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EFFECTS OF ACUTE SLEEP MANIPULATION ON EXECUTIVE FUNCTIONING IN SCHOOL-AGE CHILDREN

Gail C. Robertson

A dissertation
submitted in partial fulfillment
of the requirements for the degree of
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Committee Approval

To the Graduate Faculty:

The members of the committee appointed to examine the doctoral dissertation of GAIL CARROLL ROBERTSON find it satisfactory and recommend that it be accepted.

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November 11, 2013

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RE: Your application dated 11/11/2013 regarding study number 3991: The effects of acute sleep restriction on executive functions in school-age children

Dear Ms. Robertson:

Thank you for your response to requests from a prior review of your application for the new study listed above.

You are granted permission to conduct your study as most recently described effective immediately. The study is subject to continuing review on or before 11/11/2014, unless closed before that date.

Notify the HSC of any adverse events. Serious, unexpected adverse events must be reported in writing within 10 business days.

Submit progress reports on your project in six months. You should report how many subjects have participated in the project and verify that you are following the methods and procedures outlined in your approved protocol. Then, report to the Human Subjects Committee when your project has been completed. Reporting forms are available on-line.

Please note that any changes to the study as approved must be promptly reported and approved. Some changes may be approved by expedited review; others require full board review. Contact Patricia Hunter (208-282-2179; fax 208-282-4723; email: humsubj@isu.edu) if you have any questions or require further information.

Sincerely,

Ralph Baergen, PhD, MPH, CIP
Human Subjects Chair

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Abstract

A major deficit in the field of sleep restriction research is a lack of clear understanding of exactly how much sleep deprivation is harmful and the extent of neurobehavioral deficits due to acute sleep restriction. The present study assessed variations in acute sleep restriction varying from one hour restriction on one night compared to one hour restriction on four consecutive nights, as well as acute extension varying from one hour extension on one night compared to one hour extension on four consecutive nights. This study aimed to identify differences in neurobehavioral performance across the different acute sleep restriction and extension periods, particularly as compared to a control group (e.g., no sleep manipulation). Participants were a normative sample of 70 school-aged children (8-11 years-old). Findings illustrated an effect of acute sleep extension and restriction across three primary domains of neurocognitive functioning: sustained attention, reaction time, and working memory span. Clinical implications and trajectory of research was discussed.

Keywords: sleep problems, sleep restriction, sleep extension, executive function, actigraphy, children

Effects of acute sleep manipulation on executive functioning in school-age children

According to the National Sleep Foundation, more than two thirds of children experience one or more sleep problems at least a few nights a week (Foundation, 2011). These problems include not being able to fall asleep, not being able to stay asleep, and not having an adequate amount of sleep. In addition, chronic sleep problems affect at least 30% of children in the U.S. (Blunden et al., 2004; Laberge et al., 2001). The National Sleep Foundation suggests that "school-age children (5-10 years) need 10-11 hours of sleep daily…[yet] at the same time, there is an increasing demand on their time from school (e.g., homework), sports and other extracurricular activities" (Foundation, 2013). As these children enter middle school and high school, sleep duration decreases even more while involvement in school work and social activities with friends and peers increases.

Sleep problems (e.g., insomnia, inadequate sleep) have been linked to serious medical epidemics such as obesity and diabetes (Nixon et al., 2008; Smaldone, Honig, & Byrne, 2007). It has also been linked to heightened risk for depression (Gregory et al., 2005), substance use and abuse (Wong, Brower, Nigg, & Zucker, 2010; Wong, Brower, & Zucker, 2009) and suicidal behavior (Wong & Brower, 2012; Wong, Brower, & Zucker, 2011). Particularly salient to the school-age population, studies have linked sleep difficulties with decrements in attention and concentration (Meijer, Habekothe, & Van Den Wittenboer, 2000), reaction time (Sadeh, Gruber, & Raviv, 2002), memory (Wilhelm, Diekelmann, & Born, 2008), behavioral regulation (Paavonen, Porkka-Heiskanen, & Lahikainen, 2009; Stein, Mendelsohn, Obermeyer, Amromin, & Benca,

2001; Touchette et al., 2007), and cognitive performance (Bub, Buckhalt, & El-Sheikh, 2011; Carvalho et al., 2004; O'Brien & Gozal, 2004) – all of which have the potential to impact school performance and a child's ability to perceive and comprehend the material presented to them.

Previous studies have identified a relationship between neuropsychological functioning and sleep behavior. Sadeh, Gruber, and Raviv (2002) found an association between fragmented sleep and poorer performance on neurobehavioral tasks requiring higher level executive control – specifically the Continuous Performance Test (CPT) and digit span tasks. In support of these results, studies have also consistently found a relationship between Attention-Deficit Hyperactivity Disorder symptomology (ADHD) and disruptions of sleep (e.g., Dahl, 1996; Chervin, Bassetti, Ganoczy, & Pituch, 1997; Corkum, Tannock, Moldofsky, Hogg-Johnson, & Humphries, 2001; Touchette et al., 2007). ADHD symptomology typically presents as inattentiveness, hyperactivity, decrement in inhibitory control, and variable reaction time. Essentially, executive functions – such as planning, initiation, self-regulation, and inhibition appear particularly susceptible to disruptions in sleep.

Most studies examining sleep behaviors and patterns have utilized an experimental design in which assessment and collection of the independent variable (e.g., cognitive or neuropsychological testing scores, processing speed time) occurs before sleep measurement and directly afterwards. This design is necessary when implementing sleep restriction or deprivation and comparing it to control as it allows a cause and effect relationship to be ascertained. Almost all previous studies of sleep have implemented this design, and for the purposes of review these studies are the focus. Further, a major

deficit in the field of sleep restriction research is a clear understanding of exactly how much sleep deprivation is harmful and to what extent neurobehavioral deficits occurs due to acute lengths of sleep restriction.

Sleep restriction studies among children vary in length but require multiple nights of sleep restriction and uninterrupted sleep (e.g., a week-long study). The commitment required by parents and children for a sleep restriction study is great. An at-home sleep protocol is preferred over lab-based sleep assessment by polysomnography due to accessibility and the benefits of a natural home setting. Though sleep restriction studies typically overlap with school attendance, this study's restriction is constrained to one hour per night rather than a full night of deprivation. It is believed that this amount of restriction should not place an undue burden on either the subjects or their parents. To examine the relationship between sleep problems and neurocognitive performance, it is necessary to have a sufficient delay between the first and second study sessions (i.e., pre-restriction and post restriction) in order to avoid practice effects. While a 2 or 3 week protocol would be ideal, the length of the current protocol was shortened to only 1 week and measures of executive functioning which were particularly susceptible to practice effects were conducted only at post-assessment.

Multiple studies have utilized a weeklong design with school-age samples and found this period to be feasible for children and adolescents. A study by Beebe and colleagues (2008) evaluated 13 to 17 year olds utilizing a 3-week alternating short, long, controlled at-home restriction sleep protocol. They found that those adolescents in the restricted sleep week had greater problems with sleepiness, attention, irritability, behavior regulation, and metacognition. Additionally, the sleep restriction group was able to

successfully comply with the sleep protocol procedures. Another study by Jiang and colleagues (2011) again evaluated using a home-based sleep restriction protocol in adolescents with similar feasibility findings, but different effects on neurobehavioral performance. They had 13 to 16 year old adolescents participate in a 2-week long sleep manipulation, including 5 school days with a restricted sleep period (6 hours in bed per night). Sleepiness and reaction times increased during the restricted week, however working memory was not impacted. Part of the utility of actigraphy is its relatively low intrusiveness and the ability to maintain a naturalistic setting of study. Experimental sleep-restriction studies are essential to assert a relationship between neurocognitive functioning and sleep.

The present study assessed variations in sleep restriction and extension using objective activity monitoring through actigraphy, as well as parent and self-reports of subjective sleep experiences. At present, a few limited studies have evaluated extended acute sleep restriction (1 to 3 hrs. per night for 3 to 4 nights), yet no studies have compared this extended sleep restriction period with only one night of acute sleep restriction. With an evaluation of individual performance on the Continuous Performance Test and other inhibitory control tasks of executive functioning, this study aimed to identify differences in neurobehavioral performance across acute sleep restriction periods. Following, the current status of research in the field of sleep will be reviewed with an effort to convey those areas which have provided the theoretical backdrop for the current study, identify gaps in the literature expanded on by the findings in this study, and identify gaps which still remain to be filled by future research.

Literature Review

Sleep

Definition. Sleep is defined as a loss of awareness, loss of responsivity, and the occurrence of restorative processes (Dahl, 1996a, 1999). It is not simply a state of relaxation or even of rest, nor is it simply a lack of wakefulness. With increasing sleep deprivation, individuals experience progressively more severe and performance hindering deficits. Because individual differences in sleep necessity are so varied, sufficient sleep is often defined by an individual's performance while awake or "optimal daytime functioning" (Dahl, 1999). While full-night sleep deprivation has previously been believed to be more detrimental, recent research has shown that chronic acute sleep restriction of only a few hours a night may be as damaging, if not more so due to its seemingly innocuous nature. To truly understand the effects of sleep, it is essential to develop a foundation of literature spanning the variations in sleep duration and quality across the developmental trajectory.

Development. As part of the arousal regulation system, sleep-wake patterns sometimes dramatically vary between individuals (Dahl, 1999). Throughout development, an individual's sleep-wake schedule transitions into a relatively balanced divided sleep schedule in adolescence, with most individuals settling into a period of continuous nocturnal sleep and an extended daytime wakeful period. This transition is "one of the first markers of early biobehavioral organization and adaptation" (Sadeh & Anders, 1993; Thoman, 1975, 1990 as cited from Sadeh, Raviv, and Gruber, 2000).

In the first year of life, the most dramatic transition from a short sleep-wake cycle to a more bimodal system occurs before the first year of life when a child begins

"consolidating their nocturnal sleep" or sleeping through the night (Anders, 1979). This early developmental process appears to occur quite quickly, tapering off as the child grows older. Early childhood is marked by a decrease in naps (Weissbluth, 1995), "delayed evening bedtime" (Sadeh et al., 2000), and thus a tapering off of sleep duration overall. As children transition into adolescence, their sleep needs increase again to approximately 10 to 11 hours, yet increasing demands on time such as school schedules and extracurricular activities decrease the availability of sufficient time devoted to sleep (Foundation, 2011).

Effects of Insufficient Sleep

If sleep duration is not sufficient, individuals will experience a) sleepiness, b) decrements to motivation, c) emotional changes, and d) alterations in attention and performance (Dahl, 1999). As an individual's sleep is restricted over time, "the homeostatic drive to sleep rises, and cognitive performance begins to decline" (Jiang et al., 2011). Individuals tend to report these symptoms as either tiredness, sleepiness, or drowsiness. Furthermore, sleep problems differ widely across developmental periods with sleep disorder prevalence ranging from 3 to 50% (Schreck, Mulick, & Rojahn, 2005).

Parental ratings and self-report. Schreck, Mulick, and Rojahn (2005) evaluated what sleep behaviors were reported by parents and their prevalence in school-aged children in the United States. In this study, they evaluated 1,459 parent reports (Behavioral Evaluation of Disorders of Sleep questionnaire) of sleep problems among 5 to 12 year-olds. Results indicated only 4% of children were reported as having significant global sleep problems and only 9% met clinical significance. When compared

to the National Sleep Foundation's report of children with sleep problems (i.e., third of children have sleep problems), this data suggests that either reports of sleep problems in children are inconsistent or that there is a factor unaccounted for across studies demonstrating a higher prevalence rate.

Similarly, it appears that sleep need differs greatly among individuals, and in particular adolescents. An early longitudinal study by Strauch and Meier (1988) collected from 1975-1985 showed that German adolescents' sleep quantity on the weekend averaged 30 minutes less in 10 to 14 year-olds, with the difference increasing to over 2 hours by age 18. While this was considered to be a demonstration of less need for sleep as adolescents age, it may also demonstrate changing social expectations, changes in circadian rhythms, or simply a decrease in available sleep time. In fact, research since this study indicates that adolescents need more sleep than their younger counterparts due to pubertal changes in sleep patterns and daytime alertness (Carskadon, 1990).

A study by Fredriksen and colleagues (2004) of 11 – 15 year-olds found that decreases in sleep over the middle school years was related to higher levels of depressive mood and lower self-esteem. These reports highlighted the effects of poorer sleep on mood and self-concept, and evidenced problems with decreased sleep duration and quality over middle childhood. However, these studies did not indicate a relative shift in sleep required for functioning at varying ages, but rather a change in actual sleep behavior without direct causation. At the very least, these studies indicate a changing societal atmosphere surrounding sleep behavior and shorter sleep times as adolescents mature.

Developmentally, sleep has been linked longitudinally with externalizing

problems such as hyperactivity and inattention, as well as neuro-developmental deficits. A study by Touchette (2007) evaluated 1,492 children at age 6 using sleep duration reports from 2.5 to 6 years-old and questionnaires regarding daytime behavior. They determined that children should be given the opportunity to sleep at least 10 hours per night in early childhood. Without sufficient sleep, these children tend to show signs of sleepiness beyond the typical yawning or "droopy eyelids."

Actigraph. Sleep can be measured and assessed using a variety of methods including: Polysomnography (PSG), electroencephalography (EEG), questionnaire-style reports, sleep diaries, observation, or activity monitoring. Objective measures of sleep include those which are separate from individual-judgment and thus unbiased by the participant (e.g., activity monitoring/actigraph or polysomnography). Actigraphy is a continuous measure of activity based on gross motor movements, of which the data can then be translated into a valid and reliable estimate of sleep-wake boundaries and content. Sadeh et al. (1989) developed algorithms which agree with polysomnography in denoting these sleep-wake boundaries, quantity, and some level of quality 85-95% of the time (Sadeh, 2008). The ability of actigraph to be used in a naturalistic setting has allowed for more accurate assessments of natural sleep (Aronen, Paavonen, Fjällberg, Soininen, & Törrönen, 2000; Sadeh & Acebo, 2002; Sadeh et al., 2002). It has been used successfully in research and clinical practice (Sadeh and Acebo, 2002).

There are several limitations of actigraphy. Sadeh (2008) identified 4 limitations: 1) if child sleeps in a moving object such as a parent's arms or stroller, data will not reflect accurately whether the child's activity increases and decreases, 2) actigraph watches are dependent on attachment by the participant, particularly if allowed to be

removed, and thus can be inappropriately placed or forgotten, 3) actigraph watches are subject to the technical glitches associated with any mechanical device or watch, 4) logs of activity and/or sleep are essential to verify activity data and prevent other limitations from occurring (Acebo, Sadeh, Seifer, Tzischinsky, & Carskadon, 2000; Acebo et al., 2005; Acebo et al., 1999; Sadeh, 2008). Furthermore, sleep stages cannot be identified through actigraphy alone (Aronen et al., 2000). But, in comparison to polysomnography and EEG, which both require the individual being assessed to sleep in the lab with wires attached to them, actigraph watches provide an efficient, cost and time effective means of collecting objective sleep –wake data within the individual's natural home setting.

Effect of Sleep Problems on Executive Functioning

Executive control is demonstrated by an individual's ability to organize and "coordinate performance on two separate tasks," "switch retrieval strategies," "attend selectively to one stimulus and inhibit…others," and "hold and manipulate information in long-term memory" (Baddeley, 1996). Essentially, executive functioning is a broad concept used to describe the control an individual exerts in planning, categorizing/organizing, cognitive manipulation, attention, and self-regulation (Baddeley, 1996, 1998; Miyake et al., 2000; Robbins, Weinberger, Taylor, & Morris, 1996). This ability is represented in an individual's ability to acquire and understand a rule, cognitively hold the rule within their consciousness, initiate or inhibit actions regarding the rule, and switch between multiple rules or within a rule. Throughout development, an individual's executive functioning abilities change based on brain physiology and environmental interaction (Diamond, 2006).

A person's ability to interact, manipulate, and understand the world around them

is affected by their executive functioning capabilities and cognition in general. For instance, children are often required to follow specific rules and directions at school, hold ideas in mind, and complete tasks according to those rules while inhibiting alternative responding. Barkley's (1997) model goes a step further and asserts that central to executive functions is the concept or strategy of inhibition. This theory postulated that development of inhibitory control progressed with development of the prefrontal cortex (Brocki & Bohlin, 2004).

A number of studies have explored the association between varying tasks believed to be linked to activity in the prefrontal cortex. When these prefrontal cortex functions are impaired, complex behavior, attention, inhibition, planning, and most regulatory behaviors are impacted. These deficits can then extend to the creation or exacerbation of numerous social, emotional, and psychiatric dysfunction (Dahl, 1996a; Horne, 1993; Smedje, Broman, & Hetta, 2001).

Horne (1993) evaluated "dual tasks" and creative or flexible thinking. Flexibility is an essential component of executive functioning. It is most clearly exemplified in an individual's ability to *think outside of the box* or switch processes or solutions when the task demands it. These tasks, which require prefrontal cortex processing, were also found to be sensitive to sleep loss. While these deficits can be observed in a clinical setting, it is more evident in a school setting or when an individual's executive control or processes are deficient, and thus impact other behaviors.

A study by Harrison and Horne (1998) assessed twenty adults on short language tasks. Each adult was randomly assigned to either the no sleep deprivation or 36 hours of continuous sleep deprivation group. They found that significant sleep loss appeared to

"interfere with novel responses and the ability to suppress routine answers." These results not only demonstrated the negative impact sleep deprivation can have on executive control, but also countered arguments made that sleep deprivation only causes detriments to tasks which are long, tedious, and related to "nonspecific arousal" (Kjellberg, 1977; Wilkinson, 1992) or when no compensatory effort is made (Horne & Pettitt, 1985). Essentially, regardless of novelty or short duration, tasks requiring the prefrontal cortex are impaired by sleep loss.

Studies have highlighted a potential association between poor sleep and ADHD in children (Lavigne et al., 1999; Ring et al., 1998). However, it is important to note that lapses in attention during simple tasks can "mimic or exacerbate symptoms of ADHD, including distractibility, impulsivity, and difficulty with effortful control of attention" and has consistently been linked to deficits in multi-tasking and completion of complex tasks (Dahl, 1999). A previous study by Chervin and colleagues (1997) observed these same similarities between ADHD and sleep deprivation, specifically regarding self-control or inhibitory processes of impulsive behavior and attention. Yet even when research consistently demonstrated a relationship between sleep loss and neurocognitive performance, it is difficult to assert the directionality of the relationship. Further complicating this relationship and delineating it from ADHD symptomology, sleep deprivation appears to be at least partially mediated by motivation or increased effort (Dahl, 1999).

Because executive functioning is so essential for everyday cognition and behavior, individuals with poor sleep are at increased risk for exhibiting impairments with understanding and manipulating rules, directions, holding ideas in one's mind, and

inhibiting behavior that is incongruent with the task. These impairments have the potential to "progress…or [elicit] a spiral of negative effects" in a person's life (Dahl, 1999). Longitudinal studies in epidemiology have shown increasing incidence and association of behavioral problems beyond specified cognitions with sleep (Aronen et al., 2000; Blader, Koplewicz, Abikoff, & Foley, 1997; Dahl, 1996a; Fallone, Acebo, Arnedt, Seifer, & Carskadon, 2001; Zuckerman, Stevenson, & Bailey, 1987). Smedje, Broman, and Hetta (2001) demonstrated in a study of 635 children 6 years-old to 8 years-old, that "36% of children with global reports of sleep problems…can be expected to have significant problems and conversely, that 15% of children with behavioral problems have global reports of sleep problems." They found that both quantity and quality of sleep are implicated in sleep problems. This varied literature on the implications of sleep deficits on neurocognitive performance highlights the importance of evaluating this relationship experimentally, so directionality and control can be asserted.

Sleep Restriction and Impaired Neurocognitive Performance. A study by Sadeh, Gruber, and Raviv (2003) assessed children ranging in age from 9 to 12 years old for their sleep and neurobehavioral functioning. They had children restrict their sleep over the course of three nights, with compliance and sleep measured with actigraphy. Using a pretest-posttest design evaluating neurobehavioral functioning (e.g., digit span, reaction time, continuous performance, and motor behavior), they found that three nights of one hour restricted sleep led to longer reaction times, while increasing sleep by one hour over the three nights led to improved forward digit span and performance on the Conner's continuous performance test. Interestingly, with this acute sleep restriction, subjective report of sleep quality improved even as alertness decreased.

These results supported previous literature linking sleep disruption or insufficient sleep with deficits in attention and executive control (Dahl, 1996a, 1999). Sadeh and colleagues (2002) found that tasks like the CPT and digit span were performed better by those children with extended sleep as compared to when they restricted sleep time. Additionally, cognitive functioning has been implicated in the deficits attributed to sleep deprivation, including psychomotor behavior requiring attention, planning, and motor coordination (Stepanski, 2002). Using EEG to measure sleep fragmentation, a number of studies have found decrements in tasks related to attention, concentration, and focus. In particular, with sleep disruptions or deprivation deficits are demonstrated in vigilance (Bonnet, 1986a, 1986b), reaction time (Stepanski, Lamphere, Roehrs, Zorick, & Roth, 1987), and trail-making tasks (S. E. Martin, Engleman, Deary, & Douglas, 1996). Similar results have been found in adults and adolescents, but few studies have evaluated the effects of sleep restriction in childhood and early adolescence.

Studies of children have demonstrated mixed results. While some studies demonstrate a link between poor sleep and cognitive performance, other studies have found that acute sleep restriction resulted in either no impairment or even in some cases improvement. For example, a study by Carskadon and colleagues (1981b) with children allowed only 5 hours of sleep or one night total sleep deprivation indicated that less sleep did not affect motor performance. In contrast, a study by Randazzo, Muelback, Schweitzer, and Walsh (1998) found that acute sleep restriction in early adolescence (10-14 year-olds) was associated with impairments to cognitive functioning when the sleep loss was experimentally created.

Another study randomly assigned individuals to one of three conditions (3, 5, or 8

hours of sleep) for two nights (Cote et al., 2009). They found that deficits were evident not only in sleepiness but also in mood and reaction time. Similar results were found in a study by Gruber and colleagues (2011) evaluating children with ADHD. They restricted 7 to 11 year old children's sleep by one hour for six days in a row and evaluated change in Conner's continuous performance test (CPT) scores. With restriction, omission errors increased, reaction times slowed, and children's scores had higher variability in ISIs. Yet, commission errors actually decreased, showing a relative improvement in scores when comparing pre and post-testing.

In a recent study evaluating one hour of sleep restriction for only 4 nights in 8 to 12 year old children, positive affective responses were diminished, children demonstrated more emotional dysregulation, and problems with working memory and attention with this acute sleep restriction (Vriend et al., 2013). These results matched those found by Alhola and Polo-Kantola (2007), who found that sleep deprivation impaired attention and working memory, as well as decision-making.

In contrast, some studies counter the finding of impaired performance on tests of inhibition and show no increases in hyperactive-impulsive behavior or sustained attention following sleep restriction. A study by Fallone and colleagues (2001) assessed the impact of "acute sleep restriction on daytime behavior and performance" in 8 to 15 year-olds. This study utilized 5 nights of baseline sleep and assignment to either optimized or restricted sleep for a night of lab-observation. They found that the sleep restriction was associated with shorter daytime sleep latency, increased sleepiness, and increases in inattentive behaviors – but did not find an association on any other performance measures.

These contrasting studies exemplify the need for further research into sleep behavior and cognitive/behavioral performance, particularly studies focused on delineating the differences among varying lengths of sleep restriction. While results regarding full-night sleep deprivation are relatively consistent, the results regarding acute or short-term sleep restriction are varied. A thorough literature review did not identify any studies comparing partial sleep restriction (1-hr per night) across multiple nights vs. only one night. A previous study carried out by this author (Robertson, 2013) showed that without sleep restriction, when compared to overall quality of sleep over three nights, sleep quality obtained during the night directly prior to neurocognitive testing held the strongest correlational relationship. Because executive functioning is so essential for everyday cognition and behavior, individuals with poor sleep are at increased risk for exhibiting impairments with understanding and manipulating rules, directions, holding ideas in one's mind, and inhibiting behavior that is incongruent with the task.

This study expanded on previous literature on the relationship between sleep and neurocognitive functioning, structuring the design after the studies by Sadeh and colleagues (Sadeh et al., 2002; Sadeh, Gruber, & Raviv, 2003). Specifically, children in this study were randomly assigned to either a control no-restriction group, a single night of sleep restriction or extension, or a repeated sleep restriction or extension over four nights (1-hr restriction each night).

Present Study

Sleep holds a vital role in children's development, cognitive functioning, and general well-being. Acute sleep restriction studies in children encompass a wide range of variation in sleep deprivation from 1-hr in one night to 4 hours in one night, to 7 hours

across 7 nights or 21 hours across 7 nights. These variations in sleep loss may be detrimental. With the ambiguity in the effects of short-term sleep loss, it is imperative to examine the impact of various acute restrictions on neurobehavioral functioning.

This study examined the potential relationship of sleep behavior to inhibitory control processes in executive functioning. Specifically, a comparison was sought between different lengths of acute sleep manipulation. Based on previous results, it was hypothesized that acute sleep restriction would be associated with impairments in neurocognitive functioning, particularly inhibitory functioning. This decrement was expected to be greater in children who had prolonged acute sleep restriction than in those restricted on only one night or not restricted at all. Complementing this deficit in effect, it was also hypothesized that acute sleep extension would be associated with improvement in neurocognitive functioning.

Furthermore, given the normal sample of children without chronic sleep problems, it was hypothesized that acute restriction the night directly prior to neurocognitive testing would also show decreased performance in neurocognitive measures, but not more severe decrements than the prolonged sleep restriction.

To evaluate these questions, a number of hypotheses were proposed in addition to a general evaluation of the neurocognitive abilities impacted by sleep restriction.

Hypothesis 1. Neurocognitive performance was predicted to be impaired in experimental sleep restriction groups compared to the control group. Moreover, the prolonged sleep restriction group will demonstrate more decrement in performance of inhibitory functioning than the acute sleep restriction group.

Hypothesis 2. Neurocognitive performance was predicted to be maintained or improved in experimental sleep extension groups compared to the control group. Moreover, the prolonged sleep extension group will demonstrate better performance of inhibitory functioning than the acute sleep restriction groups and control.

Method

Participants

Seventy children participated in this study ranging in age from 8 to 11 (*M* = 10.2 yrs., SD = 1.1). In addition, at least one primary guardian was required to participate in completing questionnaires about their child's sleep and assisting with actigraph compliance. Children were excluded if one or more of the following criteria were met: acute or chronic physical illness that affects sleep, a diagnosed sleep disorder, or medications limiting ability to participate or comply with the requirements of the procedure. Three additional children were originally recruited, but were excluded during the pre-screening process due to pre-existing conditions (e.g., ADHD, sleep disorder).

Demographic characteristics for children and their parents are presented in Table 1 (pg. 19). Children were largely equally split between male and female (42.9% and 55.7%, respectively), with one child identifying as "Other." For the purposes of analyses, the child who identified as "Other" was classified by their sex and primary reported gender orientation. Children were Caucasian or white in ethnicity (85.7%), multi-racial (8.6%), Hispanic/Latino/Mexican (4.3%), and Asian (1.4%). Due to the large percentage of Caucasian participants in the sample, the sample was recoded into a dichotomous variable of Caucasian/White participants and Non-Caucasian participants for the purpose of analyses.

Table 1
Demographic Descriptive Statistics

Characteristic	Child		Parent [rp]	
	Range	M ± SD	Range	M ± SD
Age	8.1 – 12.0*	10.2 ± 1.1		
Grade	2 – 7*	4.2 ± 1.3		
Individuals in House			2 - 10	4.8 ± 1.6
	N	% of sample	N	% of sample
Gender				
Male	30	42.9	8	11.4
Female	39	55.7	62	88.6
Other	1	1.4	0	0.0
Ethnicity				
Caucasian/White	60	85.7	65	92.9
Hispanic/Mexican	3	4.3	3	4.3
Asian	1	1.4	1	1.4
Ind/Native-American	0	0.0	1	1.4
Multi-racial	6	8.6	0	0.0
Puberty				
Pre-pubertal	27	38.6		
Early Puberty	21	30.0		
Mid-pubertal	18	25.7		
Late Puberty	4	5.7		
Post-pubertal	0	0.0		
Marital Status				
Married			56	80.0
Divorced			8	11.4
Living w/Partner			2	2.9
Civil Union			1	1.4
Single			2	2.9
Widowed			1	1.4
Household Income				
Under $25,000			9	12.9
$25,000-50,000			22	31.4
$50,000-75,000			22	31.4
$75,000-100,000			10	14.3
$100,000-150,000			4	5.7
Would rather not say			3	4.3
Father's Education				
Middle School			1	1.4
High School			19	27.1
Some College			14	20.0
Vocational School			7	10.0
Bachelor's Degree			16	22.9
Master's Degree			4	5.7
Professional Degree			9	12.9
Mother's Education				
Middle School			0	0.0
High School			6	8.6
Some College			38	54.3
Vocational School			5	7.1
Bachelor's Degree			13	18.6
Master's Degree			5	7.1
Professional Degree			1	1.4

*Note: *one child was 11 years-old and in 6th grade at start of study; rp = reporting parent.*

The majority of children fell between the pre-pubertal and mid-pubertal stages of development (94.3%), with only four children in the late puberty stage. No children were identified as post-pubertal, or completing puberty. Gender (1 = male, female = 0), ethnicity (1 = Caucasian, 0 = Not Caucasian), age, and pubertal stage (utilizing the continuous pubertal development score) were controlled for in analyses if they significantly predicted the outcome variables. Demographic covariates with no significant relationship with the dependent variables were dropped from analyses to increase the statistical power of finding a statistical significant relationship between independent and dependent variables.

Procedure

This study was approved by the Human Subjects Committee of Idaho State University. Informed consent was obtained from the guardian or parent of each child. Additionally, assent was obtained from each child. Each parent-child pair received one of two incentives for participating. Parent-child pairs from the community received a $15.00 gift certificate for school supplies in compensation for their participation, while each participating parent recruited from the ISU SONA System received five research credits for taking part in this study.

Parents with children who meet the inclusion criteria were recruited through the Idaho State University SONA Systems web-based human subject pool and from the community via posted flyers, online advertisements, and word-of-mouth. Parents and children were asked to participate in two study sessions in the ISU Psychology Department (see description of each session below). During the sessions, neurocognitive measures were counterbalanced across participants (i.e., CPT administered first or last

and the order of the three other measures completed in counterbalanced order). Additionally, children were asked to wear an actigraph watch (activity monitoring device) for four nights after the first session. They were randomly assigned to one of five sleep conditions: 1-hour sleep restriction for the four consecutive nights, 1-hour sleep restriction for only the final night, 1-hour sleep extension for four consecutive nights, 1-hour sleep extension for only the final night, or a no restriction control condition. Each session was conducted by the principal investigator of this study or her trained research assistants.

Online Prescreening. Prior to attending any study sessions, parents were asked to complete a battery of questionnaires in a secure online website. They were asked to sign an informed consent and were briefed on the content of both sessions and their responsibilities throughout. Parents then completed the child health history (Zucker & Fitzgerald, 2002; Appendix A), a demographics questionnaire (Appendix B), and the *Children's Sleep Habits Questionnaire* (CSHQ; Appendix D). Following completion of the questionnaires, parents were asked to schedule a time for the first and second study sessions.

Session 1. When children and their parents arrived for the first session, the informed consent previously signed and the content of the two in-person sessions was briefly reviewed. Children were also given an explanation of their responsibilities during the study period and asked for assent. Children completed a short puberty scale (Carskadon & Acebo, 1993; Appendix C), the Sleep Self-report (SSR; Appendix E), the Conner's Continuous Performance Test (CPT), backward digit span, color-word interference task from the Delis-Kaplan Executive Functions System, and the Early

Adolescent Temperament Questionnaire-Revised (Rothbart, Ellis & Posner, 2004). Following the battery, children and their parents were educated on the use of the actigraphy (i.e., information on activity monitoring, when the children were to begin wearing them, and what sleep schedule they should maintain). Children were instructed to attach the activity monitor to the wrist of their non-dominant hand, with parental support if necessary. Children were required to wear the actigraph for four consecutive nights (from one-half hour before going to bed to one-half hour after waking). Children were asked either to maintain their typical weekday sleep schedule (if in the control group) or to follow their typical weekday sleep schedule with restriction or extension (if in experimental group). To assure compliance to the sleep schedule and as a reminder, parents received a phone call or text message reminding (parent choice) them of the sleep schedule for each night and verifying the child's compliance. In addition, instructions for completing the daily sleep diary were explained to both the child and parent (Appendices F and G). Children and their parents were permitted to ask questions throughout this session regarding any component of their participation. Children were asked again prior to the end of session one whether they assent to both wearing the actigraphy watch and attending the second session for neurobehavioral testing. Following these instructions, the child and parent were reminded of their scheduled second session on the day following the last night cycle.

Session 2. During the follow-up appointment parents completed the Child Behavior Checklist (CBCL) while their child completed the lab portion of the experiment. Each child completed a neurobehavioral evaluation including a second administration of the CPT (14 minutes), the Delis-Kaplan Executive Function System

color-word interference (D-KEFS; 5 minutes), backward digit span (5 minutes), and the Wisconsin Card Sorting Task (WCST; 15 minutes). The actigraphy watch and sleep diaries were collected from the children and their parents. Finally, both the child and their parent were debriefed and given a $15.00 gift card for school supplies as compensation for their participation or research credits; children were also be given a small compensation from a prize box (e.g., specialty pencil, notebook, small non-peanut candy, etc.).

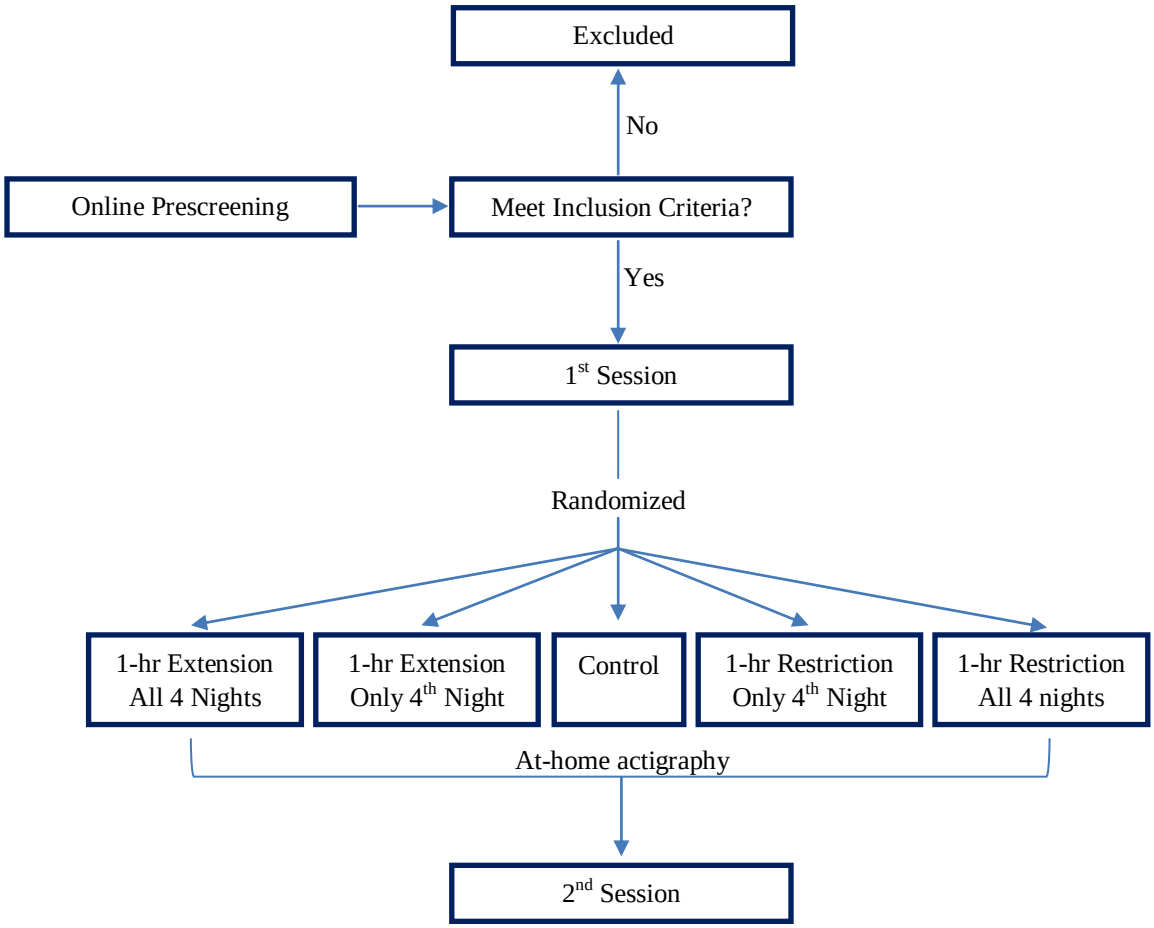

Figure 1. Procedure flowchart. Figure illustrating the course of procedures from recruitment to completion of 2nd session.

Measures

Actigraphy. Activity monitoring data included the following sleep measures: (a) sleep onset time – defined by the first minute after reported bedtime as identified by sleep analysis sleep-wake algorithm and that was followed by at least 15 minutes of continuous sleep; (b) time of morning awakening – defined by the first minute following at least 15 minutes of continuous sleep; (c) sleep duration – defined as the minutes from sleep onset to morning awakening; (d) true sleep time – defined as the minutes from sleep onset to morning awakening, excluding periods in the night of wakefulness; (e) sleep percentage – the percentage of the sleep duration composed of true sleep; (f) periods of wakefulness – defined by the number of wakeful periods lasting 5 minutes or longer that are preceded and followed by at least 15 minutes of continuous sleep; (g) longest sleep period – longest period of continuous sleep without any wakefulness; (h) motionless sleep percentage – defined as the percentage of the sleep duration for which there was no recorded activity. These sleep measures have previously been used in actigraphy research and have been found to maintain validity and reliability in natural setting with school-aged children (Sadeh & Acebo, 2002; Sadeh et al., 2003; Sadeh, Hauri, Kripke, & Lavie, 1995). Actigraphic raw data were translated and coded using scoring analysis software for PC using a 1-minute epoch.

Daily sleep diaries. In addition to the objective sleep measures assessed through actigraph, daily sleep diaries were utilized to obtain subjective sleep information from both the children and parents (Appendix F and G). Information obtained on the subjective measures included: (a) time in bed – defined as child in bed with lights out; (b) morning rise time– defined by time of initial alertness; (c) periods of night wakefulness –

defined by number of times remembered awakening in the night for 5 minutes or longer; (d) sleep quality – assessed on a 5-point scale ranging from *very bad* (1) to *very good* (5); (e) duration to fall asleep – assessed on a 4-point scale ranging from 1 (*less than 5 minutes)* to 4 (*more than 30 min.*); (f) evening tiredness– assessed using a 5-point scale ranging from *very alert* (1) to *very tired* (5); (g) morning tiredness – assessed using a 5-point scale ranging from *very alert* (1) to *very tired* (5).

Children's Sleep Habits Questionnaire (CSHQ). The CSHQ is a retrospective, 45-item parent-report questionnaire used to examine sleep behaviors in young children (Owens, Spirito, & McGuinn, 2000). It yields eight subscales pertaining to sleep behaviors including: (1) bedtime resistance; (2) sleep-onset delay; (3) sleep duration; (4) sleep anxiety; (5) night waking; (6) parasomnias; (7) sleep-disordered breathing; and (8) daytime sleepiness.

Sleep Self-report (SSR). The SSR is an 18-item, 1-week retrospective survey for 7 to 12 year olds designed to assess domains similar to the CSHQ (Owens, Maxim, Nobile, McGuinn, & Msall, 2000). Items address difficulty going to bed and falling asleep, sleep duration, night waking, and daytime sleepiness.

Connor's Continuous Performance Test - II (CPT-II). The CPT is an attention test commonly used in clinical assessments for impulsivity, inattentiveness, inhibitory control, and vigilance (Conners et al., 2000). As individuals are presented with a string of letters (varied in speed of presentation), individuals are told to click the space bar when presented with any letter except "X." The test yields a number of measures including: response times/reaction times, variability, omission and commissions, and consistency across testing.

The CPT-II is essential to this research study to accurately capture and examine the attention and inhibition components over continuous sustained performance. It is widely used in ADHD research and clinical assessments of attention, inhibition, and impulsivity. However, unlike many other computerized continuous performance tasks, the CPT-II's administration duration is only 14 minutes, while most other tests require 20 or more minutes. Duration of testing is particularly important when testing younger children or as part of a comprehensive battery.

Delis-Kaplan Executive Function System (D-KEFS). The D-KEFS assesses a wide range of executive functions including flexibility of thinking, inhibition, problem solving, planning, impulse control, concept formation, abstract thinking, and creativity in verbal and spatial modalities. Because each test can stand alone, for this study only one subtest was administered which specifically assesses inhibition: the Color-Word Interference Test. This task measures an individuals' ability to inhibit natural responding in order to respond in accordance with a set of defined rules.

Wisconsin Card Sorting Test (WCST). WCST (Grant & Berg, 1993) assesses an individual's ability to develop and maintain a problem-solving strategy across changing stimulus conditions. For the purposes of this study, the WCST provided a measure of perseveration and failure to maintain or sustain a cognitive set. The test is structured such that four stimulus cards, composed of three stimulus parameters (color, form, and number) are presented to the participant. Individuals are required to sort response cards according to these parameters and alter their strategy multiple times throughout the presentation without explicit information regarding the goal.

Early Adolescent Temperament Questionnaire – revised (EATQ-R). The EATQ-R (Ellis, Rothbart, & Posner, 2004; Rothbart, Ellis, & Posner, 2004) measures the three components of effortful control (attentional control, inhibitory control, and activation control). Items include statements such as "Even when I feel energized, I can usually sit still without much trouble if it is necessary" (inhibitory control). Responses are on a 5-point likert style scale from agree to disagree.

WISC-IV Backward Digit Span. The backward digit span (Wechsler Intelligence Scale for Children – Fourth Edition, Wechsler, 2003) is a measure designed to assess auditory short-term memory, sequencing skills, attention, and concentration. It involves utilization of working memory, transformation of information, mental manipulation, and visuospatial imaging. To complete the digit span backward, the child is required to repeat the numbers presented in reverse order, with increasing length.

Child Behavior Checklist (CBCL). The CBCL is a parent report questionnaire used to assess a child's behavioral and/or emotional problems for ages 6 to 18 (Achenbach & Edelbrock, 1983). The first section of this questionnaire consists of 20 competence items, and the second section consists of 120 items on behavior or emotional problems during the past 6 months. Subtests measure domains of: Aggressive Behavior, Anxious/Depressed, Attention Problems, Delinquent Rule-Breaking Behavior, Social Problems, Somatic Complaints, Thought Problems, Withdrawn, Externalizing, Internalizing, Total Problems, plus DSM-oriented scales. The CBCL is widely used to assess behavior problems across childhood with established reliability and validity. This is a necessary component of evaluation to assure sleep disruptions and/or executive functioning are primary factors, with or without behavioral components. Furthermore,

because this study is conducted with a normative sample it is essential to have accurate representations of variability within the group.

Puberty Scale. The Puberty Scale is a self-rating scale used to measure a child's pubertal status in a noninvasive manner (Carskadon & Acebo, 1993). The scale contains 5 items assessing physical evidence of puberty (3 questions are common between boys and girls, while 2 questions are sex-specific). Scores on the items provide a Puberty Development Scale (PDS). The "Puberty Category Scores" for boys assess body hair growth, voice change, and facial hair growth, while the score for girls assess body hair growth, breast development, and menarche. Scoring is based on an algorithm used by Carskadon and colleagues. For items one through four on the girls' version and all items on the boys' version, response options were scored "not yet started" as one point, "barely started" as two points, "definitely started" as three points, and "seems complete" as four points. Menstruation was coded four points, while no menstruation was coded one point. Point values were averaged for all items to give a Pubertal Development Scale (PDS) score. Puberty Category Scores were classified by summing values (Crockett, 1988, unpublished). Based on scores, children were placed in either a pre-pubertal (boys -3 or fewer points; girls – 2 points and no menarche), early pubertal (boys - 4-5 points, no 3-point responses; girls – 3 points and no menarche), mid-pubertal (boys - 6, 7, or 8, no 4-point responses; girls – more than 3 points and no menarche), late pubertal (boys - 9-11 points; girls – greater than or equal to 7 points and menarche), or post-pubertal (boys - 12 or more points; girls – greater than 8 points and menarche).

Research Design and Statistical Analyses

Previous studies evaluating sleep through actigraphy data have utilized sample sizes ranging from 27 to 140; many sleep restriction studies are limited to between 40 to 90 individuals. Based on past studies (Acebo et al., 1999; Sadeh & Acebo, 2002; Sadeh et al., 2002, 2003; Sadeh et al., 1995; Sadeh et al., 2000), the effect size was estimated to be small to moderate. With a small to moderate effect size (f^2 = .15), an alpha of .05, and five primary predictors (IVs are sleep manipulation groups; covariates are age, gender, ethnicity, and pubertal status) in repeated measures ANOVA, a sample size of 15 per group was required to attain a power of .8 (Cohen, 1977, 2013).

Data analyses began with an examination of descriptive statistics collected through the demographics questionnaire (e.g., age of children and parents, gender, ethnicity, family income). The distribution of these variables was primarily normal or equivalently split regarding sex and age, while ethnicity was expectedly strongly skewed. Because Pocatello, ID is predominantly white Caucasian, it was expected that the sample collected would also demonstrate this area-specific norm.

The distribution of all variables was examined and tested for non-normality (Tabachnick & Fidell, 2001). Sleep behavior and patterns were normally distributed across the sample with some poor sleepers and some above average sleepers represented in addition to the normal range. Specifically, the CBCL was utilized during initial evaluation to elucidate normal distributions of sleep and behavior problems, as well as a provision of daily activities. Descriptive statistics of all variables and zero-order correlations among all major variables was obtained.

Repeated measures ANOVA/ANCOVAs were completed with Time (session one and two) utilized as the within-subject factor and manipulation group as the between subjects factor predicting to neurocognitive performance. Covariates were included as needed including age, ethnicity, gender, and puberty development score. A-priori contrasts were completed in an ANCOVA controlling for session one neurocognitive performance scores to evaluate hypotheses: full-week extension versus control, combined extension groups versus control, full-week restriction versus control, and combined restriction groups versus control.

Results

Descriptive Analyses

Sleep Variables. Actigraphy variables were all continuous time or percentage scores. Higher scores indicate a greater length of time or percentage. Actigraphy variables, averaged across the four nights of the study, were approximately normally distributed as indicated by the non-significant z-tests for skewness and kurtosis – average sleep duration (S = 0.26, S_S = 0.30, z = 0.87; K = 0.02, S_K = 0.58, z = 0.03), average wake after sleep onset (WASO; S = 0.35, S_S = 0.29, z = 1.21; K = 0.78, S_K = 0.57, z = 1.37), and average sleep efficiency (S = 0.25, S_S = 0.30, z = 0.83; K = 0.31, S_K = 0.58, z = 0.54). Average sleep onset latency (S = 0.93, S_S = 0.30, z = 3.1; K = 0.32, S_K = 0.58, z = 0.55) was slightly positively skewed, with a non-significant level of kurtosis. Examination of the distribution overlay and P-P plots for these variables demonstrated data largely aligned with the normal distribution. The slight skewness observed with the z –statistic on average sleep onset latency was not observed when evaluating the P-P plot or distribution overlay. With a transformation, this variable's skewness did decrease slightly, but there was no measurable effect on analyses and thus the original variable was maintained. Normal distribution was consistent when these actigraphy variables were evaluated as sums rather than averaged.

When evaluating actigraphy scores on only the last night of data collection, sleep duration was normally distributed as indicated by non-significant z-tests for skewness and kurtosis – 4th night sleep duration (S = 0.44, S_S = 0.30, z = 1.47; K= -0.57, S_K = 0.58, z = -0.01). In contrast, 4th night WASO (S = 0.89, S_S = 0.30, z = 2.97; K = 0.47, S_K = 0.58, z = 0.81), 4th night sleep efficiency (S = -1.02, S_S = 0.30, z = -3.40; K = 1.79, S_K = 0.58, z =

3.09), and 4th night sleep onset latency (S = 2.17, S_S = 0.30, z = 7.23; K = 6.60, S_K = 0.58, z = 11.38) were positively skewed and in the case of efficiency and onset latency also had significant kurtosis. Examination of the distribution overlay and P-P plots for these variables demonstrated data largely aligned with the normal distribution, even with the small sample size. Transformations did not improve the distribution for WASO, but a square root transformation did improve the distribution of sleep efficiency (S = 0.09, S_S = 0.30, z = 0.30; K = 0.75, S_K = 0.58, z = 1.29) and onset latency (S = 0.62, S_S = 0.30, z = 2.07; K = 1.19, S_K = 0.58, z = 2.05), allowing them to be used in analyses without breaking assumptions of normality.

Both the Child Sleep Diary (CSD) and Parent-report Sleep Diary (PSD) contained six sleep variables of interest. Bedtime and waketime were both utilized in scoring actigraphy sleep periods and thus were not independently evaluated as predictor variables for analyses. Means and standard deviations for sleep diary variables on both PSD and CSD are presented in Tables 2 and 3 separated by manipulation groups. Table 2 presents the sleep diary variables averaged across all four nights of the study, and Table 3 presents these diary variables on only the last night of evaluation. Sleep quality, sleep onset latency, nighttime tiredness, and morning tiredness were likert-style ratings. The possible range for average sleep quality was 1 – 5, where higher scores indicated better sleep. The possible range for average sleep onset latency was 1 to 4, where 1 was equivalent to 0-5 minutes and 4 was equivalent to greater than 31 minutes. Finally, the average nighttime (i.e., prior to bedtime) and morning tiredness ratings ranged from 1 to 4, where higher scores indicated more tiredness. Comparing the full-week extension to control to full-week restriction, patterns of responding can be seen. Specifically, in regards to sleep

quality, children and parents in the full-week extension group rated their quality highest between the manipulation groups. While in contrast, night tiredness and morning tiredness were highest for children in the full-week restriction groups. These patterns were evident when averaged across the four nights, as well as when evaluating only the final night of manipulation.

Table 2
Sleep diary descriptive statistics separated by group, averaged across four nights (N=67).

	Group				
	Extension			Restriction	
Variable	Full Week M ± SD	One Night M ± SD	Control M ± SD	One Night M ± SD	Full Week M ± SD
Parent Report					
Sleep Quality [a]	4.25 ± 0.53	3.84 ± 0.42	4.18 ± 0.43	4.11 ± 0.42	4.13 ± 0.57
Sleep Latency [b]	2.15 ± 0.72	2.34 ± 0.69	2.41 ± 0.85	2.25 ± 0.56	1.68 ± 0.53
Night Tiredness [c]	2.35 ± 0.60	2.43 ± 0.72	2.79 ± 0.53	2.73 ± 0.51	3.14 ± 0.41
Morning Tiredness [c]	1.93 ± 0.59	2.27 ± 0.44	2.21 ± 0.54	2.31 ± 0.63	2.61 ± 0.48
Child Report					
Sleep Quality [a]	4.23 ± 0.62	3.82 ± 0.84	4.11 ± 0.66	4.02 ± 0.50	4.07 ± 0.57
Sleep Latency [b]	1.88 ± 0.80	2.30 ± 0.94	2.15 ± 0.90	2.16 ± 0.84	2.44 ± 0.93
Night Tiredness [c]	2.70 ± 0.60	3.14 ± 0.76	2.86 ± 0.60	2.76 ± 0.67	2.89 ± 0.48
Morning Tiredness [c]	2.21 ± 0.88	2.66 ± 0.68	2.25 ± 0.75	2.61 ± 0.69	2.45 ± 0.56

Note: [a] Very Bad (1) to Very Good (5) ; [b] 0-5 minutes (1) to 31+ minutes (4); [c] Very Alert (1) to Very Tired (4)

Table 3
Sleep diary descriptive statistics separated by group, Last night only (N=67).

	Group				
	Extension			Restriction	
Variable	Full Week M ± SD	One Night M ± SD	Control M ± SD	One Night M ± SD	Full Week M ± SD
Parent Report					
Sleep Quality [a]	4.21 ± 0.89	3.80 ± 0.42	4.29 ± 0.99	4.13 ± 0.74	4.10 ± 0.57
Sleep Latency [b]	2.36 ± 1.08	2.50 ± 1.08	2.00 ± 0.96	2.13 ± 0.99	1.70 ± 0.82
Night Tiredness [c]	2.14 ± 0.77	1.80 ± 1.03	2.57 ± 0.94	3.07 ± 0.88	3.50 ± 0.71
Morning Tiredness [c]	1.86 ± 0.95	1.90 ± 0.74	2.14 ± 0.86	2.40 ± 0.74	2.64 ± 0.67
Child Report					
Sleep Quality [a]	4.62 ± 0.65	3.73 ± 1.42	4.50 ± 1.00	4.27 ± 0.80	4.20 ± 0.79
Sleep Latency [b]	2.15 ± 0.99	2.45 ± 1.04	2.00 ± 0.91	2.13 ± 1.19	2.20 ± 1.32
Night Tiredness [c]	2.92 ± 0.86	3.00 ± 1.18	2.54 ± 0.88	2.71 ± 0.99	2.80 ± 0.79
Morning Tiredness [c]	1.85 ± 1.07	2.45 ± 1.21	2.08 ± 0.95	2.67 ± 1.05	2.30 ± 0.68

Questionnaires. Total scores and subscale scores calculated in the sleep self-report (SSR), children's sleep health questionnaire (CSHQ), and child behavior checklist

(CBCL) were described in Table 4 (pg. 33). Overall, questionnaire variables were normally distributed as demonstrated by non-significant z-scores for skewness and kurtosis. Examination of the distribution overlay and P-P plots for these variables demonstrated data aligned with the normal distribution. Though the subscales on the CSHQ were significantly positively skewed, with significant kurtosis z-scores, these variables were not transformed because they were not utilized as predictor or outcome variables in analyses. Subscales on the early adolescent temperament questionnaire were normally distributed and analyses with CBCL sleep item summation scores were not improved with transformation to address skewness or kurtosis. The scores displayed in Table 4 demonstrate largely normal distribution of sleep problems, with less problems than would be typical in a clinical population. Children were very similar in their presentation pre-manipulation.

Table 4
Mean, standard deviation, skewness, and kurtosis of questionnaire scales.

Variable	Mean	Std. Dev.	Range	Skewness $S \pm S_S$	Kurtosis $K \pm S_K$
SSR					
Sleep dist. score	36.95	6.62	26 – 52	0.36 ± 0.30	-0.74 ± 0.59
CSHQ					
Sleep dist. score	42.77	5.94	33 – 56	0.55 ± 0.29	-0.51 ± 0.57
Bedtime resistance	6.96	1.73	6 – 14	2.40 ± 0.29	5.73 ± 0.57
Sleep onset delay	1.54	0.70	1 – 3	0.91 ± 0.29	-0.40 ± 0.57
Sleep duration	3.63	1.16	3 – 8	2.16 ± 0.29	4.26 ± 0.57
Sleep anxiety	5.04	1.50	4 – 10	1.60 ± 0.29	1.78 ± 0.57
Night wakings	3.56	0.86	2 – 7	1.57 ± 0.29	3.77 ± 0.57
Parasomnias	8.33	1.36	7 – 13	1.52 ± 0.29	2.89 ± 0.57
Sleep dis. breathing	3.11	0.32	3 – 4	2.48 ± 0.29	4.26 ± 0.57
Daytime sleepiness	12.90	3.16	8 – 23	0.80 ± 0.29	1.04 ± 0.57
CBCL					
7 sleep items [a]	1.01	1.14	0 – 4	0.89 ± 0.29	-0.17 ± 0.57
4 sleep items [b]	0.46	0.85	0 – 3	2.06 ± 0.29	3.60 ± 0.57

Note: [a] trouble sleeping, sleeps less, sleeps more, overtired, nightmares, wets the bed, and sleeps or talks in sleep; [b] trouble sleeping, sleeps less, sleeps more, overtired.

Neurocognitive Variables. The distribution of neurocognitive functioning variables, from the CPT, digit span backwards, Wisconsin card sort, and D-KEFS color-

word interference were evaluated and are presented in Tables 5 through 8 (pg. 34). Within the CPT, primary variables of interest were the clinical confidence index, commission errors, omission errors, perseverative errors, and hit reaction time. The majority of time 1 and 2 CPT variables were normally distributed with non-significant skewness and kurtosis z-scores. Time 1 and 2 omission errors percentile scores had slight positive skews (Time 1: $S = 1.38$, $S_S = 0.29$, $z = 4.76$; $K = 1.16$, $S_K = 0.57$, $z = 2.04$; Time 2: $S = 1.08$, $S_S = 0.29$, $z = 3.52$; $K = -0.05$, $S_K = 0.57$, $z = -0.09$). In addition, time 1 perseverative errors percentile also had a slight positive skew ($S = 1.10$, $S_S = 0.29$, $z = 3.79$; $K = -0.03$, $S_K = 0.57$, $z = -0.05$). Examination of the distribution overlay and P-P plots for these variables demonstrated data largely aligned with the normal distribution. Consistent with this finding, transformations did not improved skewness and kurtosis statistics; and thus, the original values were maintained. In Table 5, it is evident that children's performance consistently changed between session one and two, but primarily remained in the typical non-clinical range.

Table 5
Full Sample Mean, Standard Deviation, Skewness, and Kurtosis of CPT – Time 1 and 2

Variable	Mean	Std. Dev.	Range	Skewness $S \pm S_S$	Kurtosis $K \pm S_K$
Clinical Confidence Index					
T1	34.40	17.91	0.10 – 67.88	-0.09 ± 0.29	-0.94 ± 0.57
T2	43.74	19.25	0.10 – 90.21	0.21 ± 0.29	0.02 ± 0.57
Omissions %tile					
T1	38.09	19.15	19.37 – 94.79	1.38 ± 0.29	1.16 ± 0.57
T2	42.69	23.86	16.02 – 99.00	1.08 ± 0.29	-0.05 ± 0.57
Commissions %tile					
T1	58.68	29.15	1.00 – 98.87	-0.49 ± 0.29	-0.86 ± 0.57
T2	50.99	33.72	1.00 – 97.69	-0.22 ± 0.29	-1.41 ± 0.57
Hit Reaction Time %tile					
T1	56.70	23.65	8.59 – 99.00	-0.01 ± 0.29	-1.01 ± 0.57
T2	62.11	26.03	7.49 – 99.00	-0.21 ± 0.29	-0.94 ± 0.57
Perseverations %tile					
T1	47.61	22.88	21.53 – 99.00	1.10 ± 0.29	-0.03 ± 0.57
T2	54.62	25.89	21.53 – 99.00	0.60 ± 0.29	-1.09 ± 0.57

Primary variables in the D-KEFS color-word interference task included inhibition condition and switching condition time and error scaled scores. Most time 1 and 2 variables were normally distributed with largely non-significant skewness and kurtosis z-scores, with the exception of time 2 inhibition condition errors scaled score (S = -1.42, S_S = 0.29, z = -4.90; K = 1.59, S_K = 0.57, z = 2.79) and time 2 switching condition errors scaled scores (S = -1.14, S_S = 0.29, z = -3.93; K = 0.90, S_K = 0.57, z = 1.58). Examination of the distribution overlay and P-P plots for these variables demonstrated data aligned with the normal distribution. Again, transformations did not affect analyses; and thus, the original values were maintained. Performance across the sample improved by approximately one scaled score unit between session one and two demonstrating appropriate improvement due to practice effects (Table 6).

Table 6
Full Sample Mean, Standard Deviation, Skewness, and Kurtosis of D-KEFS Color-word Interference – Time 1 and 2

Variable	Mean	Std. Dev.	Range	Skewness $S \pm S_S$	Kurtosis $K \pm S_K$
Inhibition cond. time SS					
T1	11.23	2.05	4 – 15	-0.61 ± 0.29	1.32 ± 0.57
T2	12.57	2.00	8 – 17	-0.20 ± 0.29	-0.77 ± 0.57
Inhibition cond. errors SS					
T1	9.51	3.80	1 – 14	-0.82 ± 0.29	-0.20 ± 0.57
T2	10.93	3.15	1 – 14	-1.42 ± 0.29	1.59 ± 0.57
Switching cond. time SS					
T1	11.03	2.17	4 – 15	-0.47 ± 0.29	0.27 ± 0.57
T2	12.36	2.11	6 – 16	-0.56 ± 0.29	0.24 ± 0.57
Switching cond. errors SS					
T1	9.23	3.49	1 – 14	-0.86 ± 0.29	0.01 ± 0.57
T2	10.19	3.60	1 – 15	-1.14 ± 0.29	0.90 ± 0.57

Primary variables in the backwards digit span task included digit span total score and longest digit span. Time 1 and 2 total scores were slightly positively skewed with significant kurtosis (Time 1: S = 0.99, S_S = 0.29, z = 3.41; K = 1.53, S_K = 0.57, z = 2.68; Time 2: S = 1.11, S_S = 0.29, z = 3.83; K = 1.88, S_K = 0.57, z = 3.30). Time 2 longest digit

span was also slightly positively skewed (S = 0.93, S_S = 0.29, z = 3.21; K = 0.90, S_K = 0.57, z = 1.58). Examination of the distribution overlay and P-P plots for these variables demonstrated data largely aligned with the normal distribution. Again, transformations did not improve skewness or kurtosis statistics, and thus the original values were maintained. Interestingly, the sample overall did not appear to change between session one and two on the backward digit span task (Table 7).

Table 7
Full Sample Mean, Standard Deviation, Skewness, and Kurtosis of Digit Span Backwards– Time 1 and 2

Variable	Mean	Std. Dev.	Range	Skewness $S \pm S_S$	Kurtosis $K \pm S_K$
Total score					
T1	6.29	1.76	3 – 12	0.99 ± 0.29	1.53 ± 0.57
T2	6.29	1.76	3 – 12	1.11 ± 0.29	1.88 ± 0.57
Longest digit span					
T1	3.66	1.08	2 – 7	0.59 ± 0.29	0.29 ± 0.57
T2	3.58	1.03	2 – 7	0.93 ± 0.29	0.90 ± 0.57

Variables evaluated in the Wisconsin Card Sorting Task included percentile ranks on total errors and perseverative errors. Scores were normally distributed with only slight kurtosis (Errors percentile: S = -0.43, S_S = 0.29, z = 1.48, K = -1.36, S_K = 0.58, z = 2.34; Perseverative Errors percentile: S = -0.43, S_S = 0.29, z = 1.48; K = -1.02, S_K = 0.58, z = 1.76). Examination of the distribution overlay and P-P plots for these variables demonstrated data aligned with the normal distribution. Thus, the original values were maintained (Table 8).

Table 8
Mean, Standard Deviation, Skewness, and Kurtosis of Wisconsin Card Sorting Task – Time 2

Variable	Mean	Std. Dev.	Range	Skewness $S \pm S_S$	Kurtosis $K \pm S_K$
Number of errors %tile	59.30	33.20	2 – 99	-0.43 ± 0.29	-1.36 ± 0.58
Perseverative errors %tile	61.75	28.52	2 – 99	-0.43 ± 0.29	-1.02 ± 0.58

Note: lower percentiles scores are associated with poorer performance.

Compliance

Each child's compliance with the experimental sleep manipulation was assessed prior to analyses. Based on precedent set in previous literature involving restriction and extension of sleep, compliance was based on two factors: reported time in bed and activity level assessed through actigraphy. Without pre-manipulation actigraphy data, it was impossible to base compliance purely on sleep-wake periods produced through actigraphy. Previous literature has asserted a 30 minute criterion for compliance. That is, based on actigraphy data a child increased or decreased their sleep period by an average of 30 minutes or more. Because compliance in this study was based partially on self- or parent-report, the criterion was set higher (i.e., 45 minutes on average). First, reported time in bed from the sleep diary was compared to typical time in bed reported on the children's sleep habits questionnaire and as reported in the first session. Second, actigraphy-based sleep initiation time and time in bed were compared to typical time in bed reported on the children's sleep habits questionnaire and as reported in the first session, with an addition of 15 minutes for average onset latency accounted for. Thus, a child in the extension group would have a reported manipulation time in bed at least 45 minutes prior to reported pre-manipulation time in bed and would have actigraphy data supporting sleep onset prior to that same pre-manipulation time. Similarly, a child in the restriction group would have a reported manipulation time in bed at least 45 minutes after their reported pre-manipulation time in bed and would have actigraphy data supporting a sleep onset after that same pre-manipulation time. Children in the control group were those who maintained their typical pre-manipulation sleep times. In addition, for those children in the four-night extension or restriction groups, as well as the control each night

was compared for consistency across the week. Children who differed more than 30 minutes between nights were considered noncompliant with the sleep manipulation.

Given these criteria, two children were excluded based on consistency. These childrens' sleep patterns did not fit any manipulation group and thus were excluded from the primary analyses. Nine children were moved based on their sleep patterns to a different manipulation group.

Main Findings

Comparison of manipulation groups on neurocognitive performance.

Repeated neurocognitive measures were administered in the first and second session of the study to all participants. The various sleep restriction and extension groups were compared for differences in neurocognitive performance, controlling for the effect of time, pertinent demographic characteristics, and level of puberty. Non-significant Box's M and Levene's tests were assured in each model. In the overall F test, we tested whether the five groups were different across time as well as whether a significant interaction effect between time and manipulation groups was present for the dependent variables of executive functioning. To increase the power of detecting differences among the comparison groups, apriori analyses comparing the groups were conducted based on the hypotheses (i.e., control vs. all restriction groups, control vs. all extension groups, 4-night extension vs control vs 4-night restriction groups). This analysis allows for the hypotheses to be answered in a more precise fashion than the overall repeated measures analysis by comparing specific sleep manipulation groups in a strategic and planned manner.

Digit Span Backwards.

Total score. A repeated measures ANCOVA was completed with digit span backwards total score in session one and two compiling the time-based variable for within subject effects, the restriction manipulation group as the between subjects comparison, and ethnicity and puberty score as covariates. Homogeneity of error variance of the dependent variable for both session one and session two was assured with a non-significant Levene's test (Session one, $p = .384$; Session two, $p = .453$). A non-significant Box's M test assured homogeneity of variance-covariance matrices ($p = .257$). This repeated measures mixed ANCOVA demonstrated a significant main effect of time, suggesting that children's total score on the backward digit span varied between session one and session two. For the four-night accumulated sleep manipulation groups (i.e., both restriction and extension manipulation groups), the means at session two were lower than session one. The scores for those children in the one night restriction and extension groups as well as the control group increased. However the interaction effect of time and restriction group was non-significant, $F(4, 61) = 1.983$, $p = .108$ (see Table 9). Thus, while controlling for the effects of repeated assessment (i.e., Time), there was no significant effect of sleep manipulation when comparing all five manipulations.

Apriori contrast analyses were completed in an ANCOVA model controlling for session one backward digit span performance to compare the groups based on the hypotheses (i.e., control vs. all restriction groups, control vs. all extension groups, 4-night extension vs control vs 4-night restriction groups).

Hypothesis 1. The contrast comparing the control group to all the restriction groups combined was non-significant ($F(1, 60) = 2.716$, $p = .105$), though performance

was in the predicted direction. Specifically, those children who either restricted their sleep by one hour on the night prior to testing or on all four nights prior performed worse in total score on the backward digit span task during session two when combined (Restriction groups, M = 6.00 (1.52); Control group, M = 6.67 (2.23)). When evaluating only the performance between children who restricted their sleep for a full four nights to those in the control group, the contrast was trending toward significance ($F(1, 60) = 3.413$, $p = .070$). Children who restricted their sleep for one hour on each of the four nights prior to assessment performed significantly worse than those children in the control group by over a full point in total score (Full-week restriction, M = 5.33 (1.37); Control, M = 6.67 (2.23); Table 10).

Hypothesis 2. The contrast comparing the control group to both extension groups combined was non-significant ($F(1, 60) = 1.823$, $p = .182$). There was not a significant difference between those children who extended their sleep in any way and those children in the control group (Extension groups, M = 6.40 (1.76); Control group, M = 6.67 (2.23)). However, when evaluating only the performance between children who extended their sleep by an hour each night for a full four nights to those in the control group, the contrast was significant ($F(1, 60) = 5.507$, $p = .022$). Children who changed their sleep schedule to add an extra hour of sleep on each of the four nights prior to assessment performed significantly worse than those children in the control group by just under half a point in total score (Full-week extension, M = 6.21 (1.63); Control, M = 6.67 (2.23); Table 10). Contrary to the hypothesis, these children performed worse than those who maintained their typical sleep schedule.

Table 9
Repeated Measures Analysis of Variance Multivariate Tests– Digit Span Backwards Total Score

Effect	Wilk's Λ	*MS*	*F*	Df_1	Df_2	*p*
Time	0.888	5.806	7.705	1	61	0.007
Time x Ethnicity	0.892	5.546	7.361	1	61	0.009
Time x Puberty	0.854	7.842	10.409	1	61	0.002
Time x Manipulation Group	0.885	1.494	1.983	4	61	0.108

Table 10
Means at Time 1 and 2 across Manipulation Groups – Digit Span Backwards Total Score

	Full-week Extension		One Night Extension		Control		One Night Restriction		Full-week Restriction	
Time/Session	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
T1	6.50	1.51	6.36	2.25	6.47	2.20	6.31	1.40	5.75	1.49
T2	6.21	1.63	6.64	1.96	6.67	2.23	6.50	1.46	5.33	1.37

Longest span. A repeated measures mixed ANCOVA was completed with backwards digit span longest span in session one and two compiling the time-based variable for within subject effects, the restriction group as the between subjects comparison, and ethnicity and puberty score as covariates. Homogeneity of error variance of the dependent variable for both session one and session two was assured with a non-significant Levene's test (Session one, $p = .914$; Session two, $p = .084$). A non-significant Box's M test assured homogeneity of variance-covariance matrices ($p = .168$). This repeated measures mixed ANCOVA demonstrated a non-significant main effect of time, suggesting that children's change in longest span on the backward digit span was not due to practice effects alone. However, the interaction effect of time and restriction group was significant, $F(4, 61) = 2.985$, $p = .026$ (see Table 11). Thus, while controlling for the effects of repeated assessment (i.e., Time), there was a significant effect of sleep manipulation when comparing all five manipulations.

Apriori contrast analyses were completed in an ANCOVA model controlling for session one backward digit span performance to compare the groups based on the

hypotheses (i.e., control vs. all restriction groups, control vs. all extension groups, 4-night extension vs control vs 4-night restriction groups).

Hypothesis 1. The contrast comparing children in the control group to children in both restriction groups combined was significant ($F(1, 60) = 6.656$, $p = .012$). Specifically, those children who either restricted their sleep by one hour on the night prior to testing or on all four nights prior had a significantly shorter backward digit span during session two than children who did not alter their sleep (Restriction groups, M = 3.43 (0.96); Control group, M = 4.00 (1.42)). Similarly, when evaluating only the performance between children who restricted their sleep for a full four nights to those in the control group, the contrast was also significant ($F(1, 60) = 6.284$, $p = .015$). Children who restricted their sleep for one hour on each of the four nights prior to assessment had a backward digit span a full letter shorter than those children who did not alter their sleep (Full-week restriction, M = 3.08 (0.90); Control, M = 4.00 (1.42); Table 12). Further, it is interesting to note that children in the control group improved their performance between session one and session two, while children in the full-week restriction group had their performance drop (see Table 12).

Hypothesis 2. The contrast comparing children in the control group to those children who extended their sleep either on one night or across all four nights prior to assessment was significant ($F(1, 60) = 7.973$, $p = .006$). There was a significant difference between those children who extended their sleep in any way and those children in the control group (Extension groups, M = 3.48 (0.82); Control group, M = 4.00 (1.42)). A significant contrast also was evident when evaluating only the performance between children who extended their sleep by an hour each night for a full four nights to those in

the control group ($F(1, 60) = 10.332$, $p = .002$). Children who changed their sleep schedule to add an extra hour of sleep on each of the four nights prior to assessment had a significantly shorter span than those children in the control group (Full-week extension, $M = 3.43$ (0.76); Control, $M = 4.00$ (1.42); Table 12). However, this difference was in the opposite direction from hypothesized, with children in the extension group performing worse than those children who had unaltered sleep.

Table 11
Repeated Measures Analysis of Variance and Multivariate Tests– Digit Span Backwards Longest Span

Effect	Wilk's Λ	*MS*	*F*	Df_1	Df_2	*p*
Time	0.966	1.131	7.173	1	61	0.146
Time x Ethnicity	0.893	3.816	7.331	1	61	0.009
Time x Puberty	0.927	2.513	4.828	1	61	0.032
Time x Manipulation Group	0.836	1.554	2.985	4	61	0.026

Table 12
Means at Time 1 and 2 across Manipulation Groups – Digit Span Backwards Longest Span

	Full-week Extension		One Night Extension		Control		One Night Restriction		Full-week Restriction	
Time/Session	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
T1	3.93	1.00	3.73	1.27	3.60	1.18	3.69	1.01	3.42	1.00
T2	3.43	0.76	3.55	0.93	4.00	1.42	3.69	0.95	3.08	0.90

D-KEFS color-word interference.

Inhibition condition time. A repeated measures ANOVA was completed with the color-word interference task inhibition condition completion time in session one and two compiling the time-based variable for within subject effects and the restriction group as the between subjects comparison. No covariates were utilized because none were significantly related to either between or within subject variables. Homogeneity of error variance of the dependent variable for both session one and session two was assured with a non-significant Levene's test (Session one, $p = .271$; Session two, $p = .259$). A non-significant Box's M test assured homogeneity of variance-covariance matrices ($p = .122$).

This repeated measures mixed ANOVA demonstrated a significant main effect of time, suggesting that children's completion speed on the inhibition condition was at least partially accounted for by repeated measurement – a within subject effect. The interaction effect of time and restriction group was non-significant, $F(4, 63) = 1.34$, $p = .265$ (see Table 13). Thus, while controlling for the effects of repeated assessment (i.e., Time), there was a significant effect of sleep manipulation when comparing all five manipulations.

Apriori contrast analyses were completed in an ANOVA model controlling for session one inhibition condition completion time scaled score to compare the groups based on the hypotheses (i.e., control vs. all restriction groups, control vs. all extension groups, 4-night extension vs control vs 4-night restriction groups).

Hypothesis 1. The contrast comparing children in the control group to children in both restriction groups combined was non-significant ($F(1, 60) = 0.032$, $p = .860$). There was not a significant difference in completion time on the inhibition condition of the D-KEFS color-word task between children who either restricted their sleep by one hour on the night prior to testing or on all four nights prior than children who did not alter their sleep (Restriction groups, $M = 12.75$ (1.74); Control group, $M = 12.27$ (2.15)). Similarly, when evaluating only the performance between children who restricted their sleep for a full four nights to those in the control group, the contrast was also non-significant ($F(1, 60) = 0.101$, $p = .752$). Children who restricted their sleep for one hour on each of the four nights prior to assessment did not perform any faster or slower than those children who had unaltered sleep (Full-week restriction, $M = 11.83$ (1.34); Control, $M = 12.27$ (2.15); Table 14).

Hypothesis 2. The contrast comparing children in the control group to those children who extended their sleep either on one night or across all four night prior to assessment was also non-significant ($F(1, 62) = 0.101$, $p = .752$). There was no difference in speed of performance between children who extended their sleep in any way and those children in the control group (Extension groups, $M = 12.44$ (2.20); Control group, $M = 12.27$ (2.15)). Further, the contrast in performance between children who extended their sleep by an hour each night for a full four nights to those in the control group was also non-significant ($F(1, 62) = 2.257$, $p = .138$). Children who changed their sleep schedule to add an extra hour of sleep on each of the four nights prior to assessment performed no differently than those children in the control group (Full-week extension, $M = 13.00$ (2.35); Control, $M = 12.27$ (2.15); Table 14). However, based on means presented in Table 14, children in the full-week extension did perform better during the second session than those children in the control group and findings were in the hypothesized direction.

Table 13
Repeated Measures Analysis of Variance Multivariate Tests – D-KEFS Inhibition Condition Time SS

Effect	Wilk's Λ	*MS*	*F*	Df_1	Df_2	*p*
Time	0.627	56.718	37.483	1	63	0.000
Time x Manipulation Group	0.922	2.028	1.340	4	63	0.265

Table 14
Means at Time 1 and 2 across Manipulation Groups – D-KEFS Inhibition Condition Time SS

	Full-week Extension		One Night Extension		Control		One Night Restriction		Full-week Restriction	
Time/Session	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
T1	10.79	2.75	11.00	1.61	11.00	1.69	12.38	1.63	10.58	2.19
T2	13.00	2.35	11.73	1.85	12.27	2.15	13.44	1.71	11.83	1.34

Switching condition time. A repeated measures ANOVA was completed with the color-word interference task switching condition completion time in session one and two compiling the time-based variable for within subject effects and the restriction group as the between subjects comparison. No covariates were utilized because none were

significantly related to either between or within subject variables. Homogeneity of error variance of the dependent variable for session one was assured with a non-significant Levene's test (Session one, $p = .067$), but session two had significantly different error variance in the condition time scaled score across manipulation groups ($p = .007$). A non-significant Box's M test assured homogeneity of variance-covariance matrices ($p = .304$). This repeated measures mixed ANOVA demonstrated a significant main effect of time, suggesting that children's completion speed on the switching condition was at least partially accounted for by repeated measurement – a within subject effect. The interaction effect of time and restriction group was non-significant, $F(4, 63) = 1.233$, $p = .306$ (see Table 15).

Apriori contrast analyses were completed in an ANOVA model controlling for session one completion time on the switching condition to compare the groups based on the hypotheses (i.e., control vs. all restriction groups, control vs. all extension groups, 4-night extension vs control vs 4-night restriction groups).

Hypothesis 1. The contrast comparing children in the control group to children in both restriction groups combined was non-significant ($F(1, 62) = 0.038$, $p = .846$). There was not a significant difference in completion time on the switching condition of the D-KEFS color-word task between children who either restricted their sleep by one hour on the night prior to testing or on all four nights prior than children who did not alter their sleep (Restriction groups, $M = 12.61$ (1.95); Control group, $M = 12.07$ (1.49)). Similarly, when evaluating only the performance between children who restricted their sleep for a full four nights to those in the control group, the contrast was also non-significant ($F(1, 62) = 0.049$, $p = .825$). Children who restricted their sleep for one hour on each of the

four nights prior to assessment did not perform any faster or slower than those children who had unaltered sleep (Full-week restriction, *M* = 11.67 (2.15); Control, *M* = 12.07 (1.49); Table 16).

Hypothesis 2. The contrast comparing children in the control group to those children who extended their sleep either on one night or across all four night prior to assessment was also non-significant ($F(1, 62) = 0.034$, $p = .854$). There was no difference in speed of performance between children who extended their sleep in any way and those children in the control group (Extension groups, *M* = 12.16 (2.56); Control group, *M* = 12.07 (1.49)). Further, the contrast in performance between children who extended their sleep by an hour each night for a full four nights to those in the control group was also non-significant ($F(1, 62) = 0.036$, $p = .850$). Children who changed their sleep schedule to add an extra hour of sleep on each of the four nights prior to assessment performed no differently than those children in the control group (Full-week extension, *M* = 12.00 (2.99); Control, *M* = 12.07 (1.49); Table 16).

Table 15
Repeated Measures Analysis of Variance Multivariate Tests – D-KEFS Switching Condition Time SS

Effect	Wilk's Λ	*MS*	*F*	Df_1	Df_2	*p*
Time	0.512	65.149	59.998	1	63	0.000
Time x Manipulation Group	0.8927	1.339	1.233	4	63	0.073

Table 16
Means at Time 1 and 2 across Manipulation Groups – D-KEFS Switching Condition Time SS

	Full-week Extension		One Night Extension		Control		One Night Restriction		Full-week Restriction	
Time/Session	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
T1	10.64	2.90	10.64	1.63	10.60	1.76	12.63	1.75	9.92	1.68
T2	12.00	2.99	12.36	2.01	12.07	1.49	13.31	1.49	11.67	2.15

Inhibition condition error scaled score. A repeated measures ANOVA was completed with the color-word interference task inhibition condition error scaled scores in session one and two compiling the time-based variable for within subject effects and

the restriction group as the between subjects comparison. No covariates were utilized, because none were significantly related to either between or within subject variables. Homogeneity of error variance of the dependent variable for session one and session two was assured with a non-significant Levene's test (Session one, $p = .529$; Session two, $p = .137$). A non-significant, at $p < .001$, Box's M test assured homogeneity of variance-covariance matrices ($p = .009$), though potential for unequal variances was considered given the slightly unequal group sizes. This repeated measures mixed ANOVA demonstrated a significant main effect of time, suggesting that children's errors scores on the inhibition condition was at least partially accounted for by repeated measurement – a within subject effect. The interaction effect of time and restriction group was non-significant, $F(4, 63) = 1.632$, $p = .117$ (see Table 17).

Apriori contrast analyses were completed in an ANOVA model controlling for session one inhibition errors scaled scores to compare the groups based on the hypotheses (i.e., control vs. all restriction groups, control vs. all extension groups, 4-night extension vs control vs 4-night restriction groups).

Hypothesis 1. The contrast comparing children in the control group to children in both restriction groups combined was non-significant ($F(1, 62) = 0.009$, $p = .925$). There was not a significant difference in number of errors on the inhibition condition of the D-KEFS color-word task between children who either restricted their sleep by one hour on the night prior to testing or on all four nights prior than children who did not alter their sleep (Restriction groups, $M = 10.50$ (3.39); Control group, $M = 10.00$ (3.55)). Similarly, when evaluating only the performance between children who restricted their sleep for a full four nights to those in the control group, the contrast was also non-significant (F(1,

62) = 0.001, p = .971). Children who restricted their sleep for one hour on each of the four nights prior to assessment did not have more errors than those children who had unaltered sleep (Full-week restriction, M = 10.50 (4.08); Control, M = 10.00 (3.55); Table 18).

Hypothesis 2. The contrast comparing children in the control group to those children who extended their sleep either on one night or across all four night prior to assessment was approaching significance (F(1, 62) = 3.442, p = .068). Children who extended their sleep in any way had higher scaled scores than those children who had unaltered sleep (Extension groups, M = 11.92 (2.47); Control group, M = 10.00 (3.55)). More specifically, this scaled score indicated that children who extended their sleep in some way had fewer errors on the inhibition condition of the D-KEFS than those children in the control group. Further, the contrast in performance between children who extended their sleep by an hour each night for a full four nights to those in the control group was significant (F(1, 62) = 5.910, p = .018). Children who changed their sleep schedule to add an extra hour of sleep on each of the four nights prior to assessment had fewer errors, and a scaled score 2.5 points higher than those in the control condition, a difference of almost a full standard deviation (Full-week extension, M = 12.57 (1.87); Control, M = 10.00 (3.55); Table 18).

Table 17
Repeated Measures Analysis of Variance Multivariate Tests – D-KEFS Inhibition Condition Error SS

Effect	Wilk's Λ	*MS*	*F*	Df_1	Df_2	*p*
Time	0.816	72.550	14.192	1	63	0.000
Time x Manipulation Group	0.906	8.341	1.632	4	63	0.117

Table 18
Means at Time 1 and 2 across Manipulation Groups – D-KEFS Inhibition Condition Error SS

	Full-week Extension		One Night Extension		Control		One Night Restriction		Full-week Restriction	
Time/Session	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
T1	9.36	3.41	9.36	4.90	8.73	3.75	10.00	4.05	9.83	3.49
T2	12.57	1.87	11.09	2.95	10.00	3.55	10.50	2.92	10.50	4.08

Switching condition error scaled score. A repeated measures ANOVA was completed with the color-word interference task switching condition error scaled scores in session one and two compiling the time-based variable for within subject effects and the restriction group as the between subjects comparison. No covariates were utilized because none were significantly related to either between or within subject variables. Homogeneity of error variance of the dependent variable for session one and session two was assured with a non-significant Levene's test (Session one, $p = .529$; Session two, $p = .137$). A non-significant Box's M test assured homogeneity of variance-covariance matrices ($p = .206$). This repeated measures mixed ANOVA demonstrated a significant main effect of time, suggesting that children's errors scores on the switching condition was at least partially accounted for by repeated measurement – a within subject effect. The interaction effect of time and restriction group was non-significant, $F(4, 63) = 1.532$, $p = .204$ (see Table 19).

Apriori contrast analyses were completed in an ANOVA model controlling for session one switching condition errors scaled scores to compare the groups based on the hypotheses (i.e., control vs. all restriction groups, control vs. all extension groups, 4-night extension vs control vs 4-night restriction groups).

Hypothesis 1. The contrast comparing children in the control group to children in both restriction groups combined was non-significant ($F(1, 62) = 0.215$, $p = .644$). There

was not a significant difference in number of errors on the switching condition of the D-KEFS color-word task between children who either restricted their sleep by one hour on the night prior to testing or on all four nights prior than children who did not alter their sleep (Restriction groups, M = 10.21 (3.52); Control group, M = 9.67 (4.17)). Similarly, when evaluating only the performance between children who restricted their sleep for a full four nights to those in the control group, the contrast was also non-significant (F(1, 62) = 0.528, p = .470). Children who restricted their sleep for one hour on each of the four nights prior to assessment did not have more errors than those children who had unaltered sleep (Full-week restriction, M = 8.92 (3.40); Control, M = 9.67 (4.17); Table 20).

Hypothesis 2. The contrast comparing children in the control group to those children who extended their sleep either on one night or across all four night prior to assessment did not demonstrate a significant difference between groups (F(1, 62) = 1.350, p = .250). Children who extended their sleep did not have significantly fewer errors than children who had unaltered sleep (Extension groups, M = 10.56 (3.48); Control group, M = 9.67 (4.17)). Further, the contrast in performance between children who extended their sleep by an hour each night for a full four nights to those in the control group was also non-significant (F(1, 62) = 1.347, p = .250). Children who changed their sleep schedule to add an extra hour of sleep on each of the four nights prior to assessment did not differ from children in the control group on errors in the switching condition of the D-KEFS (Full-week extension, M = 10.64 (3.25); Control, M = 9.67 (4.17); Table 20).

Table 19
Repeated Measures Analysis of Variance Multivariate Tests – D-KEFS Switching Condition Error SS

Effect	Wilk's Λ	*MS*	*F*	Df_1	Df_2	*p*
Time	0.904	32.999	6.721	1	63	0.012
Time x Manipulation Group	0.911	7.524	1.532	4	63	0.204

Table 20
Means at Time 1 and 2 across Manipulation Groups – D-KEFS Switching Condition Error SS

	Full-week Extension		One Night Extension		Control		One Night Restriction		Full-week Restriction	
Time/Session	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
T1	8.93	2.81	9.09	4.18	9.33	3.66	9.13	4.11	9.42	3.20
T2	10.64	3.25	10.46	3.91	9.67	4.17	11.19	3.39	8.92	3.40

Connor's CPT.

Clinical confidence index. A repeated measures ANCOVA was completed with the CPT clinical confidence index in session one and two compiling the time-based variable for within subject effects, the restriction group as the between subjects comparison, and ethnicity as a covariate. Puberty score was not included because it was not significantly related to either between or within subject variables. Homogeneity of error variance of the dependent variable for session one and session two was assured with a non-significant Levene's test (Session one, $p = .529$; Session two, $p = .137$). A non-significant Box's M test assured homogeneity of variance-covariance matrices ($p = .682$). This repeated measures mixed ANCOVA demonstrated a significant main effect of time, suggesting that children's errors scores on the switching condition was at least partially accounted for by repeated measurement – a within subject effect. The interaction effect of time and restriction group was also significant, $F(4, 62) = 3.036$, $p = .024$ (see Table 21). Thus, there was a difference in clinical confidence index scores between the five manipulation groups above and beyond those attributed to repeated measurement.

Apriori contrast analyses were completed in an ANCOVA model controlling for session one clinical confidence index on the CPT to compare the groups based on the

hypotheses (i.e., control vs. all restriction groups, control vs. all extension groups, 4-night extension vs control vs 4-night restriction groups).

Hypothesis 1. The contrast comparing children in the control group to children in both restriction groups combined was non-significant ($F(1, 61) = 0.117$, $p = .676$). There was not a significant difference in clinical confidence index score on the CPT between children who either restricted their sleep by one hour on the night prior to testing or on all four nights prior than children who did not alter their sleep (Restriction groups, M = 48.31 (20.26); Control group, M = 47.00 (17.23)). However, when limiting the contrast to only the performance between children who restricted their sleep for a full four nights to those in the control group, the contrast was approaching significance ($F(1, 61) = 3.184$, $p = .079$). Children who restricted their sleep for one hour on each of the four nights prior to assessment had a lower clinical confidence index score than those children who had unaltered sleep (Full-week restriction, M = 38.49 (12.33); Control, M = 47.00 (17.23); Table 22). The session two finding was opposite from hypothesized, as a lower clinical confidence index is indicative of fewer measures consistent with ADHD on the CPT. However, observing the means in Table 22 below, elucidates this finding. Specifically, children in the control group increased their score between session one and session two by approximately 11 points, while children in the full-week restriction only improved by one point. This may demonstrate an effect not captured by repeated measures analysis or contrast.

Hypothesis 2. The contrast comparing children in the control group to those children who extended their sleep either on one night or across all four night prior to assessment was approaching significance ($F(1, 61) = 3.379$, $p = .071$). Children who

extended their sleep in any way had significantly lower clinical confidence index, indicative of fewer measures consistent with ADHD, scores than those children who had unaltered sleep (Extension groups, M = 37.12 (18.26); Control group, M = 47.00 (17.23)). More specifically, this scaled score indicated that children who extended their sleep in some way appeared less like children with a diagnosis of ADHD than those children in the control group. Further, the contrast in performance between children who extended their sleep by an hour each night for a full four nights to those in the control group was significant ($F(1, 61) = 4.790$, $p = .032$). Children who changed their sleep schedule to add an extra hour of sleep on each of the four nights prior to assessment had a lower clinical confidence index and appeared nonclinical compared to those in the control group (Full-week extension, M = 33.95 (14.94); Control, M = 47.00 (17.23); Table 22).

Table 21
Repeated Measures Analysis of Variance Multivariate Tests – CPT Clinical Confidence Index

Effect	Wilk's Λ	*MS*	*F*	Df_1	Df_2	*p*
Time	0.821	1356.255	13.519	1	62	0.000
Time x Ethnicity	0.891	763.571	7.611	1	62	0.008
Time x Restriction Group	0.836	304.558	3.036	4	62	0.024

Table 22
Means at Time 1 and 2 across Manipulation Groups – CPT Clinical Confidence Index

	Full-week Extension		One Night Extension		Control		One Night Restriction		Full-week Restriction	
Time/Session	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
T1	27.87	16.58	34.90	19.03	36.32	17.87	35.98	18.06	37.37	15.52
T2	33.95	14.94	41.16	21.86	47.00	17.23	55.66	22.19	38.49	12.33

Omission errors percentile. A repeated measures ANCOVA was completed with the CPT omission errors percentile scores in session one and two compiling the time-based variable for within subject effects, the restriction group as the between subjects comparison, and ethnicity as a covariate. Puberty was not included because it was not significantly related to either between or within subject variables. Homogeneity of error

variance of the dependent variable for session one and session two was not assured, because the Levene's test was significant (Session one, $p = .052$; Session two, $p = .000$). However, this was attributed largely to intentionally altered manipulation group sizes to account for significant outliers. A non-significant Box's M test, at $p < .001$, assured homogeneity of variance-covariance matrices ($p = .010$). Results should be interpreted with caution given these statistics and the greater likelihood of Error. This repeated measures mixed ANOVA demonstrated a non-significant main effect of time, suggesting that changes in the children's omission errors percentile scores should not be attributed to a within subject effect. The interaction effect of time and restriction group was significant, $F(4, 62) = 2.623$, $p = .043$ (see Table 23). There was a significant difference in omission error percentile scores between the five manipulation groups.

Apriori contrast analyses were completed in an ANCOVA model controlling for session one omission errors percentile on the CPT to compare the groups based on the hypotheses (i.e., control vs. all restriction groups, control vs. all extension groups, 4-night extension vs control vs 4-night restriction groups).

Hypothesis 1. The contrast comparing children in the control group to children in both restriction groups combined was approaching significance ($F(1, 58) = 3.741$, $p = .058$). However, this finding was in the opposite direction than hypothesized. Children who either restricted their sleep by one hour on the night prior to testing or on all four nights prior had fewer omission errors, and a lower percentile rank, than children who did not alter their sleep (Restriction groups, $M = 39.58$ (24.83); Control group, $M = 50.61$ (24.26)). When limiting the contrast to only the performance between children who restricted their sleep for a full four nights to those in the control group, the contrast was

significant ($F(1, 58) = 5.721$, $p = .020$). Children who restricted their sleep for one hour on each of the four nights prior to assessment had a lower percentile rank for omission errors, or fewer omission errors overall, than those children who had unaltered sleep (Full-week restriction, $M = 28.44$ (9.56); Control, $M = 50.61$ (24.26); Table 24). This finding was opposite from hypothesized, as a lower percentile rank is indicative of fewer omission errors.

Hypothesis 2. The contrast comparing children in the control group to those children who extended their sleep either on one night or across all four night prior to assessment was significant ($F(1, 58) = 7.564$, $p = .008$). Children who extended their sleep in any way had significantly lower percentile ranks on omission errors, indicative of fewer omission errors on the CPT, than those children who had unaltered sleep (Extension groups, $M = 36.36$ (16.74); Control group, $M = 50.61$ (24.26)). Further, the contrast in performance between children who extended their sleep by an hour each night for a full four nights to those in the control group was also significant ($F(1, 58) = 7.968$, $p = .007$). Children who changed their sleep schedule to add an extra hour of sleep on each of the four nights prior to assessment had a lower omission error percentile rank than those in the control group (Full-week extension, $M = 34.76$ (16.09); Control, $M = 50.61$, (24.26); Table 24).

Table 23
Repeated Measures Analysis of Variance Multivariate Tests – CPT Omission Errors Percentile

Effect	Wilk's Λ	*MS*	*F*	Df_1	Df_2	*p*
Time	0.989	98.194	0.672	1	62	0.415
Time x Ethnicity	0.869	1359.949	9.309	1	62	0.003
Time x Manipulation Group	0.855	383.199	2.623	4	62	0.043

Table 24
Means at Time 1 and 2 across Manipulation Groups – CPT Omission Errors Percentile

	Full-week Extension		One Night Extension		Control		One Night Restriction		Full-week Restriction	
Time/Session	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
T1	33.46	14.93	39.09	15.20	38.20	19.53	36.18	17.16	30.59	10.90
T2	34.76	16.09	38.84	18.41	50.61	24.26	48.50	29.69	28.44	9.56

Commission errors percentile. A repeated measures ANOVA was completed with the CPT commission errors percentile scores in session one and two compiling the time-based variable for within subject effects and the restriction group as the between subjects comparison. Covariates were not included because they were not significantly related to either between or within subject variables. Homogeneity of error variance of the dependent variable for session one and session two was not assured Levene's test was significant (Session one, $p = .971$; Session two, $p = .945$). A non-significant Box's M test assured homogeneity of variance-covariance matrices ($p = .932$). This repeated measures mixed ANOVA demonstrated a significant main effect of time, suggesting that changes in the children's commission errors percentile scores were at least partially attributed to a within subject effect of repeated measurement. The interaction effect of time and restriction group was non-significant, $F(4, 63) = 1.055$, $p = .386$ (see Table 25). There were no differences in commission error percentile scores between the five manipulation groups above and beyond those attributed to repeated measurement.

Apriori contrast analyses were completed in an ANOVA model controlling for session one commission errors percentile on the CPT to compare the groups based on the hypotheses (i.e., control vs. all restriction groups, control vs. all extension groups, 4-night extension vs control vs 4-night restriction groups).

Hypothesis 1. The contrast comparing children in the control group to children in both restriction groups combined was non-significant ($F(1, 62) = 0.001$, $p = .981$). Children who either restricted their sleep by one hour on the night prior to testing or on all four nights prior did not have significantly different percentile ranks on commission errors than children who did not alter their sleep (Restriction groups, $M = 42.28$ (32.59); Control group, $M = 57.59$ (35.49)). When limiting the contrast to only the performance between children who restricted their sleep for a full four nights to those in the control group, the contrast was also non-significant ($F(1, 62) = 0.259$, $p = .612$). Children who restricted their sleep for one hour on each of the four nights prior to assessment had a lower percentile rank for commission errors, or fewer commission errors overall, than those children who had unaltered sleep (Full-week restriction, $M = 45.74$ (34.64); Control, $M = 57.59$ (35.49); Table 26).

Hypothesis 2. The contrast comparing children in the control group to those children who extended their sleep either on one night or across all four night prior to assessment was non-significant ($F(1, 62) = 1.542$, $p = .219$). Children who extended their sleep in any way did not have significantly different percentile ranks on commission errors than those children who had unaltered sleep (Extension groups, $M = 55.06$ (32.88); Control group, $M = 57.59$ (35.49)). Similarly, the contrast in performance between children who extended their sleep by an hour each night for a full four nights to those in the control group was also non-significant ($F(1, 62) = 1.143$, $p = .289$). Children who changed their sleep schedule to add an extra hour of sleep on each of the four nights prior to assessment did not have significantly different percentile ranking for commission

errors compared to those in the control group (Full-week extension, M = 47.47 (33.25); Control, M = 57.59 (35.49); Table 26).

Table 25
Repeated Measures Analysis of Variance Multivariate Tests – CPT Commission Errors Percentile

Effect	Wilk's Λ	*MS*	*F*	Df_1	Df_2	*p*
Time	0.913	1506.509	5.997	1	63	0.017
Time x Manipulation Group	0.937	265.145	1.055	4	63	0.386

Table 26
Means at Time 1 and 2 across Manipulation Groups – CPT Commission Errors Percentile

	Full-week Extension		One Night Extension		Control		One Night Restriction		Full-week Restriction	
Time/Session	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
T1	47.55	27.11	67.07	28.13	69.46	28.26	53.84	29.28	50.89	28.81
T2	47.47	33.25	64.72	31.21	57.59	35.49	39.69	31.86	45.74	34.64

Hit reaction time percentile. A repeated measures ANOVA was completed with the CPT hit reaction time percentile scores in session one and two compiling the time-based variable for within subject effects and the restriction group as the between subjects comparison. Covariates were not included because they were not significantly related to either between or within subject variables. Homogeneity of error variance of the dependent variable for session one and session two was assured with a non-significant Levene's test (Session one, p = .699; Session two, p = .493). A non-significant Box's M test, at $p < .001$, assured homogeneity of variance-covariance matrices (p = .046). This repeated measures mixed ANOVA demonstrated a significant main effect of time, suggesting that changes in the children's hit reaction time percentile scores were at least partially attributed to a within subject effect of repeated measurement. The interaction effect of time and restriction group was significant, $F(4, 63) = 3.068$, p = .023 (see Table 27). Thus, there were significant differences in the hit reaction time percentile scores between the five manipulation groups above and beyond those attributed to repeated measurement.

Apriori contrast analyses were completed in an ANOVA model controlling for session one hit reaction time percentile scores on the CPT to compare the groups based on the hypotheses (i.e., control vs. all restriction groups, control vs. all extension groups, 4-night extension vs control vs 4-night restriction groups).

Hypothesis 1. The contrast comparing children in the control group to children in both restriction groups combined was non-significant ($F(1, 62) = 0.189$, $p = .665$). Children who either restricted their sleep by one hour on the night prior to testing or on all four nights prior did not have significantly different percentile ranks on hit reaction time, being neither faster nor slower, than children who did not alter their sleep (Restriction groups, $M = 67.42$ (25.07); Control group, $M = 60.35$ (31.53)). When limiting the contrast to only the performance between children who restricted their sleep for a full four nights to those in the control group, the contrast was also non-significant ($F(1, 62) = 1.006$, $p = .320$). Children who restricted their sleep for one hour on each of the four nights prior to assessment did not perform significantly different on hit reaction time than those children who had unaltered sleep (Full-week restriction, $M = 61.75$ (29.07); Control, $M = 60.35$ (31.53); Table 28).

Hypothesis 2. The contrast comparing children in the control group to those children who extended their sleep either on one night or across all four night prior to assessment was non-significant ($F(1, 62) = 0.417$, $p = .521$). Children who extended their sleep in any way did not have significantly different percentile ranks on hit reaction time than those children who had unaltered sleep (Extension groups, $M = 58.88$ (22.69); Control group, $M = 60.35$ (31.53)). Similarly, the contrast in performance between children who extended their sleep by an hour each night for a full four nights to those in

the control group was also non-significant ($F(1, 62) = 1.343$, $p = .251$). Children who changed their sleep schedule to add an extra hour of sleep on each of the four nights prior to assessment did not have significantly different percentile ranking for hit reaction time, neither faster nor slower reaction times, compared to those in the control group (Full-week extension, $M = 55.70$ (23.24); Control, $M = 60.35$ (31.53); Table 28). Though not significant, those in the full-week extension did have a slightly lower percentile rank than children in the control group by five percentile units, in the hypothesized direction.

Table 27
Repeated Measures Analysis of Variance Multivariate Tests – CPT Hit Reaction Time Percentile

Effect	Wilk's Λ	*MS*	*F*	Df_1	Df_2	*p*
Time	0.923	694.597	5.224	1	63	0.026
Time x Manipulation Group	0.837	407.890	3.068	4	63	0.023

Table 28
Means at Time 1 and 2 across Manipulation Groups – CPT Hit Reaction Time Percentile

	Full-week Extension		One Night Extension		Control		One Night Restriction		Full-week Restriction	
Time/Session	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
T1	57.55	21.25	57.77	26.01	54.89	24.12	55.51	24.12	63.87	23.28
T2	55.70	23.24	62.93	22.39	60.35	31.53	71.68	21.60	61.75	29.07

Perseverations percentile. A repeated measures ANOVA was completed with the CPT perseverations percentile scores in session one and two compiling the time-based variable for within subject effects and the restriction group as the between subjects comparison. Covariates were not included because they were not significantly related to either between or within subject variables. Homogeneity of error variance of the dependent variable for session one and session two was assured with a non-significant Levene's test (Session one, $p = .135$; Session two, $p = .379$). A non-significant Box's M test assured homogeneity of variance-covariance matrices ($p = .248$). This repeated measures mixed ANOVA demonstrated a significant main effect of time, suggesting that changes in the children's perseverations percentile scores were at least partially attributed

to a within subject effect of repeated measurement. The interaction effect of time and restriction group was non-significant, $F(4, 63) = 0.405$, $p = .804$ (see Table 29). There was not a significant difference in the hit reaction time percentile scores between the five manipulation groups when considered together above and beyond those attributed to repeated measurement.

Apriori contrast analyses were completed in an ANOVA model controlling for session one perseveration errors percentile on the CPT to compare the groups based on the hypotheses (i.e., control vs. all restriction groups, control vs. all extension groups, 4-night extension vs control vs 4-night restriction groups).

Hypothesis 1. The contrast comparing children in the control group to children in both restriction groups combined was non-significant ($F(1, 62) = 2.05$, $p = .160$). Children who either restricted their sleep by one hour on the night prior to testing or on all four nights prior did not have significantly different percentile ranks on perseveration errors, having neither more nor less errors, than children who did not alter their sleep (Restriction groups, $M = 47.95$ (23.56); Control group, $M = 63.61$ (27.81)). When limiting the contrast to only the performance between children who restricted their sleep for a full four nights to those in the control group, the contrast remained non-significant ($F(1, 62) = 2.46$, $p = .120$). Children who restricted their sleep for one hour on each of the four nights prior to assessment did not perform significantly better or worse on perseverative errors than those children who had unaltered sleep (Full-week restriction, $M = 40.96$ (21.80); Control, $M = 63.61$ (27.81); Table 30).

Hypothesis 2. The contrast comparing children in the control group to those children who extended their sleep either on one night or across all four night prior to

assessment was non-significant ($F(1, 62) = 1.397$, $p = .242$). Children who extended their sleep in any way did not have significantly different percentile ranks on perseverative errors than those children who had unaltered sleep (Extension groups, $M = 54.91$ (25.29); Control group, $M = 63.61$ (27.81)). Though not a significant contrast, the children in the extension groups did rank approximately 9% lower, which indicates a lower rate of perseverative errors and is a trend in the hypothesized direction with children in the extension group performing better than those in the control. Similarly, the contrast in performance between children who extended their sleep by an hour each night for a full four nights to those in the control group was also non-significant ($F(1, 62) = 1.404$, $p = .241$). Children who changed their sleep schedule to add an extra hour of sleep on each of the four nights prior to assessment did not have significantly different percentile ranking for perseverative errors, neither accruing more or less errors over the course of performance on the CPT, compared to those in the control group (Full-week extension, $M = 48.20$ (24.24); Control, $M = 63.61$ (27.81); Table 30). Again though not significant, those in the full-week extension did have a lower percentile rank than children in the control group by fifteen percentile units, in the hypothesized direction. This places the control group in a clinically at-risk range for perseverative errors and the full-week extension children consistent with average performance.

Table 29
Repeated Measures Analysis of Variance Multivariate Tests – CPT Perseverations Percentile

Effect	Wilk's Λ	*MS*	*F*	Df_1	Df_2	*p*
Time	0.889	1657.610	7.846	1	63	0.007
Time x Manipulation Group	0.975	85.548	0.405	4	63	0.804

Table 30
Means at Time 1 and 2 across Manipulation Groups – CPT Perseveration Percentile

	Full-week Extension		One Night Extension		Control		One Night Restriction		Full-week Restriction	
Time/Session	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
T1	41.66	21.31	60.01	24.11	51.05	26.06	45.08	19.83	36.36	13.87
T2	48.20	24.24	63.44	25.05	63.61	27.81	53.20	24.13	40.96	21.80

Wisconsin Card Sorting Task.

Errors percentile. An ANOVA comparing WCST errors percentile scores across sleep manipulation groups was completed. WCST was only assessed at the second session due to novelty being essential in its administration. Results of the ANOVA were non-significant (see Table 31).

Apriori contrast analyses were completed in the ANOVA model to compare the errors percentile scores from the WCST between the groups based on the hypotheses (i.e., control vs. all restriction groups, control vs. all extension groups, 4-night extension vs control vs 4-night restriction groups).

Hypothesis 1. The contrast comparing children in the control group to children in both restriction groups combined was non-significant ($F(1, 61) = 0.001$, $p = .978$). Children who either restricted their sleep by one hour on the night prior to testing or on all four nights prior performed similar to those children who did not alter their sleep, earning neither more nor less errors on the WCST (Restriction groups, $M = 59.41$ (32.83); Control group, $M = 63.00$ (35.23)). When limiting the contrast to only the performance between children who restricted their sleep for a full four nights to those in the control group, the contrast remained non-significant ($F(1, 61) = 0.575$, $p = .451$). Children who restricted their sleep for one hour on each of the four nights prior to assessment did not perform significantly better or worse than those children who had

unaltered sleep (Full-week restriction, M = 71.09 (29.51); Control, M = 63.00 (35.23); Table 32).

Hypothesis 2. The contrast comparing children in the control group to those children who extended their sleep either on one night or across all four night prior to assessment was non-significant ($F(1, 62) = 1.397$, $p = .242$). Children who extended their sleep in any way did not have significantly different percentile ranks on perseverative errors than those children who had unaltered sleep (Extension groups, M = 57.33 (34.35); Control group, M = 63.00 (35.23)). Similarly, the contrast in performance between children who extended their sleep by an hour each night for a full four nights to those in the control group was also non-significant ($F(1, 61) = 0.238$, $p = .627$). Children who changed their sleep schedule to add an extra hour of sleep on each of the four nights prior to assessment did not have significantly different percentile ranking for errors on the WCST, neither accruing significantly more or less errors over the course of their performance, compared to those in the control group (Full-week extension, M = 54.69 (36.72); Control, M = 63.00 (35.23); Table 32).

Table 31
Analysis of Variance – WCST Errors Percentile

Effect	*df*	*MS*	*F*	*p*
Intercept	1	230137.449	201.351	.000
Manipulation Group	4	753.907	0.660	0.622
Error	60	1142.969		

Note: R^2= 0.042

Table 32
Means across Manipulation Groups – WCST Error Percentile

	Full-week Extension		One Night Extension		Control		One Night Restriction		Full-week Restriction	
Variable	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Error %tile	54.69	36.72	60.46	32.80	63.00	35.23	51.38	33.45	71.09	29.51

Perseverative errors percentile. An ANOVA comparing WCST perseverative errors percentile scores across sleep manipulation groups was completed. WCST was only assessed at the second session due to novelty being essential in its administration. Results of the ANOVA were non-significant (see Table 33).

Apriori contrast analyses were completed in the ANOVA model comparing perseverative error percentile scores on the WCST across sleep manipulation groups based on the hypotheses (i.e., control vs. all restriction groups, control vs. all extension groups, 4-night extension vs control vs 4-night restriction groups).

Hypothesis 1. The contrast comparing children in the control group to children in both restriction groups combined was non-significant ($F(1, 61) = 0.019$, $p = .891$). Children who either restricted their sleep by one hour on the night prior to testing or on all four nights prior performed similar to those children who did not alter their sleep, earning neither more nor less perseverative errors on the WCST (Restriction groups, $M = 60.22$ (28.09); Control group, $M = 62.64$ (31.96)). When limiting the contrast to only the performance between children who restricted their sleep for a full four nights to those in the control group, the contrast remained non-significant ($F(1, 61) = 0.716$, $p = .401$). Children who restricted their sleep for one hour on each of the four nights prior to assessment did not perform significantly better or worse than those children who had unaltered sleep (Full-week restriction, $M = 70.00$ (24.58); Control, $M = 62.64$ (31.96); Table 34).

Hypothesis 2. The contrast comparing children in the control group to those children who extended their sleep either on one night or across all four night prior to assessment was non-significant ($F(1, 61) = 0.221$, $p = .640$). Children who extended their

sleep in any way did not have significantly different percentile ranks on perseverative errors than those children who had unaltered sleep (Extension groups, M = 65.21 (25.17); Control group, M = 62.64 (31.96)). Similarly, the contrast in performance between children who extended their sleep by an hour each night for a full four nights to those in the control group was also non-significant ($F(1, 61) = 0.008$, $p = .930$). Children who changed their sleep schedule to add an extra hour of sleep on each of the four nights prior to assessment did not have significantly different percentile ranking for perseverative errors on the WCST, neither accruing more or less errors over the course of their performance, compared to those in the control group (Full-week extension, M = 61.23 (31.12); Control, M = 62.64 (31.96); Table 34).

Table 33
Analysis of Variance – WCST Perseverative Errors Percentile

Effect	*df*	*MS*	*F*	*p*
Intercept	1	248786.281	330.490	.000
Manipulation Group	4	739.348	0.982	0.424
Error	60	752.779		

Note: $R^2 = 0.061$

Table 34
Means across Manipulation Groups – WCST Perseverative Errors Percentile

	Full-week Extension		One Night Extension		Control		One Night Restriction		Full-week Restriction	
Variable	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Perseveration %tile	61.23	31.12	68.27	22.58	62.64	31.96	53.13	30.54	70.00	24.58

Discussion

The current study examined the effect of acute and prolonged sleep restriction and extension on executive functioning, specifically inhibitory control. An experimental pre- and post-manipulation design allowed the evaluation of differences in neurocognitive functioning across acute sleep manipulations. Previous literature has identified broadly a relationship between neuropsychological functioning and sleep behavior, though with limited specificity. At present, only a few studies have evaluated extended acute sleep restriction (1 to 3 hours per night for 3 to 4 nights; Sadeh et al., 2003; Alhola and Polo-Kantola, 2007; Vriend et al., 2013), yet no studies have compared variations in acute sleep restriction and extension periods in the same study. A study by Sadeh and colleagues specified a relationship between fragmented sleep and poorer performance on neurobehavioral tasks requiring higher level executive control (Sadeh et al., 2002). Based on these results, less fragmented sleep was associated with better performance on CPT and digit span tasks. In addition, Sadeh and colleagues presented a model evaluating both extension and restriction of sleep duration (Sadeh et al., 2003). However, only two manipulation groups were compared, a group of children who were asked to restrict their sleep by one hour on each of three nights and a group of children who were asked to extend their sleep by one hour on each of three nights. Moreover, the neurobehavioral tasks assessed were not targeted – instead evaluating multiple domains of neurobehavioral functioning. No control group was formally utilized, however a pre-manipulation assessment with actigraphy provided individual baselines. The present study was modeled after the studies by Sadeh and colleagues, and aimed to expand the methodology to include variations in acute sleep restriction and extension, while also

reproducing and increasing specificity in neurocognitive performance findings. As such, a number of neurocognitive tasks were utilized to focus attention on inhibitory control, attentional control, and perseverative responding.

In addition to scores on the CPT (i.e., clinical confidence index, omission errors, commission errors, reaction time, and perseverative errors) and backward digit span, this study also evaluated performance on the color-word interference task of the D-KEFS and Wisconsin Card Sorting Task (WCST). With the exception of the WCST (due to the possibility of practice effects), all measures were presented prior to the sleep manipulation and after.

Evaluation of findings with respect to hypotheses

Overall, it was hypothesized there would be a significant difference in neurocognitive performance across measures between extension groups and control, as well as between restriction groups and control – and further, this finding would extrapolate out to a significant difference between extension and restriction groups as the extremes of manipulation. These hypotheses had mixed findings.

When contrasting restriction groups for hypothesis one, findings were mixed, with only backward digit span total score and longest span significantly different between groups and in the correct direction. Specifically, children who restricted their sleep in any manner had lower scores on the backward digit span task and a shorter digit span ceiling. This effect was particularly salient, with almost a full digit difference between control and restriction group. Change scores further clarified this effect, with the children in the control group demonstrating an increase in performance, while those in the restriction groups had decreased performance between session one and two. Backwards digit span

length is a measure of working memory, and more specifically longest span identifies a ceiling of capability rather than an executive functioning skill. Though the association between working memory and sleep is established, this is the first study to directly link improvements in basic working memory performance to sleep extension and decrements in performance to sleep restriction. Though statistically non-significant, there was a similar trend for inhibition condition completion time on the D-KEFS, such that children who restricted their sleep had slower completion times.

Finally, contrary to expectations, there was a significant difference in omission error scaled scores on the CPT between children who restricted their sleep and the control group, however this difference was the opposite direction than hypothesized. Children in the restriction group had better scores, or less omission errors, than those in the control group. A similar finding was observed in the clinical confidence index score of the CPT, such that children in the restriction group performed better than those in the control. However, further visual evaluation of the means at session one and two indicated that children in the control group improved their performance, while children in the restriction group did not.

Comparing performance of children in the extension groups, both combined and full-week extension only, to the control group for hypothesis two demonstrated more consistency in direction of findings. Both omission errors and clinical confidence index scores on the CPT were significantly different between manipulation groups, such that children who extended their sleep had better scores. The clinical confidence index on the CPT is a discriminatory function indicating how closely the clinical profile produced during assessment matching a clinical profile, rather than a nonclinical one. Thus, when

contrasting the extension group to the control group, it was evidenced that children in the extension groups had lower clinical likelihood of ADHD symptomology. In essence, those children who extended their sleep were less likely to demonstrate behavioral performance consistent with ADHD than those in the control group. Though only approaching significance, this same pattern was observed when comparing children in the full-week restriction group to the control. Specifically, those children in the full-week restriction tended to have higher confidence index scores indicative of performance more in alignment with ADHD, than those in the control group. These findings may indicate that slight changes in sleep patterns can dramatically change the overall neurobehavioral presentation of a child. While not diagnostic nor necessarily easily detected, a child who has inadequate sleep may perform similarly to a child with ADHD, having difficulties in the classroom, during formal assessment, or social interactions.

Further, children in the extension groups had fewer omission errors than children in the control group. More specifically, children with an extra hour of sleep either on one final night or one each of four nights were less likely to fail to respond to targets on the CPT. This measure of the CPT is often considered a measure of inattention or sustained attention. Sustaining attention is essential across multiple domains of functioning. Children who fail to attend or have greater inattention tend to perform more poorly on tasks and may even appear to have memory problems. Further, attending to stimuli is essential to and a first step to understanding material presented. These findings that children in the extension group performed better and were more attentive than those in the control group may provide evidence that extending sleep duration can increase likelihood of sustained attention and reduce instances of "zoning out" in children.

Similar to hypothesis one, performance on the inhibition condition completion time scores demonstrated a trend in the correct direction, though non-significant. Children in the extension groups had faster speed of completion on the task. Further, children in the extension conditions demonstrated significantly fewer errors in the inhibition condition of the D-KEFS color-word interference task than other groups.

Finally, children in the extension groups performed worse in session two on the backwards digit span, with shorter digit spans than those in the control. Though these scores would appear to be counter to expectations, when change scores were evaluated it was noted that those children in the extension group had greater change from session one to session two than those in the control group. These change scores may speak to the effect sleep extension had on these groups better than their session two scores alone, given the relatively small effect.

Though reaction time was noted as a significant interaction in repeated measures analyses, the strength of this effect was only moderate and did not produce any significant contrast scores. This result may be due to limited power, small effect, or attributed to the measurement instrument. It is noted that Sadeh and colleagues assessed reaction time independent of CPT, while this study limited assessment of reaction time to the CPT making it difficult to discern possible variance attributed to motor speed instead of reaction time as cognitive construct. Regardless, it is valuable to acknowledge the differences between children in the sleep extension, restriction, and control groups on reaction time even without specific contrasts to clarify changes in performance. Reaction time is often associated with and appears impacted by sleep. Further, other performance can be impacted by changes in reaction time. For example, accurate assessment of

working memory necessitates accurate speed of processing and reaction time. If a child is particularly slow to respond in a working memory task, the timing of stimuli may change or the trace may degrade making manipulation or cognitive flexibility difficult to parse apart.

Given the premise of this study, deleterious effects on inhibitory functioning was expected. However, findings did not support this kind of specificity. In fact, one of the primary measures of inhibitory control, commission errors on the CPT, was non-significant across all analyses. Previous studies, including one by this author, have shown decrements in performance on inhibitory control tasks associated with poor sleep or higher rates of sleep disturbance. It may be that inhibitory control is more broadly associated with chronic sleep concerns or restrictions, rather than acute changes in sleep. Findings from this study do not completely preclude the possibility of a relationship between inhibitory functioning and changes in sleep duration. The clinical confidence index for the CPT does include commission errors as a component of measurement and the switching condition on the D-KEFS, which was approaching significance, also requires inhibitory control as a central component to complete successfully.

Further, no significant differences between the one night only and full-week sleep manipulations were found. When single night effects were evaluated independently, they were non-significant and mixed on directionality. There did not appear to be significant differences between performance when sleep was manipulated on only one night versus control or typical sleep patterns. In fact, though non-significant, the mean score performance for the one night only manipulation groups often appeared impaired regardless of whether sleep was extended or restricted. It is difficult to determine why

this was found. Perhaps altering the children's sleep pattern on only one night was disruptive to the consistent schedule and thus impaired performance regardless of actual sleep attained. This explanation would support consistency in sleep schedule over specific duration once a threshold for necessary sleep duration is met. In contrast, this finding could be related more broadly to compliance with sleep manipulation procedures and difficulty of asserting a manipulation on only one night accurately.

Overall, manipulating sleep on an acute scale of only one hour on one night or across four separate consecutive nights appeared to affect some aspects of neurocognitive performance. Though inhibitory control was not specifically highlighted in the findings, limited assessment of working memory span, sustained attention, and broad clinical presentation were all impacted by acute extension and restriction of sleep. Further, though not clearly delineated in contrasts of restriction and extension groups, reaction time was again supported as a main aspect of neurocognitive functioning impacted by changes in sleep.

Association between Altered Sleep and Executive Functioning

These results offer a number of contributions to the empirical literature regarding the associations between sleep and neurocognitive functioning. First, it is one of only a few studies to evaluate sleep extension in addition to restriction, as well as the only one to evaluate different types of acute extension and restriction. This study highlights the broader implications of acute sleep changes, specifically for improving or impairing performance in working memory, sustained attention, and reaction time. Inhibitory control, while contributing to different scores across the various sleep manipulation groups, was not significantly nor specifically impacted in this study as evidenced by a

lack of effect on commission errors and perseverative errors across measures. This may indicate the sleep manipulation in this study was not strong enough to elicit changes in inhibitory control, inhibitory control is not as impacted by acute changes in sleep as previously thought, or that effects are more attributable to other variables.

If the manipulation in this study was not strong enough to elicit change in the measures of inhibitory control, this study provides evidence that neither the acute sleep manipulation of one hour the night prior to assessment nor four hours accumulated sleep restriction are sufficient to impair inhibitory control. However, given the other areas of neurocognitive performance effected in this study, it appears there is an effect for acute changes in sleep duration. Particularly interesting is the effect extension had on limited areas of speed of processing, and sustained attention. This study provides initial evidence that extending sleep by a relatively minor amount (i.e., one hour for one to four nights) can have a beneficial impact on several areas of neurocognitive performance. However, it is important to note that these same changes in sleep appeared to have an impairing effect on specific domains (i.e., digit span backwards performance). Given digit span backwards was the only task related to working memory with significant findings, it is difficult to assert predictions related to this finding.

Secondly, this study rules out perseveration as an area of neurocognitive performance impacted by acute changes in sleep. This domain was assessed across two primary measures including the CPT and WCST, with neither demonstrating significant change in perseverative responding based on the sleep manipulation. Thus, this study further narrows the scope of assessment for future studies.

Finally, findings further clarify the necessary period of sleep restriction or extension to elicit change in neurocognitive performance. While not completely delineated, this study's findings demonstrate an impact on a number of neurocognitive domains when sleep was extended or restricted by one hour each of four nights prior to assessment. However, the effects did not clearly demonstrate a directionality of performance if only the final night's sleep was changed. Instead, it appeared that any change in the night prior to testing, if no nights prior were changed, negatively impacted neurocognitive performance on some domains. This finding may highlight the importance of consistency or sleep patterns, even in acute extension or restriction paradigms. In contrast, these findings may simply represent greater difficulty in compliance with one night of change in sleeping habits. Evaluating differences in acute sleep changes continues to remain an area in need of more research.

Clinical Implications of Findings

For clinicians, researchers, sleep and developmental specialists, and pediatricians, the implications of this study are evident. The primary results of this study highlight the impact acute changes in sleep can have across neurocognitive domains. In particular, as children present to clinicians with attention problems or difficulty in school, this study points to the importance of assessing short term or acute changes in sleep that may impact these areas of cognitive functioning.

Given the broad domains effected by acute changes in sleep, researchers should include sleep as a standard assessment when utilizing objective tasks that are fully or partially time-based, or require working memory. Inaccurate or insufficient assessment of

acute sleep concerns or changes may confound findings and even elevate some children to clinical levels of impairment.

Further supporting previous studies, the CPT appears to remain consistent in its sensitivity to sleep extension and restriction. In this study, effects were particularly salient in the clinical confidence index, omission errors, and reaction time – indicators of sustained attention and attentional regulation, clinical presentation, and speed. Behavioral regulation and executive functioning control processes are associated with ADHD and other externalizing pathology, as well as a whole host of internalizing concerns. Sleep, both chronic and acute patterns, should be fully and accurately assessed in children. This study helps to further elucidate this relationship between sleep and neurocognitive performance and may help identify underlying mechanisms of change in children's performance and improve differential diagnosis.

Acute changes in sleep quantity appeared to have dramatic effects on neurocognitive functioning when significant. This study added domains not previously assessed in the acute sleep restriction and extension literature, as well as a multi-method approach to assessing each area. Inhibitory control was examined through evaluation of commission errors and errors in the inhibition and switching conditions of the D-KEFS. A limited subset of working memory was assessed through the digit span backwards, D-KEFS, and WCST. Perseverative responding was assessed through the CPT and WCST. And sustained attention was assessed through an evaluation of omission errors on the CPT, as well as integrated into completion of the WCST and D-KEFS. While perseverative responding did not appear effected by the acute manipulation of sleep, findings were mixed for inhibitory control, working memory, and sustained attention.

These findings can have broad implications for school performance and may even be more detrimental. Without specificity in the domains effected, it is difficult to target interventions for potential deficits that may not be immediately recognized in parents or teachers, let alone school administration. Working memory, inhibitory control, and sustained attention are essential skills in the classroom allowing children to perform tasks efficiently and accurately. However, acute changes in sleep appear innocuous. Parents are faced with the nightly task of assuring their child has had sufficient sleep to perform well in school and other activities. Yet, children commonly request "just one more hour." Interestingly, in this study, there did not appear to be sufficient evidence to assert that the night prior to assessment was more detrimental to performance than prolonged accumulation of sleep loss or gain over multiple days, nor was there evidence against. It is possible the night prior to evaluation is the most dangerous, performance by those children in the one night only manipulation groups did not have consistent evidence for an effect on performance beyond children with four nights of manipulation. Regardless, one hour appears relatively minor when talking about a difference of 8:00pm to 9:00pm, but this study demonstrated that four nights with accumulated sleep loss of only an hour did effect neurocognitive performance.

Study Limitations

These results highlight the limitations of experimental research of sleep and of the current study more specifically. Almost all studies examining sleep behaviors and patterns have utilized an experimental design in which assessment and collection of the independent variable (e.g., cognitive or neuropsychological testing scores, processing speed time) occurs before sleep measurement and directly afterwards. However, this

design and the present study does not allow for objective pre-assessment evaluation of sleep (e.g., utilizing actigraphy prior to implementing manipulation). This study attempted to account for this concern by maintaining a control group with no restriction or extension implemented, as well as multiple questionnaire-style measures regarding typical sleep behavior collected prior to manipulation.

Sleep restriction studies among children vary in length but require multiple nights of sleep restriction and uninterrupted sleep (e.g., a week-long study). The commitment required by parents and children for a sleep restriction study is great. An at-home sleep protocol is preferred over lab-based sleep assessment by polysomnography due to accessibility and the benefits of a natural home setting. Though sleep restriction studies typically overlap with school attendance, this study's restriction was constrained to one hour per night rather than a full night of deprivation. It is believed that this amount of restriction would not place an undue burden on either the subjects or their parents, but does introduce a limitation to the study. Specifically, acute sleep manipulation periods could not be easily extended beyond the hour per night without potential harm to the subjects or impact on daily functioning.

Further, to examine the relationship between sleep problems and neurocognitive performance, it was necessary to have a sufficient delay between the first and second study sessions (i.e., pre-restriction and post restriction) in order to avoid practice effects. While a 2 or 3 week protocol would be ideal, the length of the current protocol was only 1 week and measures of executive functioning which were susceptible to practice effects were conducted only at post-assessment. It is possible that the small effects sought as between subject effects were washed out by the within subject time effect on some

measures, which would not have occurred with a longer delay. The CPT, however, has strong evidence that practice effects do not occur as readily as other neurocognitive measures and thus can be used multiple time within a short duration, even within the same day without practice or time effects impacting performance.

Finally, actigraphy was utilized due its relatively low intrusiveness and the ability to maintain a naturalistic setting of study. However, with a naturalistic setting there are errors in control that must be addressed. For example, in a naturalistic setting, an actigraph watch might be forgotten a night or incorrectly placed. Study compliance is dependent on parent and child acceptability of the procedures and ability to maintain the schedule. In a dedicated sleep laboratory, these concerns would be eliminated.

Future Directions

This study offers an expansion on previous research and contributes significantly to the field of children's sleep and executive functioning. More specifically, this study expanded on a few limited studies assessing the effects of acute sleep manipulations neurocognitive functioning.

Future research should first consider expanding the subject pool to allow for more powerful comparisons and broader sample characteristics (e.g., fewer exclusionary criteria). With a larger sample size, statistical power to detect any significant association between sleep and executive functions will increase. Given the issues with compliance on this study, particularly for those children in the extensions groups, future studies need to include a pre-manipulation sleep assessment period. This will provide information about objective assessment of compliance and provide a point of comparison for individual changes in sleep patterns. Additionally, future studies should consider utilizing a model

of sleep extension dependent on morning wake time, rather than bedtime. While restriction is more easily manipulated by moving bedtime, extension would be better maintained by wake time and would allow for individual difference in sleep onset latency to be controlled.

Some of the findings in working memory and sustained attention were inconsistent with the hypotheses, but were noted in two previous studies. Gruber and colleagues (2011) found effects of acute sleep restriction on omission errors and reaction times in children with ADHD, while seeing an improvement on commission errors. Another study demonstrated emotional dysregulation, and secondary concerns with working memory and attention during an acute restriction, however again results were mixed (Vriend et al., 2013). These are the only two studies known to evaluate acute restriction with findings in working memory, as well as mixed results on effects. Future research should investigate the validity of the current study's findings in light of these findings, specifically on the effects of inhibitory and attentional control, as well as working memory on executive functions. Targeted evaluation of the working memory construct may clarify whether there are specific aspects of working memory effected by changes in sleep or if the effect is broad.

These associations and mixed findings may be further clarified within the context of the two-process model of sleep, the regulation of sleep and wakefulness controlled by the homeostatic sleep drive and circadian rhythms. Previous evaluations have implicated efficiency, rather than duration, as a primary sleep variable associated with neurobehavioral and neurocognitive performance (e.g., Sadeh et al., 2002; Robertson, 2013). How variables of sleep efficiency, sleep onset latency, and wake after sleep onset

predict daytime neurocognitive performance are more difficult to evaluate in a sleep manipulation experimental model. Performance deficits have been associated with increased homeostatic drive to sleep (Jiang et al., 2011), however how sleep efficiency is affected by homeostatic sleep drive in an experimental sleep manipulation study is unclear. Conceptually, homeostatic sleep drive should increase slightly in an individual who restricts their sleep. One would expect to observe shorter sleep onset latency and thus increased efficiency acutely due to this increase in the homeostatic sleep drive. While in contrast, a child who attempts to extend their sleep duration on the front-end of their night may have a longer sleep onset latency and thus worsened efficiency. This process may help explain the mixed results found in this study. More specifically, those neurocognitive variables with significant findings counter expectations may represent a stronger association with sleep efficiency and onset latency than sleep duration. Future research should consider this two-process model when evaluating those aspects of sleep which impact neurocognitive performance.

Further, in consideration of circadian rhythms and individual sleep patterns, it is important to acknowledge that both the extension and restriction sleep manipulations in this study were completed at bedtime, rather than at wake time or mid-night. With one hour sleep manipulation, it is estimated that at least one REM cycle was affected in the present study. However, given the limitations of actigraphy, this study cannot assert how much an affect the sleep manipulation had on each child's sleep cycle definitively. Future research should investigate the differences incurred by manipulating sleep at different periods during the night (e.g., comparing manipulation at bedtime, mid-night, and wake time).

Even though sleep manipulation appears to affect various domains of executive functions, the question remains whether these findings would generalize to daily performance. Broader school performance assessments and follow-up assessments of behavioral correlates would help elucidate these findings. For example, the clinical confidence index is typically considered a tool to help identify children who perform in a way similar to children diagnosed with ADHD. A post-manipulation assessment of daytime behaviors would provide evidence of whether these typical children truly behave like children with psychopathology.

Moreover, it may be beneficial to compare a sample of children with pathology (e.g., ADHD, impulse disorder, internalizing problems) to a normal sample to evaluate discrepancies in performance gains or losses. Perhaps sleep extension is more beneficial for children with pre-existing psychopathology. In contrast, those children with more internalizing problem presentations may have effects demonstrated through mood and affect, rather than cognitive performance (i.e., mood regulation rather than inhibitory control broadly). These different domains should be evaluated across acute and long-term sleep patterns within the same child to identify those aspects of neurocognitive functioning impacted solely by acute changes.

Finally, future research should evaluate covariates of this relationship or variables that impact initial stable performance versus those variables of interest that impact change during manipulation (e.g., effortful control, pre-existing externalizing or internalizing symptomology, parental sleep habits). There may be environmental variables or children characteristics that mediate or moderate this relationship. Greater specificity in characterizing the relationship between sleep and neurocognitive functions

allows for interventions to target at-risk populations and larger systems in the lives of children (i.e., school administration).

Similarly, future research should investigate how children fill their time in bed if onset latency or wake after sleep onset change in those children who attempt to extend their sleep duration (e.g., increase), as well as during the increased time prior to bedtime if sleep is restricted. Though children were instructed to remain consistent with their night time routines, this study did not formally query children on their behavior while in bed beyond a basic self-report and parent-report of pre-manipulation behaviors. With greater understanding of the natural home environment and behaviors surrounding sleep during manipulation, the relationship between acute changes in sleep and neurocognitive performance can be better understood and attributed to experimental manipulation (i.e., narrowing the scope of causality).

This study attempted to answer a number of questions regarding the effects of acute sleep manipulation on executive functioning in children including: effect of extending or restricting sleep on inhibitory control specifically, effect differences between acute sleep restriction and extension periods, and ruling out other related executive functioning components (e.g., perseverative responding). Findings indicated a beneficial effect of acute sleep extension on reaction time, completion time, inhibitory errors, omission errors, and general presentation style. However, extending sleep also appeared to impair performance in working memory tasks. Similarly, findings regarding acute sleep restriction were mixed with detriment appearing to occur in domains of working memory and completion time, while improving performance in omissions. While not as specific as hypothesized, these findings do lend support to the effect of

children's sleep on neurocognitive performance, highlighting the complexity of executive functioning and sleep's role in children's performance.

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Appendix A

Child Health History
Idaho State University

ID # _____

Relationship to child: _____

1. Child's date of birth: _ _/ _ _/ _ _ _ _
2. Child's age: _____ Years, _____ Months
3. Within the past 3 years, has your child had a regular physician or a clinic he/she usually attends?
   a. YES
   b. NO (Go to Question 4)
4. Do you remember the date of your child's last physical examination within the past 3 years?
   a. YES
   b. NO (Go to Question 5)

   _ _/ _ _/ _ _ _ _
   (Month, day, year of last physical)
5. What is your child's current height? _____ ft. _____ ins.
6. What is your child's current weight? _____ lbs.
7. Has your child been on a medication program for hyperactivity for a period of time, such as Ritalin or other medication in the past year?
   a. YES
   b. NO (Go to Question 8)

   Age Started: _____ Age Ended: _____
8. Has your child been on a medication program for any other long term or chronic condition(s) in the past year (such as asthma, cystic fibrosis, etc.)?
   a. YES
   b. NO (Go to Question 9)

Medication	Age Started	Age Ended	Reason (Condition)
_____	_____	_____	_____
_____	_____	_____	_____

Child Health History ID # _____
Idaho State University

The next set of questions deal with other medications your child has taken in the PAST MONTH. If he/she has taken the medication, write in the brand of medication taken, TOTAL number of days he/she has taken the medication in the past month (estimate, if necessary), and the reason(s) for taking them.

9. Has your child taken any pain or fever relievers (aspirin, Tylenol, etc.) in the past month?
   a. YES
   b. NO (Go to Question 10)

Medication	Days	Reasons	(Illness/Condition)

10. Has your child taken any cough medicine (Robitussin, Pediacare, Triaminic, etc.) in the past month?
    a. YES
    b. NO (Go to Question 11)

Medication	Days	Reasons	(Illness/Condition)

11. Has your child taken any decongestants/nasal spray (Sudafed, Dimetapp, Actifed, etc.) in the past month?
    a. YES
    b. NO (Go to Question 12)

Medication	Days	Reasons	(Illness/Condition)

12. Has your child taken any Antihistamines (Chlortrimaton, Actifed, Benadryl, etc.) in the past month?
    a. YES
    b. NO (Go to Question 13)

Medication	Days	Reasons	(Illness/Condition)

Child Health History ID # _____
Idaho State University

13. Has your child taken any multisystem cold remedies (Nyquil, Coridiidin, Cotylenol, etc.) in the past month?
    a. YES
    b. NO (Go to Question 14)

Medication	Days	Reasons	(Illness/Condition)

14. Has your child taken any antibiotics (Penicillin, Amoxicillin, etc.) in the past month?
    a. YES
    b. NO (Go to Question 15)

Medication	Days	Reasons	(Illness/Condition)

15. Has your child taken any asthma medication in the past month?
    a. YES
    b. NO (Go to Question 16)

Medication	Days	Reasons	(Illness/Condition)

16. Has your child taken any allergy medication in the past month?
    a. YES
    b. NO (Go to Question 17)

Medication	Days	Reasons	(Illness/Condition)

17. Has your child taken any vitamins/dietary supplements in the past month?
    a. YES
    b. NO (Go to Question 18)

Medication	Days	Reasons	(Illness/Condition)

Child Health History ID # _____
Idaho State University

18. Has your child taken any neuroleptic medications (Thorazine, Mellaril, Stelazine, Prolixin, Haldol, Clozaril, Risperidol, etc.) in the past month?
    a. YES
    b. NO (Go to Question 19)

Medication	Days	Reasons	(Illness/Condition)

19. Has your child taken any tricyclic antidepressants (Prozac, Zoloft, Desyrel, Effexor, etc.) in the past month?
    a. YES
    b. NO (Go to Question 20)

Medication	Days	Reasons	(Illness/Condition)

20. Has your child taken any monoamine oxidase inhibitors (Nardil, Parnate, etc.) in the past month?
    a. YES
    b. NO (Go to Question 21)

Medication	Days	Reasons	(Illness/Condition)

21. Has your child taken lithium in the past month?
    a. YES
    b. NO (Go to Question 22)

Medication	Days	Reasons	(Illness/Condition)

Child Health History ID # _____
Idaho State University

22. Has your child taken any anticonvulsant medication (Depacote, Tegretol, etc.) in the past month?
    a. YES
    b. NO (Go to Question 23)

Medication	Days	Reasons	(Illness/Condition)

23. Has your child taken any anti-anxiety medication (Buspar, Valium, Librium, Dalmane, etc.) in the past month?
    a. YES
    b. NO (Go to Question 24)

Medication	Days	Reasons	(Illness/Condition)

24. Has your child taken any stimulant medication (Ritalin, Cylert, Dexedrine, etc.) in the past month?
    a. YES
    b. NO (Go to Question 25)

Medication	Days	Reasons	(Illness/Condition)

25. Has your child taken any anti-hypertensive medication (Inderal, Catapres, Tenex, etc.) in the past month?
    a. YES
    b. NO (Go to Question 26)

Medication	Days	Reasons	(Illness/Condition)

Child Health History ID # _____
Idaho State University

26. Has your child taken any other medications in the past 12 months?
    a. YES
    b. NO (Go to Question 27)

Medication	Days	Reasons	(Illness/Condition)

27. Has your child been hospitalized in the past 3 years?
    a. YES
    b. NO (Go to Question 28)

Age	Reason: Operation or Illness	# of Days

28. Has your child been in an accident resulting in injury serious enough to require immediate medical treatment (e.g., broken bones, concussion, stitches, burns, poisonings/accidental ingestion, etc.) in the past 3 years?
    a. YES
    b. NO (Go to Question 29)

Age	Reason: Operation or Illness	# of Days

29. Has your child been diagnosed with the following problems?

Chronic pain	YES	NO
Diabetes or any circulation problems	YES	NO
Sleep apnea	YES	NO
Excessive Snoring	YES	NO

Appendix B

Demographics Questionnaire
Idaho State University

ID # _____

Please answer each of these to the best of your ability. If you are unsure of an answer, please ask the researcher or leave the question blank.

1a. What is your gender?

___ Male
___ Female
___ Transgender
___ Other

1b. What is your spouse/partner's gender?

___ Male
___ Female
___ Other
___ Transgender

2. What is your child's gender?

___ Male
___ Female
___ Transgender
___ Other

3a. What is your birthdate?
__/__/____

3b. What is your child's birthdate?
__/__/____

3c. What is your spouse/partner's birthdate?
__/__/____

4a. What is your relationship to your child?

___ Biological parent ___ Step-parent ___ Grandparent
___ Foster parent ___ Adoptive parent ___ Other: _____

4b. What is your spouse/partner's relationship to your child?

___ Biological parent ___ Step-parent ___ Grandparent
___ Foster parent ___ Adoptive parent ___ Other: _____

Demographics Questionnaire ID # _____
Idaho State University

5. Who else shares your household? What is their relationship to you and your child?

Child 1: RELATIONSHIP: _____ Gender: _____ DOB: _____
Child 2: RELATIONSHIP: _____ Gender: _____ DOB: _____
Child 3: RELATIONSHIP: _____ Gender: _____ DOB: _____
Child 4: RELATIONSHIP: _____ Gender: _____ DOB: _____
Child 5: RELATIONSHIP: _____ Gender: _____ DOB: _____

Adult 1: RELATIONSHIP: _____ Gender: _____ Age: _____
Adult 2: RELATIONSHIP: _____ Gender: _____ Age: _____
Adult 3: RELATIONSHIP: _____ Gender: _____ Age: _____

6. Child's current grade?
(1st, 2nd, 3rd, etc.)

_____

7. Parent's Education?
(F= Father; M=Mother; G=Guardian)

___Elementary School
___Middle School/Junior High
___High School Diploma or GED
___Vocational/Technical School (2 year)
___Some College
___Bachelor's Degree
___Master's Degree
___Doctoral Degree
___Professional Degree (M.D., J.D., etc.)
___Other: _____

8. Ethnicity? (e.g., Caucasian, African-American, Native American)

Parent: _____
Parent: _____
Child: _____

Demographics Questionnaire ID # _____
Idaho State University

9. What is your current marital status?

___ Married
___ Civil Union
___ Living with another
___ Divorced
___ Separated
___ Single
___ Widowed
___ Would rather not say

10. What is your current household income?

___ Under $10,000
___ $10,000 – $25,000
___ $25,000 – $50,000
___ $50,000 – $75,000
___ $75,000 – $100,000
___ $100,000 – $150,000
___ Over $150,000
___ Would rather not say

11. Type of employment? (e.g., retail, teaching, farming)

Parent: _____

Parent: _____

12. Does your child have any psychological or medical diagnoses?
(e.g., ADHD, Sleep disorder, Sleep apnea)

Please list: _____

_____

13. Is your child on any medications which impact his/her sleep?

Please list: _____

_____

Demographics Questionnaire ID # _____
Idaho State University

14. Did you have any complications with your child's birth? Did your child have any developmental delays?

_____

_____

15. Has your child ever had any special education or programs at school?

_____

_____

16. Have you, your partner or your child's other parent ever had problems with drugs and/or alcohol?

YES NO DON'T KNOW

If yes, which member of the family has the problem? _____

17. Have you, your partner or your child's other parent ever had problems with sleeping or a diagnosis of a sleep disorder?

YES NO DON'T KNOW

If yes, which member of the family? _____

If yes, what was the nature of the problem? _____

_____

Appendix C

A Self-Administered Rating Scale for Pubertal Development ID # _____

Introduction: The next questions are about changes that may be happening to your body. These changes normally happen to different young people at different ages. Since they may have something to do with your sleep patterns, do your best to answer carefully. If you do not understand a question or do not know the answer, just mark "I don't know."

1. Would you say that your growth in height:
   _____ Has not yet begun to spurt
   _____ Has barely started
   _____ Is definitely underway
   _____ Seems completed
   _____ I don't know

2. And how about the growth or your body hair?
   ("Body hair" means hair any place other than your head, such as under your arms.)

   Would you say that your body hair growth:
   _____ Has not yet begun to grow
   _____ Has barely started to grow
   _____ Is definitely underway
   _____ Seems completed
   _____ I don't know

3. Have you noticed any skin changes, especially pimples?
   _____ Skin has not started changing
   _____ Skin has barely started changing
   _____ Skin changes are definitely underway
   _____ Skin changes seem complete
   _____ I don't know

Adapted from Carskadon, M.A., & Acebo, C. (1993). A self-administered rating scale for pubertal development. *Journal of Adolescent Health, 14*, 190-195.

A Self-Administered Rating Scale for Pubertal Development ID # _____

Form for boys:

4. Have you noticed a deepening of your voice?
   - _____ Voice has not yet started changing
   - _____ Voice has barely started changing
   - _____ Voice changes are definitely underway
   - _____ Voice changes seem complete
   - _____ I don't know

5. Have you begun to grow hair on your face?
   - _____ Facial hair has not yet started growing
   - _____ Facial hair has barely started growing
   - _____ Facial hair growth has definitely started
   - _____ Facial hair grown seems complete
   - _____ I don't know

Adapted from Carskadon, M.A., & Acebo, C. (1993). A self-administered rating scale for pubertal development. *Journal of Adolescent Health, 14*, 190-195.

A Self-Administered Rating Scale for Pubertal Development ID # _____

Form for girls:

4. Have you noticed that your breasts have begun to grow?
   - _____ Have not started growing
   - _____ Have barely started growing
   - _____ Breast growth is definitely underway
   - _____ Breast growth seems complete
   - _____ I don't know

5a. Have you begun to menstruate (started to have your period)?
   - _____ Yes
   - _____ No

5b. If yes, how old were you when you started to menstruate?
   - _____ age in years

Adapted from Carskadon, M.A., & Acebo, C. (1993). A self-administered rating scale for pubertal development. *Journal of Adolescent Health, 14*, 190-195.

Appendix D

Child's Sleep Habits
(Preschool and School-Aged)

Coding _____

The following statements are about your child's sleep habits and possible difficulties with sleep. Think about the past week in your child's life when answering the questions. If last week was unusual for a specific reason (such as your child had an ear infection and did not sleep well or the TV set was broken), choose the most recent typical week. Answer USUALLY if something occurs **5 or more times** in a week; answer SOMETIMES if it occurs **2-4 times** in a week; answer RARELY if something occurs **never or 1 time** during a week. Also, please indicate whether or not the sleep habit is a problem by circling "Yes," "No," or "Not applicable (N/A).

Bedtime

Write in child's bedtime: _____

	3 Usually (5-7)	2 Sometimes (2-4)	1 Rarely (0-1)	Problem?		
Child goes to bed at the same time at night	☐	☐	☐	Yes	No	N/A
Child falls asleep within 20 minutes after going to bed	☐	☐	☐	Yes	No	N/A
Child falls asleep alone in own bed	☐	☐	☐	Yes	No	N/A
Child falls asleep in parent's or sibling's bed	☐	☐	☐	Yes	No	N/A
Child falls asleep with rocking or rhythmic movements	☐	☐	☐	Yes	No	N/A
Child needs special object to fall asleep (doll, special blanket, etc.)	☐	☐	☐	Yes	No	N/A
Child needs parent in the room to fall asleep	☐	☐	☐	Yes	No	N/A
Child is ready to go to bed at bedtime	☐	☐	☐	Yes	No	N/A
Child resists going to bed at bedtime	☐	☐	☐	Yes	No	N/A
Child struggles at bedtime (cries, refuses to stay in bed, etc.)	☐	☐	☐	Yes	No	N/A
Child is afraid of sleeping in the dark	☐	☐	☐	Yes	No	N/A
Child is afraid of sleep alone	☐	☐	☐	Yes	No	N/A

Sleep Behavior

Child's usual amount of sleep each day: _____ hours and _____ minutes
(combining nighttime sleep and naps)

	3 Usually (5-7)	2 Sometimes (2-4)	1 Rarely (0-1)	Problem?		
Child sleeps too little	☐	☐	☐	Yes	No	N/A
Child sleeps too much	☐	☐	☐	Yes	No	N/A
Child sleeps the right amount	☐	☐	☐	Yes	No	N/A
Child sleeps about the same amount each day	☐	☐	☐	Yes	No	N/A
Child wets the bed at night	☐	☐	☐	Yes	No	N/A
Child talks during sleep	☐	☐	☐	Yes	No	N/A
Child is restless and moves a lot during sleep	☐	☐	☐	Yes	No	N/A
Child sleepwalks during the night	☐	☐	☐	Yes	No	N/A
Child moves to someone else's bed during the night (parent, brother, sister, etc.)	☐	☐	☐	Yes	No	N/A

Coding

Sleep Behavior (continued)

	3 Usually (5-7)	2 Sometimes (2-4)	1 Rarely (0-1)	Problem?		
Child reports body pains during sleep. If so, where? _____	☐	☐	☐	Yes	No	N/A
Child grinds teeth during sleep (your dentist may have told you this)	☐	☐	☐	Yes	No	N/A
Child snores loudly	☐	☐	☐	Yes	No	N/A
Child seems to stop breathing during sleep	☐	☐	☐	Yes	No	N/A
Child snorts and/or gasps during sleep	☐	☐	☐	Yes	No	N/A
Child has trouble sleeping away from home (visiting relatives, vacation)	☐	☐	☐	Yes	No	N/A
Child complains about problems sleeping	☐	☐	☐	Yes	No	N/A
Child awakens during night screaming, sweating, and inconsolable	☐	☐	☐	Yes	No	N/A
Child awakens alarmed by a frightening dream	☐	☐	☐	Yes	No	N/A

Waking During the Night

	3 Usually (5-7)	2 Sometimes (2-4)	1 Rarely (0-1)	Problem?		
Child awakes once during the night	☐	☐	☐	Yes	No	N/A
Child awakes more than once during the night	☐	☐	☐	Yes	No	N/A
Child returns to sleep without help after waking	☐	☐	☐	Yes	No	N/A

Write the number of minutes a night waking usually lasts: _____

Morning Waking

Write in the time of day child usually wakes in the morning: _____

	3 Usually (5-7)	2 Sometimes (2-4)	1 Rarely (0-1)	Problem?		
Child wakes up by him/herself	☐	☐	☐	Yes	No	N/A
Child wakes up with alarm clock	☐	☐	☐	Yes	No	N/A
Child wakes up in negative mood	☐	☐	☐	Yes	No	N/A
Adults or siblings wake up child	☐	☐	☐	Yes	No	N/A
Child has difficulty getting out of bed in the morning	☐	☐	☐	Yes	No	N/A
Child takes a long time to become alert in the morning	☐	☐	☐	Yes	No	N/A
Child wakes up very early in the morning	☐	☐	☐	Yes	No	N/A
Child has a good appetite in the morning	☐	☐	☐	Yes	No	N/A

Coding

Daytime Sleepiness

	3 Usually (5-7)	2 Sometimes (2-4)	1 Rarely (0-1)	Problem?		
Child naps during the day	☐	☐	☐	Yes	No	N/A
Child suddenly falls asleep in the middle of active behavior	☐	☐	☐	Yes	No	N/A
Child seems tired	☐	☐	☐	Yes	No	N/A

During the past week, your child has appeared very sleepy or fallen asleep during the following (check all that apply):

	1 Not Sleepy	2 Very Sleepy	3 Falls Asleep
Play alone	☐	☐	☐
Watching TV	☐	☐	☐
Riding in car	☐	☐	☐
Eating meals	☐	☐	☐

Appendix E

SLEEP SELF REPORT
(Child's Form)

Coding _____

[redacted]

These questions are about your sleep. The researcher will explain the form and read you the questions in class. Please mark your answer to each question in the box. There are no right or wrong answers. Please ask if you do not understand a question. Thank you!

1. Who in your family sets the rules about when you go to bed?
   ☐ Mom ☐ Dad ☐ You ☐ Other: _____
2. Do you think you have trouble sleeping? ☐ Yes ☐ No
3. Do you like to go to sleep? ☐ Yes ☐ No

BEDTIME	(3) Usually (5-7)/ week	(2) Sometimes (2-4)/ week	(1) Rarely (0-1)/ week or never
4. Do you go to bed at the same time every night on school nights? (R)	☐	☐	☐
5. Do you fall asleep in the same bed every night? (R)	☐	☐	☐
6. Do you fall asleep alone? (R)	☐	☐	☐
7. Do you fall asleep in parents', brothers', or sisters' bed?	☐	☐	☐
8. Do you fall asleep in about 20 minutes? (R)	☐	☐	☐
9. Do you fight with your parents about going to bed?	☐	☐	☐
10. Is it hard for you to go to bed?	☐	☐	☐
11. Are you ready for bed at your usual bedtime? (R)	☐	☐	☐
12. Do you have a special thing (doll, blanket, etc.) you bring to bed?	☐	☐	☐
13. Are you afraid of the dark?	☐	☐	☐
14. Are you afraid of sleeping alone?	☐	☐	☐
15. Do you stay up late when your parents think you are asleep?	☐	☐	☐
SLEEP BEHAVIOR			
16. Do you think you sleep too little?	☐	☐	☐
17. Do you think you sleep too much?	☐	☐	☐
18. Do you wake up at night when your parents think you're asleep?	☐	☐	☐
19. Do you have trouble falling back to sleep if you wake up during the night?	☐	☐	☐
20. Do you have nightmares?	☐	☐	☐
21. Does pain wake you up at night? Where is that pain?	☐	☐	☐
22. Do you sometimes go to someone's bed during the night? If yes,	☐	☐	☐

who? _____	(3) Usually (5-7)/ week	(2) Sometimes (2-4)/ week	(1) Rarely (0-1)/ week or never
DAYTIME SLEEPINESS			
23. Do you have trouble waking up in the morning?	☐	☐	☐
24. Do you feel sleepy during the day?	☐	☐	☐
25. Do you take naps during the day?	☐	☐	☐
26. Do you feel rested after a night's sleep? (R)	☐	☐	☐

Appendix F

Daily Sleep Diary

Complete the diary each evening and morning (Day 1 will be the first evening wearing activity watch)

ID Number _____ Parent Date of Day 1 _____

	Day 1	Day 2	Day 3	Day 4	Day 5
Time up in morning		__:__	__:__	__:__	__:__
Time in bed	__:__	__:__	__:__	__:__	
# of Night Awakenings					
How well did your child sleep?		1 Very Bad 2 Bad 3 OK 4 Good 5 Very Good	1 Very Bad 2 Bad 3 OK 4 Good 5 Very Good	1 Very Bad 2 Bad 3 OK 4 Good 5 Very Good	1. Very Bad 2. Bad 3. OK 4. Good 5. Very Good
How long did it take your child to fall asleep?		1 0 – 5 min. 2 6 – 20 min. 3 21 – 30 min. 4 31 min. +	1 0 – 5 min. 2 6 – 20 min. 3 21 – 30 min. 4 31 min. +	1 0 – 5 min. 2 6 – 20 min. 3 21 – 30 min. 4 31 min. +	1. 0 – 5 min. 2. 6 – 20 min. 3. 21 – 30 min. 4. 31 min. +
How tired was your child at night?		1 Very Alert 2 Alert 3 Tired 4 Very Tired	1 Very Alert 2 Alert 3 Tired 4 Very Tired	1 Very Alert 2 Alert 3 Tired 4 Very Tired	1. Very Alert 2. Alert 3. Tired 4. 4. Very Tired
How tired was your child in the morning?		1 Very Alert 2 Alert 3 Tired 4 Very Tired	1 Very Alert 2 Alert 3 Tired 4 Very Tired	1 Very Alert 2 Alert 3 Tired 4 Very Tired	1. Very Alert 2. Alert 3. Tired 4. Very Tired

Appendix G

Daily Sleep Diary

Complete the diary each evening and morning (Day 1 will be the first evening wearing activity watch)

ID Number _____ Child Date of Day 1 _____

	Day 1	Day 2	Day 3	Day 4	Day 5
Time up in morning		_ _ : _ _	_ _ : _ _	_ _ : _ _	_ _ : _ _
Time in bed	_ _ : _ _	_ _ : _ _	_ _ : _ _	_ _ : _ _	
# of Night Awakenings					
How well did you sleep?		1 Very Bad 2 Bad 3 OK 4 Good 5 Very Good	1 Very Bad 2 Bad 3 OK 4 Good 5 Very Good	1 Very Bad 2 Bad 3 OK 4 Good 5 Very Good	1. Very Bad 2. Bad 3. OK 4. Good 5. Very Good
How long did it take to fall asleep?		1 0 – 5 min. 2 6 – 20 min. 3 21 – 30 min. 4 31 min. +	1 0 – 5 min. 2 6 – 20 min. 3 21 – 30 min. 4 31 min. +	1 0 – 5 min. 2 6 – 20 min. 3 21 – 30 min. 4 31 min. +	1. 0 – 5 min. 2. 6 – 20 min. 3. 21 – 30 min. 4. 31 min. +
How tired were you at night?		1 Very Alert 2 Alert 3 Tired 4 Very Tired	1 Very Alert 2 Alert 3 Tired 4 Very Tired	1 Very Alert 2 Alert 3 Tired 4 Very Tired	1. Very Alert 2. Alert 3. Tired 4. 4. Very Tired
How tired were you in the morning?		1 Very Alert 2 Alert 3 Tired 4 Very Tired	1 Very Alert 2 Alert 3 Tired 4 Very Tired	1 Very Alert 2 Alert 3 Tired 4 Very Tired	1. Very Alert 2. Alert 3. Tired 4. Very Tired