through ratings of daily behavior (study three). Beyond average sleep duration, sleep consistency is an important factor to consider among adolescents and emerging adults. Although additional studies are needed to address limitations of the present study and extant literature, clinical interventions to support adequate and consistent sleep may support adequate cognitive functions, specifically EF.

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VITA

Dr. Laura Nicholson earned her doctoral degree in Clinical Psychology from Loyola University Chicago. She received her B.A. in psychology at DePaul University Chicago. During her time at Loyola, she gained extensive research experience under the guidance of Dr. Amy Bohnert. As a member of Dr. Bohnert's lab, she assisted in various projects which aim to promote healthful behaviors and psychosocial functioning in children, adolescents, and young adults. Through the mentorship provided by Dr. Bohnert, she was able to pursue her interest in the role of sleep, particularly the consistency of sleep timing. Her clinical work in pediatric neuropsychology inspired her to investigate the relation between sleep and cognitive functions. Currently, Dr. Nicholson is a Pediatric Psychology Resident at Rush University Medical Center in Chicago, IL. She will specialize in pediatric neuropsychology at NorthShore University Health System and continue her work to exploring the relations between sleep and cognitive outcomes among neurodiverse youth.