

The Impact of Sleep Restriction on
Typically Developing Children's Attention

by

Sarah Brine

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Dedicated to my parents, Laura and Danny Brine,
without whom I would not be who I am today

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Abstract

Chronic sleep loss for children is a growing concern, yet few experimental studies have tested the impact of cumulative sleep restriction on cognitive functioning. The present study examined the impact of one hour less time in bed per night for 6 nights on attention in 27 typically developing children (6-12 years). Attention was assessed both objectively (CPT-II) and subjectively (questionnaires). Results showed significant differences in attention on the CPT-II, but not on subjective reports. Individual differences in daytime sleepiness and amount of sleep restriction were related to difference scores on the CPT-II. Changes in the attention as reported by teachers was related to changes in CPT-II commission errors (i.e., decreased impulsivity) and changes in child reported attention were related to changes in CPT-II reaction time. These results indicate that sleep restriction can affect children's attention; however, these changes may be subtle and not captured by subjective measures.

Keywords: attention, CPT, sleep, sleep restriction

List of Abbreviations and Symbols Used

ADHD = attention-deficit hyperactivity disorder

ADHD-CSR = attention-deficit hyperactivity disorder – child self-report

ADHD-RAR = attention-deficit hyperactivity disorder – research assistant report

ANT-I = Attention Network Test – Interaction

CBCL = Child Behavior Checklist

CCTT = Children's Color Trails Test

CPT = Continuous Performance Test

CPT- II = Continuous Performance Test – Second Edition

CPRS = Connors Parent Rating Scale

CTRS = Connors Teacher Rating Scale

CVLT = California Verbal Learning Test

M = mean

Min = minutes

MSLT = multiple sleep latency test

MSVU = Mount Saint Vincent University

n = sample size

PFC = prefrontal cortex

PSG = polysomnography

PVT = Psychomotor Vigilance Task

RA = research assistant

RM-MANOVA = repeated measures multivariate analysis of variance

RT = reaction time

SD = standard deviation

TIB = time in bed

TD = typically developing

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The Impact of Sleep Restriction on Typically Developing Children's Attention

Sleep plays an active role in brain maturation, information processing, memory and learning, as well as behavioural functioning (Sadeh, 2007). Despite the importance of sleep there is growing concern about chronic sleep loss for all ages, as decreasing sleep duration has become a hallmark of modern society (Gruber, 2013; Li et al., 2013). While there are large individual differences in the amount of sleep needed, it is clear that sleep is important for optimal functioning, and as such there are recommendations about the amount of sleep required at different developmental stages (Ferrara & De Gennaro, 2001; Hirshkowitz et al., 2015). However, factors such as 24 hour access to television, internet, and phones, as well as increases in caffeine intake, extracurricular activities, and busy lifestyles can lead to difficulties falling asleep and later sleep onset times. As such many children do not get the recommended amount of sleep (National Sleep Foundation Poll, 2004; Sadeh, 2007).

The daytime consequences of sleep loss and sleepiness in adults have been well documented, and include deficits in attention, motor performance, mood, and cognition (Durmer & Dinges, 2005). Recent research suggests that the impact of chronic sleep loss and sleepiness in children is similar to, or possibly greater than it is in adults (e.g., Sadeh et al., 2003; Peters et al., 2009; Gruber et al., 2011). Since childhood is a critical period for learning and acquiring skills, children may be particularly vulnerable to the effects of sleep loss. As such, there is a pressing need for more experimental research to determine the links between insufficient sleep in children and their daytime functioning. This information can be used to develop clinical standards of practice related to sleep and to educate health professionals and the public on the importance of sleep for children (Owens & Mindell, 2006).

There are several aspects of sleep that can be measured, but the most commonly assessed aspect is quantity of sleep (i.e., sleep duration). Sleep diaries are often used to calculate participants' sleep duration as well as time in bed (TIB) by using the recorded time the lights were turned off (i.e., lights out), sleep onset (i.e., time fell asleep), and wake time variables. Sleep duration typically refers to how long the individual slept (e.g., using sleep onset and wake time), while TIB refers to the length of time the individual spent in bed (e.g., using lights out and wake time). Sleep diaries are the most commonly used measure in clinical practice (Libman, Fichten, Bailes, & Amsel, 2000), and have been found to have good face validity, high internal consistency and good agreement with video of children's sleep (Wiggs & Stores, 1995).

While sleep diaries are often used clinically, polysomnography (PSG) is considered the gold standard for measuring sleep. PSG, which includes multiple physiological measures of sleep and is conducted in a controlled environment, is considered the gold standard for measuring sleep as it allows for differentiation of sleep states on the basis of an individual's level of arousal, autonomic response, brain activity, and muscle tone (Crabtree & Williams, 2009). However, it can be expensive and invasive due to the level of equipment and set up required, and the individual is typically required to spend the night in an unfamiliar environment such as a hospital-based sleep lab.

Another sleep measurement tool that is sometimes used in clinical practice, but more often used in research, is actigraphy. Actigraphs are wrist-watch like devices, typically worn on the non-dominant wrist, which continuously monitor activity levels where the presence of activity indicates wake state and the absence of activity indicates sleep (Ancoli-Israel et al., 2003; Lam, Mahone, Mason, & Scharf, 2011; Meltzer et al., 2012; Spruyt, Gonzal, Davvat, Roman, & Molfese, 2011). Unlike PSG, actigraphy is a non-invasive method of assessing sleep

quantity and as such is often used in sleep research (Ancoli-Israel et al., 2003). Moreover, actigraphy does not require the participant to stay overnight in a sleep lab, allowing the individual to stay in their natural sleeping environment, which minimizes laboratory effects that may influence an individual's typical sleep pattern (Crabtree & Williams, 2009). In addition, it can be used for extended periods at home. However, actigraphy does not measure sleep stages and there is some debate about how accurately it measures sleep parameters such as sleep duration (Waldon, Gendron, & Corkum, 2015).

Another commonly assessed sleep variable is daytime sleepiness. Multiple sleep latency tests (MSLT) serve as the gold standard measure of daytime sleepiness in both clinical and research settings (Balkin, et al., 2008; Billiard, 2013). For this test, the participant is asked to lie comfortably in bed in a quiet, dark room and is instructed not to resist sleep when the lights are turned off. This is done four to six times across the day in a research or clinical sleep lab setting, where sleep latency (time from lights out to sleep onset) is monitored by PSG (Balkin, et al., 2008; Billiard, 2013). MSLT serves as a measure of both sleep propensity (the tendency to fall asleep), by tracking the number of naps where the individual fell asleep, and general level of sleepiness, by calculating individual's mean sleep latency across all four naps (Balkin, et al., 2008).

As mentioned previously, short sleep duration and resulting daytime sleepiness have been associated with a range of deficits in adults including an inability to concentrate and retain information, as well as inattention (Balkin et al., 2008; Durmer & Dinges, 2005; Pilcher & Huffcutt, 1996). Researchers have reported that executive functions, such as attention, are particularly vulnerable to the effects of sleep restriction (Durmer & Dinges, 2005; Jones & Harrison, 2001; Sadeh, 2007). Though less is known about the impact of sleep loss on children,

research suggests that short sleep duration may result in daytime sleepiness, which in turn can lead to externalizing behaviours, irritability, and short attention span (Gruber, 2007). The variable negative impact of sleep restriction on children's daily functioning, in particular children's ability to pay attention, could be due to a number of reasons. One potential reason is that there may be individual differences in levels of daytime sleepiness as a result of sleep restriction (i.e., some individuals may be more sensitive to sleep restriction and thus experience more daytime sleepiness following sleep restriction than others). As such, the impact of sleep restriction on children's attention may vary from individual to individual.

According to past research, the prefrontal cortex (PFC) appears to be particularly sensitive to insufficient sleep. This in turn can lead to deficits in behavioural regulation and cognitive functioning, particularly in executive functions including attention (Jones & Harrison, 2001; Kapasz, et al., 2010; Sadeh, 2007). Given that the PFC area of the brain is both related to attention *and* affected by sleep, research examining the link between sleep and attention is warranted (Jones & Harrison, 2001). Correlational studies that have examined the association between sleep duration and attention in children have found mixed results (e.g., Coulombe, Reid, Boyle, & Racine, 2010; Lehto & Uusitalo-Malmivaara, 2013). A number of correlational studies have shown that children who sleep less are more likely to be reported as inattentive by teachers and parents (Lehto and Uusitalo-Malmivaara, 2013; Paavonen, Porkka-Heiskanen, & Lahikainen, 2009). However, a recently completed meta-analysis on sleep, cognition, and behavioural problems in school-aged children (5-12 years) found that sleep duration was not consistently associated with deficits in sustained attention (Astill Van der Heijden, Van IJzendoorn, & Van Someren, E. J., 2012). In interpreting these results it is important to consider that there may be individual differences in how shorter sleep duration impacts a child's level of

sleepiness, which, in turn, could result in inconsistent findings. These individual differences may be contributing to the mixed results found in correlational research.

Unlike correlational research studies, experimental designs, in which children's sleep durations are manipulated and controlled, allow for greater understanding of the causal relationship between sleep restriction and children's attention. To the knowledge of this researcher, there have only been ten experimental studies on the impact of sleep restriction (i.e., shortening sleep duration) on children's daily functioning to date (Carskadon, Harvey, & Dement, 1981a, 1981b; Fallone et al., 2001, 2005; Gruber et al., 2011; Peters et al., 2009; Randazzo, Muehlbach, Schweitzer, & Walsh, 1998; Sadeh, Gruber, & Raviv, 2003; Talbot, McGlinchey, Kaplan, Dahl, & Harvey, 2010; Vriend et al., 2013). Of these 10 studies, eight have measured children's attention following sleep restriction (see Table 1). Several studies reported changes in attention as assessed by subjective measures (questionnaires) following sleep manipulation (Fallone et al., 2001; Fallone et al., 2005; Vriend et al., 2013). Additionally, some studies reported changes in attention assessed by objective measures (e.g., sustained attention and reaction time) following sleep manipulation (Gruber et al., 2011; Peters et al., 2009; Sadeh et al., 2003); however, other studies did not report any changes in objectively measured attention (Carskadon et al., 1981a, 1981b; Fallone et al., 2001; Vriend et al., 2013). These inconsistencies may reflect differences in methodology. For example, the studies that assessed attention used different amounts of sleep restriction (e.g., one full night of sleep deprivation, a few nights of one-hour of sleep restriction), a variety of sleep measures (e.g., actigraphy, PSG), different settings (e.g., lab, home), a range of outcome measures (e.g., computerized attention tasks, self-report, parent-report, teacher-report), and different research designs (e.g., within-participants, between-participants designs).

Previous findings from experimental research on how cumulative sleep restriction (e.g., one hour per night) affects children's attention are important, as research shows that chronic moderate sleep loss in children is more common than a single night of substantial or complete sleep loss, and recovery from chronic sleep loss is a lot slower (Balkin et al., 2008; Li et al., 2013). For example, small changes in time spent socializing, using the computer, or staying up to do homework may contribute to cumulative sleep loss in school-aged children. Additionally, studies that implemented a cumulative restriction protocol demonstrated more statistically significant effects on children's attention compared to studies using one night of substantial or complete sleep loss (Carskadon et al., 1981a, 1981b; Fallone et al., 2001, 2005; Gruber et al., 2011; Peters et al., 2009; Sadeh, Gruber, & Raviv, 2003; Vriend et al., 2013).

Four of the ten pediatric experimental sleep manipulation studies examined cumulative sleep restriction and the results of these have also been inconsistent (Fallone et al., 2005; Gruber et al., 2011; Sadeh et al., 2003; Vriend et al., 2013). It is likely that some of this inconsistency is due to individual variability in terms of (a) how sleep restricted the child was during the sleep manipulation, and (b) how the sleep restriction impacts the individual child's level of sleepiness. Reducing TIB may not result in the same amount of sleep restriction in all participants. For instance, reducing TIB by one hour for a few nights might result in a state of significant sleepiness in some children, while for others it may not have the same negative impact. This could be due to individual differences in their response to sleep restriction. Research on sleep restriction in adults suggests that there are individual differences in the amount of nightly sleep required to maintain typical levels of daytime alertness, as well as differences in sensitivity and resilience to sleep loss (Balkin, et al., 2008; Van Dongen, Vitellaro, & Dinges, 2005).

Of the four previous experimental studies that used cumulative sleep restriction protocols, two of these studies included subjective reports that assessed children's attention following sleep restriction. Subjective reports were collected from parents (Vriend et al., 2013) and teachers (Fallone et al., 2005); informants in both studies reported significantly more inattention when children were sleep restricted compared to typical or extended sleep conditions. For example, Fallone et al. (2005) found that teachers reported that children were sleepier, more inattentive, and had greater academic problems in the sleep restriction condition as compared to both baseline and extended sleep conditions. Using subjective measures can help to capture real-life functioning during the sleep manipulation. However, there are some limitations to using subjective measures, for example, responder bias (e.g., parents are not blind to the condition and may rate their child as more inattentive due to expectations in changes in behaviour). As such, subjective reports are more credible when they are coming from multiple informants (e.g., parent, child, teacher, and researcher).

While subjective reports of inattention provide some evidence for the impact of sleep restriction on attention, objective measures, such as computerized attention tasks, allow researchers to collect a performance-based, less biased measure of participants' attention. Three of the four cumulative sleep manipulation studies also included objective reports that assessed children's attention following cumulative sleep restriction. Objective measures used included the Attention Network Test-Interaction (ANT-I; Vriend et al., 2013), the CPT-Kiddie Version (Sadeh et al., 2003), and the CPT-II (Gruber et al., 2011). The two studies that used a version of the CPT found significant differences in typically developing (TD) children's attention following sleep manipulation (extended and restricted; Gruber et al., 2011; Sadeh et al., 2003). Gruber et al. (2011) showed that TD children committed more omission errors, fewer commission errors,

and had slower reaction times (RT) on the CPT-II following sleep restriction. Sadeh et al. (2003) found that children in the extended sleep condition had improved RT on the CPT-Kiddie Version compared to children in the restricted sleep condition. However, Vriend et al. (2013) found no statistically significant differences on the alerting, orienting, and executive attention networks on the ANT-I across baseline, extended, and restricted sleep conditions. Sleep manipulation protocol and children's ages were consistent across these three studies. As such it is possible that inconsistencies in these results may be related to the objective measure used.

Not only is there a need for additional experimental sleep restriction studies that examine cumulative sleep loss with children using objective measures of attention, but it is also important that these studies take into account individual differences by including measures of daytime sleepiness. This will help to provide more insight into the relationship between sleep restriction and children's attention. Moreover, to date there are no experimental sleep restriction studies examining children's attention that have collected subjective measures, from *multiple* informants, as well as an objective measure of attention. Comparing these results may provide insight into differences in the presentation of inattention in children following sleep restriction as assessed in different settings.

The purpose of the current study is to better understand the relationship between sleep restriction and attention in TD elementary school-aged children. Data was collected as part of a large ongoing study (*Sleepy Children*), which employs a mixed within and between subjects design to examine the impact of sleep restriction on children with ADHD, compared to their TD peers, in four domains of daily functioning (attention, behaviour, learning, and emotions). The current study used a within subjects design to examine the impact of sleep restriction on TD children's attention (in the *Sleepy Children* study this data is being collected as a control group

for the ADHD group) as measured by both objective (i.e., CPT-II) and subjective measures (i.e., parent, teacher, research assistant [RA], and self-reports).

The specific research questions of the current study are as follows.

1. Does sleep restriction result in significant changes on an objective measure of attention (i.e., CPT-II)?
2. Does sleep restriction result in significant changes on subjective measures of attention based on parent, teacher, RA, and child reports?
3. Do individual differences in daytime sleepiness (as measured by MSLT) and amount of minutes children's sleep was restricted (based on sleep diary data) relate to changes on the CPT-II?
4. Are changes in subjective measures of attention related to changes in the objective measure of attention?

Method

Participants

Multiple methods were used to recruit participants, including paper and electronic advertisements (e.g., electronic newsletter at Dalhousie University and IWK Health Centre), and participants had to be 6-12 years of age with no previously diagnosed mental health disorders (which was confirmed by screening questionnaires). Participants were excluded from the study if they had a) a chronic and impairing illness (e.g., diabetes), b) a history of neurological impairments (e.g., epilepsy), c) a primary sleep disorder (e.g., sleep apnea), d) used medication during the past month that is likely to affect sleep, e) crossed more than two time zones in the last month, f) regularly slept less than 8 hours or more than 12 hours a night, and g) developed beyond Tanner puberty stage 2. These exclusion criteria were in place as all of these issues can

affect sleep and as such have the potential to bias the results of the study. These criteria were assessed by parent-completed questionnaires. Late stage exclusionary criteria included PSG evidence that indicated a primary sleep disorder such as sleep apnea. Participants were also excluded from the study if they were unable to complete the initial two weeks of baseline data collection. Participants were given two opportunities to complete this phase of the study. This late stage exclusionary criteria was implemented to ensure that participants would be able to successfully complete the study protocol for the sleep manipulation portion of the study, which was more intensive than at baseline.

Measures

Demographic questionnaire. This questionnaire has been used in previous studies and asks parents general questions about their child and family. This information was used to describe the participant sample in terms of the child's age, sex, ethnicity, presence of mental health disorders, as well as presence of medication use. Additionally, children's family composition was examined.

Screening measures.

Telephone screening questionnaire. This questionnaire, modeled after an existing questionnaire used in previous studies, asked parents questions to assess whether their child met the study's inclusion criteria and did not meet any of the exclusion criteria (e.g., medical illness), as described in the Participant section above.

Child Behaviour Checklist (CBCL; Achenbach & Rescorla, 2001). The CBCL, a parent-report questionnaire, is one of the most widely used instruments to evaluate behavioural and emotional problems in children and can be used to screen children for mental health problems. Any child who received a T-score of 70 or greater on any of the DSM – oriented

scales of this measure was excluded from participating. Previous research findings provide strong evidence for the reliability, as well as the convergent and discriminative validity of the CBCL (Nakamura, et al., 2009).

Children's Sleep Habits Questionnaire (CSHQ; Owens et al., 2000). The CSHQ is a parent-report sleep-screening instrument containing 33 items that was designed for use with school-aged children. Previous research has documented the measure's strong psychometric properties (Owens et al., 2000), and it provides both a total score and eight subscale scores.

Pubertal Developmental Scales (NICHD Study of Early Child Care and Youth Development, 2000). The *Girls' & Boys' Pubertal Developmental Scales* were used to assess Tanner stage. These questionnaires are both comprised of 5 items and are completed by the child's parent. Any child who received a score indicating that he/she is above Tanner stage 2 was excluded from the study, as sleep is affected by puberty. Both measures are widely used, and have been found to have excellent reliability and validity (Marshall & Tanner, 1969, 1970).

Outcome measures.

Sleep diary (Corkum, 1996). Sleep diaries have been found to have good face validity, high internal consistency, and good agreement with videos of children's sleep (Wiggs & Stores, 1995). The sleep diary consists of questions assessing various sleep parameters such as lights out, sleep onset, night awakenings, and wake time. The sleep diaries were used to calculate participant's average sleep duration as well as TIB by using the time the light was turned off (i.e., lights out), sleep onset, and wake time variables. Participants were considered to be successful in their sleep manipulation if their TIB was an average of 30 minutes later in the restricted sleep condition compared to their average sleep condition.

Actigraphy (Ambulatory Monitoring Inc). Actigraphy involves measurement of motor activity using an accelerometer-based device. Actigraphs resemble a small wristwatch and are typically worn on the non-dominant wrist. Previous studies have shown that the commercial software algorithms used to analyze actigraph data provide valid and reliable estimates of sleep and awake, and sleep variables such as sleep latency and sleep duration (Acebo et al., 1999; de Souza et al., 2003). Actigraphy data have been shown to be highly correlated with PSG data for identifying sleep and wake (85-90%; Cole, Kripke, Gruen, Mullaney, & Gillin, 1992), and to distinguish effectively between sleep-disturbed children (e.g., frequent night-waking) and controls (Ancoli-Israel et al., 2003).

For the current study, Micro Mini-Motionlogger actigraphs were used (Ambulatory Monitoring Inc.). These small, light-weight actigraphs have 32K of memory with a sampling rate of 16Hz, allowing for 3 weeks of data to be collected without having to download it. Data was obtained using the ACT operational software and a summary analysis was computed using the ACTIONW2 software, which employs a validated sleep estimation algorithm based on zero crossing mode (Sadeh, Sharkey, & Carskadone, 1994). Actigraphs were used to determine sleep onset/offset (e.g., when participants fell asleep and woke up), sleep duration, and the participants' adherence to the sleep schedule. Information recorded in the sleep diary was used to set the 'down' interval for the actigraphy data (i.e., time child went to bed and lights were turned off) and to help resolve any ambiguities found in the actigraphy data. Data were used to establish the child's baseline sleep duration, which served as the criterion for the sleep manipulation conditions (average vs. restricted). Actigraph data was used to determine TIB for both the sleep restriction and average sleep conditions. To be considered successful in their sleep manipulation

participants' TIB was expected to be an average of 30 minutes later in the restricted sleep condition compared to the average sleep condition.

Multiple Sleep Latency Tests (MSLT). All MSLTs were conducted in the Chronobiology Laboratory at the Abbey Lane Hospital, which has a child-friendly research sleep lab. The participant was given four nap opportunities (at 10:00 a.m., 12:00 p.m., 2:00 p.m., and 4:00 p.m.). For each nap opportunity, the child was told to lie down on a bed with his/her eyes closed and that he/she should not resist sleep. Each nap opportunity was terminated after 20 minutes if the child did not fall asleep. If the child fell asleep, he/she was awoken after three consecutive epochs of stage 1 sleep or after the first epoch of another sleep stage (thus not allowing for any significant length of sleep) as measured by PSG data. This procedure has been used with children ages five and older in previous research (Billiard, 2013). The variable of interest was the mean number of minutes to fall asleep across all four naps, which is a measure of sleepiness.

Attention measures

Connors' Continuous Performance Test – Second Edition (CPT-II; Connors, 2000).

The CPT-II is a computer-administered task that measures aspects of attention and executive functioning. Single letters are presented on the computer screen at three different rates: once per second, once every two seconds, or once every four seconds. The participant is asked to press the space bar in response to every letter except the indicated distractor letter (X). Variables used in the current study from the CPT-II included the T-scores for the total number of omissions (missed targets), total number of commissions (false hits), and overall hit reaction time (reaction time [RT]; the average speed of correct responses for the entire test). The CPT-II was used as an objective measure of children's attention during average and restricted sleep conditions. The CPT-II has strong psychometric properties (e.g., reliability and validity), as evidenced by many

years of research (Connors, 2000). Typically, commission errors represent impulsivity while omission errors represent inattention. However, commission errors may also reflect slow responses from proceeding targets. Attention may be ‘sluggish’ in that participants are responding slowly to the target, and the slow response can subsequently produce a commission error (Connors, 2000).

Connors’ Parent and Teacher Rating Scales – Third Edition (Connors 3-P & Connors 3-T; Connors 2008). The Connors 3-P (CPRS) and Connors 3-T (CTRS) include 110-items and a 115-items, respectively. These behaviour rating scales are designed to evaluate problem behaviours in the home and school environments in children ages 6 to 18 years. Extensive research has demonstrated that the Connors 3 forms have high levels of internal consistency, excellent test-retest reliability, and excellent validity (Connors, 2008). These measures were completed electronically by the child’s parent and teacher through a secure web link, and were used to assess parent and teacher subjective reports of children’s inattention during average and restricted sleep conditions. The variable of interest was the inattention index T-score.

ADHD Rating Scale-IV Modified – Testing Observations – Research Assistant (RA) Report (ADHD-RAR; 2009). The ADHD-RAR was used in previous sleep manipulation research (Vriend, 2011). It is a 22-item questionnaire that asks RAs a series of questions about the participants’ inattention and hyperactivity symptoms, as well as a series of questions about the child’s mood during the testing sessions. For the inattention and hyperactivity items, RAs are asked to circle the number that best describes the child’s behaviour during the testing session on a scale from 0 (*Never or Rarely*) to 3 (*Very Often*) with an option to circle *Not Applicable*. The current study focused on the RAs’ reports of the child’s inattention during the testing session for

average and restricted sleep conditions. The variable of interest was the total raw score on the inattention scale, which can range from 0 to 27.

Self-Report of Symptoms (Child) – Child Self-Report (ADHD-CSR; 2009). The ADHD-CSR scale was used in previous sleep manipulation research (Vriend, 2011). It is a 33-item questionnaire that asks the child to rate how much in the last week he/she engaged in each of the listed behaviours on a scale of 0 (Never) – 2 (Usually). Questions on this measure address behaviours pertaining to attention, hyperactivity, oppositional defiant disorder, anxiety, and depression. For the purpose of the current study, responses for the inattention scale during the average and restricted sleep conditions were used. The variable of interest is the total raw score on the inattention scale, which can range from 0 to 18.

Procedure

Ethics clearance for the current study was obtained from the IWK Health Centre and Mount Saint Vincent University (MSVU). As part of the *Sleepy Children* study protocol, the research coordinator described the study details and administered a brief telephone-screening questionnaire to all interested parent to ensure that the child met study eligibility criteria. If these basic criteria were met, then parents completed three additional questionnaires online, which screened for primary sleep problems, mental health difficulties, and pubertal stage. After results from these questionnaires were reviewed by the study's principal investigator, the research coordinator telephoned the parent and informed them of the outcome, and scheduled a meeting to review the study protocol if eligibility criteria were met. During this meeting both parent consent and child assent were obtained.

The sleep manipulation protocol (similar to the protocol used by Sadeh et al., 2003 and Vriend et al., 2013) consisted of a six-week, at-home, sleep restriction protocol that included two

baseline weeks, two sleep manipulation weeks, and a two week recovery phase between the two sleep conditions. Sleep conditions consisted of one restricted sleep week (i.e., requiring the child to go to bed one hour later than usual each night for one week) and one average sleep week (i.e., requiring the child to adhere to their baseline/typical sleep schedule). Over the six weeks, only four weeks of data were collected as two of the weeks provided time to washout the effects of the sleep manipulation as well as to effectively manage participants' visits to the sleep lab. At times there were three weeks between conditions, if there were scheduling problems at the sleep lab.

For the two-week baseline period, participants were given an actigraph and daily sleep diaries. Participants were instructed to wear the actigraph 24 hours a day (to record nocturnal sleep and ensure participants are not napping), and parents were asked to complete the sleep diaries for a two-week period. The children were told to follow their usual sleep schedules. At the end of this two-week baseline period, they were asked to go to the sleep laboratory for their first testing session. As part of the *Sleepy Children* study methodology, the testing included an overnight PSG assessment, daytime MSLTs, as well as direct measures of attention, behaviour, learning, and emotions. The PSG session required the child to spend the night in the sleep lab, and the MSLT consisted of four opportunities to nap in a darkened room every 2 hours over the course of the day at 10 a.m., 12 p.m., 2 p.m., and 4 p.m. Attention and learning were assessed after breakfast and before the first nap opportunity for each participant. Emotion and behavioural assessment measures, which included child self-report on attention, were administered between the first and second nap opportunity. At the end of the day at the sleep lab RAs completed a questionnaire on the child's behaviour during the testing session. Parents and teachers completed questionnaires through a secure web link at the end of each sleep condition. For the current study, only the attention measures were analyzed.

Actigraphy data from the two baseline weeks was used to create the sleep manipulation schedule. Efforts were made to ensure that the baseline weeks represented the typical sleep pattern for the child by asking the parent to indicate whether each night if their child's sleep was representative of their typical sleep habits and patterns. Using this data, bedtimes were adjusted to create two different sleep schedules: (a) restricted sleep condition required a 1 hour reduction of TIB compared to baseline weeks; (b) average sleep condition required participants to follow their typical sleep schedule. The current study used a within-subjects design as participants were randomly assigned to either have the restricted sleep condition first or the average sleep condition first, followed by the other condition. In order to eliminate carry-over effects, there was a two-week period between these two conditions in which participants were told to follow their usual sleep routines. A past study found that children required only one night of recovery sleep after one night of complete sleep deprivation (Carskadon, Harvey, & Dement, 1981), but Balkin et al., (2008) indicated that cumulative sleep restriction may result in a slower rate of recovery; as such this two-week recovery period was thought to be sufficient. The sleep manipulation conditions always followed the schedule of either Saturday through to Friday or Sunday through Saturday, so that the participants could sleep at the sleep lab during a weekend. The children were asked to wear the actigraph and parents were asked to complete the sleep diaries throughout the four-week duration of the study. Participants slept at the sleep lab and completed daytime measures and MSLTs following both the restricted sleep condition and the average sleep condition. The testing was identical to the testing session during the baseline condition, and was conducted by an RA who was blind to the condition.

Statistical Analysis

G*Power Version 3.1.7 (Faul, Erdfelder, Lang, & Buchner, 2007) was used to calculate power. Effect sizes were estimated based on two sources: 1) Gruber et al. (2011) findings of a 0.40 effect size on CPT-II measures of inattention and 2) Vriend et al. (2013) findings of a 0.75 effect size on parent report measures of attention. It was determined that a sample size of 20 TD children would give 80% power (with alpha set at .05), but we wanted to exceed this number to allow for missing data.

Descriptive analyses such as means and frequencies were conducted in order to describe the sample in terms of age, sex, ethnicity, presence of mental health disorders, presence of medication use, as well as children's family composition.

Pearson's correlations were computed to assess the relationship between participant's age and performance on all of the dependent variables of interest during both average and restricted conditions to determine if age should be considered as a possible covariate in the analyses conducted for the first two research questions. There was a significant correlation between age and CPT-II T-scores for reaction time during the average sleep condition, $r(25) = -.419, p = .030$; age and number of omissions during the restricted sleep condition, $r(25) = -.50, p = 0.03$; as well as between age and reaction time during the restricted sleep condition, $r(25) = -.64, p = .00$. No other correlations were significant. As correlations were significant for age and CPT-II variables, but not for age and the subjective measures, it was decided that age would be included as a covariate in the analyses of the impact of sleep restriction on the objective measures of attention (i.e., research question one) and not for the analyses on the impact of sleep restriction on the subjective measures of attention (i.e., research question two). This was also assessed for sex of

the participant, but none of these correlations were significant, as such sex was not included as a covariate.

In order to address the first and second research questions (i.e., impact of sleep restriction on objective and subjective measures) two separate repeated-measures multivariate analysis of variances (RM-MANOVA) were performed. Analyses followed intent-to-treat guidelines, in that all participants who were randomized were included in the analyses, regardless of adherence to the sleep protocol or completeness of data (Gupta, 2011). For the intent-to-treat analysis any missing data from the outcome measures in the restricted sleep condition was replaced with the individual's available average sleep condition data. If the average sleep condition data was not available then missing outcome measure data, for both average and restricted sleep conditions, was replaced with individual's outcome measure data from the baseline condition. For these analyses, condition (restricted versus average sleep conditions) was the within-subjects factor. The statistic Pillai's Trace statistic was used to determine if statistically significant differences were present.

For research question one it was hypothesized that the CPT-II T-scores for the number of omission and/or commission errors, as well as overall hit reaction time will be significantly higher during the restricted versus average sleep condition as slow reactions times (high T-scores) coupled with a large percentage of omissions and/or commissions indicates inattentiveness. For research question two it was hypothesized that the CTRS and CPRS inattention index T-scores, and the total raw score on the ADHD-RAR and on the ADHD-CSR will be significantly higher for the restricted versus average sleep condition.

Pearson (r) correlations were performed to address the third research question (i.e., impact of individual differences in sleep restriction and daytime sleepiness). The variables of

interest were amount of minutes children's TIB was restricted (based on sleep diary data) and difference scores for mean sleep latency across all four naps (in minutes) from average to restricted sleep condition, as well as differences scores in participants' omission errors, commission errors, and overall hit reaction time T-scores from average to restricted sleep condition. It was hypothesized that participants who had more minutes of sleep restriction as well as shorter mean sleep latency in the restricted condition compared to average condition would have higher omission/commission errors and slower RTs during the restricted condition compared to the average condition.

To address the fourth research question (i.e., the relationship between subjective and objective measures), a Pearson (r) correlational analysis was performed on the difference scores for each variable (i.e., the difference in score between restricted and average sleep condition for all variables from subjective and objective measures). Variables of interest were inattention index T-scores on the CPRS and CTRS, total scores on the ADHD-RA and the ADHD-CSR, as well as participants' T-scores for omission errors, commission errors, and overall hit reaction time. Given that changes in parent ratings have consistently been reported in sleep manipulation studies it was expected that parent ratings on the CPRS would have the highest correlation with CPT variables. It was expected that the ratings on the ADHD-CSR would have the weakest correlations with the other variables given that child self-reports have not been shown in past research to be sensitive to sleep manipulations.

Results

Sample Characteristics

Overall, the sample consisted of 27 TD children (grades 1-6), whose ages ranged between 6.07 and 12.71 years ($M = 9.17$, $SD = 1.86$), with 21 male participants and 6 female participants.

Participants were all from Nova Scotia. Twenty-six participants were identified by parents as Caucasian and one participant was identified as Multi-Racial. The children in the sample had no diagnosed mental health disorders, seizure disorders, or sleep disorders. Further, they did not typically nap and were not taking any medications that could affect sleep. Of the 27 children, 24 were from two-parent households and two children were from single parent households (one separated, one divorced), and one was not indicated.

All 27 children completed the initial baseline data collection, and were randomized to start either with the average sleep condition ($n = 16$) or the restricted sleep condition ($n = 11$). All participants completed both the average and restricted sleep conditions and slept at the sleep lab at the end of each of these conditions (i.e., baseline, average, and restricted). During their time at the sleep lab, all participants, completed daytime measures, and had the MSLT nap opportunities four separate times.

Sleep Manipulation

Sleep diary data from average and restricted sleep conditions was used to calculate mean time lights were turned off (i.e., lights out) and mean wake time during the two sleep manipulation conditions. From this, mean TIB was calculated (see Table 2). Though sleep duration (i.e., how long participants slept) would be the ideal variable in this context, TIB was used as a proxy for sleep duration as too many participants were missing the data required to accurately calculate sleep duration (i.e., the time of sleep onset was often not recorded by parents). A paired samples t-test revealed a significant difference in mean TIB (in minutes) for average ($M = 605.84$, $SD = 37.44$) and restricted ($M = 551.52$, $SD = 34.16$) sleep conditions; $t(25) = 8.91$, $p < 0.001$. Overall, these results suggest that participants spent significantly less

TIB on average (i.e., 54 minutes) during the restricted sleep condition compared to the average sleep condition.

Available actigraph data was used to confirm sleep diary data by calculating TIB during restricted and average sleep conditions. (Actigraph data was not used as the main method of confirming successful sleep manipulation as several participants ($n = 10$) were missing complete actigraph data from both sleep conditions. This missing data was replaced with available actigraph data from average or baseline conditions.) TIB was again used as proxy for sleep duration for the actigraph data in order to compare actigraph and sleep diary data. A paired samples t-test was conducted to compare mean TIB for average and restricted sleep conditions based on actigraphy data. Results revealed a significant difference in mean TIB for average ($M = 560.59$, $SD = 31.72$) and restricted ($M = 523.40$, $SD = 48.37$) sleep conditions; $t(25) = 3.818$, $p = .001$. These results suggest that overall participants spent significantly less TIB on average (i.e., 37 minutes) during the restricted sleep condition compared to the average sleep condition based on actigraphy data. These results are consistent with results based on the sleep diary data.

Research Question 1: Does sleep restriction result in significant changes on an objective measure of attention (i.e., CPT-II)?

A RM-MANOVA was conducted, using intent-to-treat approach to analyses, and included age as a covariate, and CPT-II T-scores for the number of omission errors, number of commission errors, and overall reaction time as dependent variables. The independent variable was the sleep manipulation condition (i.e., restricted and average sleep conditions). Results indicated that age is a significant covariate; $F(3,23) = 3.59$, $p = .029$, $\eta^2 = .32$. After controlling for age, the multivariate effect for the three dependent variables was approaching significance;

$F(3,23) = 2.91, p = .056, \eta^2 = .28$. Given that there was a strong trend, univariate analyses were conducted.

Univariate analyses for the effect of sleep manipulation on each of the independent variables indicated significant differences in T-scores for number of omission errors and overall reaction time, but not for number of commission errors (see Table 3). Univariate analyses for the effect of sleep manipulation on number of omission errors indicated a significant difference in T-scores in the restricted week ($M = 62.20, SD = 26.13$) compared to the average sleep week ($M = 58.03, SD = 18.64$); $F(1, 25) = 8.12, p = .009, \eta^2 = .25$. Additionally, univariate analysis for the effect of sleep manipulation on overall reaction time indicated a significant difference in T-scores in the restricted sleep condition ($M = 55.74, SD = 14.01$) compared to the average sleep condition ($M = 54.58, SD = 14.32$); $F(1,25) = 5.32, p = .03, \eta^2 = .18$. Univariate analyses for the effect of sleep manipulation on number of commission errors indicated that the difference in t-scores in the restricted sleep condition ($M = 47.78, SD = 10.04$) compared to the average sleep condition ($M = 50.40, SD = 7.77$) was not significant; $F(1, 25) = 1.86, p = .185, \eta^2 = .069$. Taken together these results suggest that participants missed significantly more targets and were significantly slower to respond during their restricted sleep condition compared their average sleep condition.

Research Question 2: Does sleep restriction result in significant changes on subjective measures of attention based on parent, teacher, RA, and child reports?

A RM-MANOVA was conducted, using intent-to-treat approach to analysis, which included T-scores for the inattention index on the CPRS and CTRS and total raw scores on the ADHD-RA and ADHD-CSR as dependent variables. The independent variable was the sleep manipulation condition (i.e., restricted and average sleep conditions). The multivariate effect for

the four dependent variables was not significant; $F(4,23) = 1.08, p = .39, \eta^2 = .16$. While the multivariate effect was not significant, univariate analyses are presented for comparison purposes. Univariate analysis indicated that there were no significant differences in T-scores for the inattention index on the CPRS and CTRS or in the total raw score on the ADHD-RAR and on the ADHD-CSR for the restricted compared to average sleep condition (see Table 4).

Research Question 3: Do individual differences in daytime sleepiness (as measured by MSLT) and amount of minutes children's sleep was restricted (based on sleep diary data) relate to changes on the CPT-II?

Pearson (r) correlations were conducted between the difference scores (i.e., the difference in score between restricted and average sleep conditions) for all of the CPT-II variables and the mean amount of sleep restriction (in minutes) as well as the difference scores (i.e., the difference in mean sleep latency between restricted and average sleep conditions) for mean sleep latency across all four MSLT naps (in minutes; see Table 5). There was a significant correlation between the amount children were sleep restricted and changes in CPT-II commission errors T-scores; $r(25) = -.44, p = .024$. Overall, this indicates that greater amount of sleep restriction is related to decreases in the number of commission errors participants made from average to restricted sleep conditions. This suggests that greater sleep restriction was related to lower impulsivity on the CPT-II. There was also a significant correlation between changes in mean sleep latency on MSLT and changes in CPT-II reaction time T-scores; $r(25) = -.43, p = .027$. This indicates that decreases in mean sleep latency is related to increases in CPT-II reaction time T-scores from average to restricted sleep conditions. This suggests that greater daytime sleepiness (as indicated by shorter mean sleep latency) is related to slower reaction times on the CPT-II (as indicated by higher CPT-II reaction time T-scores).

Research Question 4: Are changes in subjective measures of attention related to changes in the objective measure of attention?

Pearson (r) correlations were conducted on the difference scores (i.e., the difference in score between restricted and average sleep conditions) for each of the attention outcome variables in order to determine how changes in the objective measure related to changes in the subjective measures (see Table 6). There was a significant correlation between changes in CTRS inattention index T-scores and changes in CPT-II commissions T-scores; $r(25) = -.40, p = .038$. Overall, this indicates that while teachers' reports of inattention increased from average to restricted sleep condition, the number of commission errors participants made decreased. This suggests that higher inattention ratings, based on teachers' reports, were related to lower impulsivity on the CPT-II. There was also a significant correlation between changes in total inattention scores on the ADHD-CSR and changes in CPT-II reaction time T-scores; $r(25) = -.39, p = .045$. Overall, this indicates that while children's reports of inattention increased from average to restricted sleep condition, participants CPT-II reaction time T-scores decreased. This suggests that more inattention as reported by the child was related to faster reaction times on the CPT-II.

Discussion

The purpose of the current study was to better understand the relationship between sleep restriction and attention in typically developing elementary school-aged children. Overall, findings from the current study indicate that after sleep restriction of one hour reduction in TIB for one week, children demonstrated impaired attention according to the objective measure of attention, but not according to subjective reports. Individual differences in daytime sleepiness and amount of sleep restriction were related to difference scores on the objective measure of

attention. Additionally, changes in teacher-reported attention were related to changes in number of commission errors and changes in child self-reported attention were related to changes in reaction time on the objective measure of attention.

The sleep manipulation protocol, which was aiming to induce cumulative sleep restriction (i.e., restricting sleep for one hour per night for six nights), was successful (i.e., at least 30 minutes difference in TIB). On average children spent 54 minutes less in bed during the restricted sleep condition compared to the average sleep condition, based on sleep diary data. Actigraphy data confirmed that the sleep restriction protocol was successful and indicated that on average children spent 37 minutes less in bed during the restricted versus average condition. The finding that parents reported longer TIB than that calculated by actigraphy is consistent with previous research which found that parents tend to report a significantly longer TIB in children compared to TIB calculated by actigraphy (Lam et al., 2011).

The first research hypothesis was that the CPT-II T-scores for the number of omission errors and/or commission errors, as well as overall hit reaction time would be significantly higher during the restricted versus average sleep condition as slow reactions times (high T-scores) coupled with a large number of omission and/or commission errors indicates inattentiveness. Our results were consistent with previous research (Gruber et al., 2011) in that participants missed significantly more target letters (omissions) and were significantly slower to respond overall on the CPT-II during their restricted sleep condition compared to their average sleep condition. Connors (2000) highlights that higher omission errors coupled with slow reaction times can indicate that the respondent's attention is more sluggish. Our finding, which was similar to Gruber et al. (2011), indicated that participants were not significantly more likely to make commission errors during their restricted sleep condition. Higher CPT-II number of

commission errors are linked to greater impulsivity (Connors, 2000); therefore, it may be that children's decrease in attention resulted in fewer commission errors as they were generally missing targets and were slower to respond overall. The pattern of our results would indicate that the children were more sluggish during the restricted sleep condition than the average sleep condition. These results add to the existing literature by providing further support that cumulative sleep restriction over one week can impact typically developing children's attention, which can be assessed through an objective measure such as the CPT-II.

The second research hypothesis was that the questionnaires completed by parents, teachers, children, and RAs about the child's level of inattention would be significantly higher for the restricted versus average sleep condition. In contrast to the CPT-II results described previously, no significant differences in attention scores were found across the two sleep conditions. Our finding that children did not report statistically significant differences in their attention from average to restricted sleep condition is consistent with previous research (Davidson, 2011; Vriend et al., 2013). Young children typically do not have the same level of cognitive awareness of themselves as adults or even youth, and where the mean age of this sample was relatively young (approximately 9 years) it is possible that they were not able to self-report on their own perceptions of their attention. However, our findings for parent, teacher, and RA reports are contrary to previous research, which found that parents (Davidson, 2011; Vriend et al., 2013), teachers (Fallone et al., 2005), and RAs (Davidson, 2011) reported statistically significant differences in children's attention during restricted sleep compared to average sleep. It is possible that the subjective measures that were used in the current study were not sensitive to subtle changes in typically developing children's attention. However, given that statistically

significant differences in attention were found on the objective measure, it is also possible that informants missed the negative effects of sleep restriction.

The third research hypothesis was that more minutes of sleep restriction (i.e., less TIB) and increased daytime sleepiness (based on MSLT) would be related to poorer performance on the objective measure of attention from average to restricted sleep conditions. This hypothesis was partially supported in that greater sleep restriction was related to fewer commission errors from average to restricted sleep condition and greater daytime sleepiness was related to slower reactions times from average to restricted sleep condition. These results are consistent with previous research (Gruber et al., 2011), as well as findings from the current study, which found that participants were not significantly more likely to make commission errors, but were significantly more likely to be slower to respond during the restricted sleep condition. Research on sleep restriction in adults suggests that there are individual differences in the amount of nightly sleep required to maintain typical levels of daytime alertness, as well as differences in sensitivity and resilience to sleep loss (Balkin, et al., 2008; Van Dongen, Vitellaro, & Dinges, 2005). Our findings suggest that the amount of sleep restriction children experience may be related to levels of impulsivity, and slower response times may be related to increased daytime sleepiness following sleep restriction. This adds to the literature by providing further evidence that some children may be more impacted by cumulative sleep loss than others.

The fourth research hypothesis was that parent ratings of attention would be highly correlated with performance on the objective measure of attention while child self-report ratings of attention would have the weakest correlations with performance on the objective measure of attention, which was not supported. However, our findings indicated that while teachers' reports of inattention increased from average to restricted sleep condition, the number of commission

errors participants made decreased. This suggests that higher inattention ratings, based on teachers' reports, were significantly related to lower impulsivity on the CPT-II. This further supports the argument that children's decrease in attention may be related to lower impulsivity as they are generally more likely to be responding in a slow and sluggish way when tired as opposed to quickly and impulsively. Additionally, our findings indicated that more inattention, as reported by the child, from average to restricted sleep conditions was significantly related to faster reaction times on the CPT-II. This correlation is unexpected as typically slower reaction times on the CPT-II indicate increased inattentiveness. Vriend et al. (2013) and Davidson (2011) found similar results and postulated that the lack of self-reported impairment may speak to an inability of children to assess their own attention. This is also consistent with research that indicates that self-reports on performance do not necessarily correlate with actual performance (Biggs et al., 2007; Dorrian, Lamond, & Dawson, 2000).

The results of the current study are interesting as there was objective evidence that cumulative sleep restriction impacts attention, but this was not captured on the questionnaires. This is concerning as this could mean that parents, teachers, children, and individuals who work with these children may miss the negative effects of sleep restriction. Balkin et al. (2008) highlight findings that suggest that while individuals continue to have difficulty on objective measures of alertness and performance, they subjectively habituate to sleep restriction. Dorrian et al. (2000) found that individuals were able to accurately predict performance on some cognitive measures following sleep restriction, but not all. Moreover, Biggs et al. (2007) examined individuals' ability to drive following sleep restriction, and found that correlations between actual driving performance and subjective ratings of performance were not correlated. This suggests that participants were unable to accurately predict their driving performance following

sleep restriction (Biggs et al., 2007). Taken together, these studies suggest that we may not be able to consistently predict or judge performance following sleep restriction. This may have implications not only for the individual experiencing sleep restriction, but also for those who work with them or who interact with them on a daily basis.

Additionally, our findings suggest that children demonstrated sluggish attention following sleep restriction as demonstrated by performance on the CPT-II. Children who were more sleep restricted were less likely to make commission errors, and children who had increased daytime sleepiness following sleep restriction had slower RTs. This suggests that children were more sluggish and tired following sleep restriction, which indicates lower levels of arousal (i.e., alertness). Recent research suggests that the construct *sluggish cognitive tempo* (SCT), which is commonly associated with ADHD – inattentive presentation, is highly related to daytime sleepiness (Langberg, Becker, Dvorsky, & Luebke, 2014). Sleepy SCT behaviors include drowsiness, appearing sluggish or tired, and being underactive. Moreover, previous research indicates that alertness is important to performance on cognitive tasks, and that cumulative sleep restriction results in lower levels of attention and alertness (Beebe, Rose, & Amin, 2010). Arousal or alertness can be defined as the physiological reactivity of an individual ranging from sleep to excitement or panic (Coull, 1998). Research evidence indicates that arousal plays a part in attention processes (Oken, Salinsky, & Elsas, 2006) such that adequate levels of arousal and attention are needed to maintain sustained attention (Coull, 1998).

Limitations

A limitation of the current study is that not everyone was blind to the sleep condition (i.e., parents and children). Additionally, even those who were supposed to be blinded (i.e., RAs

and teachers) may have been un-blinded to the condition. As such, it is possible that attention ratings could have been impacted by responder bias.

Another significant limitation of the current study was that there was missing data. In particular there was missing actigraphy data and therefore sleep diary TIB was used to confirm successful sleep manipulation rather than sleep duration based on actigraph data. Additionally, complete participant data was limited for teacher reports as such missing data in the restricted sleep condition had to be replaced with available data from either the average or baseline sleep condition.

Moreover, this study followed an intent-to-treat design, which requires that once participants are randomized to a condition they are included in analysis regardless of adherence to sleep protocol or completeness of data. While as a group participants spent significantly less TIB during the restricted sleep condition when compared to the average sleep condition, there were individual differences in the amount children were sleep restricted. Perhaps a complete analysis, which would examine only those children with successful sleep manipulation and complete outcome measure data, would result in different findings. A larger sample size would be needed for these analyses.

A fourth limitation is that a subjective measure of daytime sleepiness was not used. Although, increased daytime sleepiness from average to restricted sleep week was significantly associated with slower RTs on the CPT-II, several participants in the study did not nap during the MSLTs. As such, it is possible that some children may have felt sleepier during the restricted sleep condition, but were unable to fall asleep during the MSLT nap opportunity given the novel environment this data was collected in (i.e., sleep lab at a hospital). Children may have felt uncomfortable in the unfamiliar setting, and stimulation throughout the day (e.g., completing

cognitive tasks, playing games, and watching movies with RAs) may have made it difficult to transition to a quiet, relaxed state. As such, it is recommended that a subjective measure of daytime sleepiness be used in future research as this may help to provide even further insight into the effects of sleep restriction on daytime sleepiness.

Future Directions

Future research should continue to explore the relationship between cumulative sleep restriction and attention. The inconsistent results between objective and subjective measures of attention raise important questions about changes in children's attention as a result of cumulative sleep restriction and whether or not parents, teachers, RAs, and even the children themselves are able to perceive changes in attention that result from cumulative sleep restriction. It may be important to examine subjective measures (e.g., questionnaires, rating-scales) with demonstrated sensitivity in order to fully capture the relationship between cumulative sleep restriction and attention in TD children. Additionally, larger sample sizes with more complete data may help to flush out these findings and provide further insight into this relationship.

Findings from the current study indicate that cumulative sleep restriction impacts TD children's attention as measured by the CPT-II; however, it would be interesting to see if children with mental health conditions, such as ADHD or learning disabilities, have a more pronounced response to sleep restriction. As stated previously, the current study is part of an ongoing study (*Sleepy Children*), which is employing a mixed within-and between-subjects design to examine the impact of sleep restriction on children with ADHD, compared to their TD peers, in four domains of daily functioning (attention, behaviour, learning, and emotions). As such, it may be possible to explore the relationship between cumulative sleep restriction and

attention even further by including those children who experience pre-existing difficulties with attention and cognitive processing.

Clinical Implications

This study involved cumulative sleep restriction over one week, and significant differences were found for attention, based on the objective measure, across sleep manipulation conditions. Previous research has indicated that the area of the brain that is particularly sensitive to insufficient sleep is also the area of the brain that is related to attention (i.e., the prefrontal cortex; Jones & Harrison, 2001; Kapasz, et al., 2010; Sadeh, 2007). Moreover, research indicates that arousal and attention are linked as evidenced by research conducted in association with the attention network theory (Coull, 1998; Fan, Mccandliss, Fossella, Flombaum, & Posner, 2005; Posner & Rothbart, 2007). Our findings suggest that children's attention was sluggish and that they were slower to respond on the CPT-II following sleep restriction. Evidence from multiple research studies indicates that attention plays a significant role in daytime functioning (Nobre & Kastner, 2014). For example, Dally (2006) found that it is inattention rather than hyperactive or impulsive behaviour that is more often associated with academic difficulty. It is possible that cumulative sleep restriction may impact TD children's performance on cognitive tasks in the classroom. This has implications for professionals, such as school psychologists, who work with children. It may be important to include a performance-based measure of attention as part of the assessment process, as well as to inquire about sleep habits in children who are referred due to inattention in the classroom.

Though significant differences were found on the objective measure of attention from average to restricted sleep conditions, differences were not reported on the questionnaires completed by parents, teachers, RAs, and children. It may be that the changes in TD children's

attention as a result of sleep restriction was too subtle to be picked up by parents, teachers, individuals who work with children, and even children themselves. Studies suggest that we may not be able to consistently predict or judge performance following sleep restriction (Balkin et al., 2008; Biggs et al., 2007; Dorrian et al., 2000). This is concerning as this could lead to health care professionals, educators, and parents not intervening to improve sleep habits in children.

Additionally, individual differences in sleep restriction and increased daytime sleepiness from average to restricted sleep conditions were related to difference scores on commission errors and RT on the CPT-II. This suggests that individual differences in the amount of cumulative sleep restriction and daytime sleepiness following sleep restriction can impact children's level of impulsivity (i.e., in this case a decrease in impulsiveness) as well as how quickly they respond (i.e., in this case slower RT). These findings are interesting as there are likely individual differences in how sleep restriction impacts humans (Balkin et al., 2008). As such, it will be important for researchers, health professionals, and educators to account for this possibility when discussing sleep habits and daytime sleepiness in children.

Importance of Findings

Our findings continue to highlight the importance of using multiple methods to assess attention such that the inclusion of an objective measure of attention may be helpful particularly if lack of attention is part of a referral question for health care professionals such as school psychologists. Additionally, education surrounding what impacts attention, such as sleep restriction, is particularly important. Children are often referred for mental health services due to inattention in the classroom, but this inattention could be occurring for many different reasons such as cumulative sleep restriction and daytime sleepiness. Results also highlight the need to

take individual differences into account when addressing the impact of sleep habits and daytime sleepiness on children cognitive functioning.

Table 1

Summary of the Studies Examining the Effects of Sleep Restriction on Children's Attention

Study	Design	Sleep Manipulation Protocol	Measures of Sleep	Measures of Attention	Findings
Carskadon, Harvey, & Dement (1981a)	Within-participants	Acute sleep restriction: No sleep for 1 night compared to 10 h time in bed for 1 night	MSLT PSG (EEG)	Listening Attention Task	Objective (MSLT) and subjective sleepiness increased. Performance on addition and memory tasks were impaired in sleep restriction condition.
Carskadon, Harvey, & Dement (1981b)	Within-participants	Acute sleep restriction: 4 h time in bed for 1 night compared to 10 h time in bed for 1 night. Slept in lab.	MSLT PSG (EEG)	Listening Attention Task	Objective sleepiness (MSLT) increased. No significant changes on cognitive tasks.
Fallone et al., (2001)	Between-participants	Acute sleep restriction: Optimized Sleep Group (10 h time in bed) and Sleep Restriction Group (4 h time in bed). Slept in lab.	PSG Actigraphy MSLT	The Child Attention Profile – RA The Restricted Academic Situation –RA The Gordon Diagnostic System	Sleep restriction increased objective (MSLT) and subjective sleepiness and inattentive behaviours (RA-rated), but not hyper/impulsive behaviours. No differences were found on objective tests of attention.
Sadeh, Gruber, & Raviv (2003)	Mixed within- and between-participants	Cumulative sleep restriction: 2 nights of normal sleep and 3 nights of ± 1 h difference in normal sleep duration	Actigraphy	CPT – Kiddie Version Visual Digit Span Test	Extended sleep led to improved memory function and CPT performance, and maintained performance on a simple reaction time test.

Study	Design	Sleep Manipulation Protocol	Measures of Sleep	Measures of Attention	Findings
Fallone et al., (2005)	Within-participants	Cumulative sleep restriction: 6.5-8 h per night for 1 week, compared to 10+ h per night for 1 week, and compared to baseline week of self-selected sleep	Actigraphy	School Situations Questionnaire – Revised - Teachers	Sleep restriction increased teacher-reported sleepiness, academic problems, and inattention.
Peters et al., (2009)	Within-participants	Acute sleep restriction: Counter-balanced Sleep Restriction (5hrs time in bed) and Control (10hrs time in bed) one night. Slept in lab.	Actigraphy	Psychomotor Vigilance Task	PVT determined visual motor RT and attention are sensitive to a single night of restricted sleep in young girls.
Gruber et al., (2011)	Mixed within- and Between-participants	Cumulative sleep restriction: 1 h less than typical time-in-bed for 6 nights compared to typical time-in-bed	Actigraphy	CPT-II	Sleep restricted led to poorer CPT scores on 2/3 of CPT measures in TD children and children with ADHD.
Vriend et al., (2013)	Between-participants	Cumulative sleep restriction: Typical Sleep, Long Sleep (1hr earlier for 4 nights), and Short Sleep (1hr later for 4 nights). Counter-balanced. At home	Actigraphy	The Connors' Parent Rating Scale – Revised The Attention Network Test – Interaction The Children's Colour Trails Test	1) Significant differences were found on parent-reported inattention with decreased attention in the Short Sleep compared with the Long Sleep condition. 2) No significant differences were found for reaction time on alerting, orienting or executive attention task (ANT-I) or on the CCTT-I.

Table 2

Mean and SD for Lights Out, Wake Time, and Time in Bed, based on Sleep Diary data, during Average and Restricted Sleep Weeks

	Average Sleep Week			Restricted Sleep Week		
	Lights Out	Wake Time	Time in Bed	Lights Out	Wake Time	Time in Bed
<i>M (SD)</i>	20:47 (.034)	6:57 (.017)	605.84 (37.44)	21:43 (.026)	6:53 (.017)	551.52 (34.16)

Note. Lights Out is in 24 hour time.

N = 27

Table 3

Univariate Analysis from RM-MANOVA for Sleep Manipulation and CPT-II Variables (Intent-to-Treat Analysis)

CPT-II Variable	<i>Sleep Condition</i> <i>M (SD)</i>		<i>F</i>	<i>p</i>	η^2
	Restricted	Average			
Omission Errors T-score	62.20 (26.13)	58.03 (18.64)	8.12	.009	.25
Commission Errors T-score	47.78 (10.04)	50.40 (7.78)	1.86	.185	.07
Reaction Time T-score	55.74 (14.01)	54.58 (14.32)	5.32	.030	.18

Note. Analyses included all participants who had been randomized. Missing data from the Restricted sleep condition was replaced with available Average sleep condition data.

N = 27

Table 4

Univariate Analysis from RM-MANOVA for Sleep Manipulation and Subjective Measures (Intent-to-Treat Analysis)

Subjective Variable	<i>M (SD)</i>		<i>F</i>	<i>p</i>	η^2
	Restricted	Average			
CPRS Inattention Index T-score	48.67 (12.72)	45.78 (6.5)	2.84	.104	.098
CTRS Inattention Index T-score	51.81 (10.0)	50.93 (8.19)	.421	.522	.016
ADHD-RAR (Total Inattention Score)	.67 (1.21)	.63 (1.28)	.046	.832	.002
ADHD-CSR (Total Inattention Score)	4.48 (3.56)	3.74 (3.11)	2.02	.168	.072

Note. Analyses included all participants who had been randomized. Missing data was replaced with available Average sleep condition data. If the Average sleep condition data was not available then any missing outcome measure data, for both Average and Restricted sleep conditions, was replaced with outcome measure data from the Baseline condition.

^aCPRS = Connors parent rating scale, CTRS = Connors teacher rating scale, ADHD-RAR = attention-deficit hyperactivity disorder research assistant report, ADHD-CSR = attention-deficit hyperactivity disorder child self-report.

N = 27

Table 5

Bivariate Correlations between difference scores for all CPT-II variables and the mean amount of sleep restriction (in minutes) as well as the difference scores for mean sleep latency (in minutes) across all four MSLT naps

	CPT-II Omissions	CPT-II Commissions	CPT-II Reaction Time
MSLT Sleep Latency	-.26	-.06	-.43*
Sleep Restriction	.13	-.44*	.09

Note. $N = 27$

* $p < .05$

Table 6

Bivariate Correlations between the Difference Scores for the Objective Measure of Attention and the Difference Scores for the Subjective Measures of Attention

	CPT-II Omissions	CPT-II Commissions	CPT-II Reaction Time
CPRS Inattention Index	-.006	-.16	.05
CTRS Inattention Index	-.003	-.40*	-.05
ADHD-RAR Total Inattention Score	-.14	.05	-.31
ADHD-CRS Total Inattention Score	-.31	.31	-.39*

Note. CPRS = Connors parent rating scale, CTRS = Connors teacher rating scale, ADHD-RAR = attention-deficit hyperactivity disorder research assistant report, ADHD-CRS = attention-deficit hyperactivity disorder child self-report.

* $p < .05$

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