Impact of Sleep Characteristics on Daytime Functioning in Children

by

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To my parents, Chris and Marilyn, for inspiring me to dream big.

To my husband and best friend, Jesse, for his unconditional love and support.

And to my son, Nicholas.

"The day is done they say good night and somebody turns off the light.

The moon is high the sea is deep they rock and rock and rock to sleep."

- Sandra Boynton

Good night Nicholas!

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Abstract

Sleep appears to play a critical role in regulating daytime functioning in children. However, few child-focused studies have used objective measures of sleep and examined its role in emotional functioning, memory, and attention. This dissertation consisted of 2 studies. Study 1 examined children's typical sleep and how it correlates with daytime functioning in 32 typically developing children (14 boys, 18 girls), 8 to 12 years of age (*M*=9.8 y, *SD*=1.4). Participants wore actigraphs (recording devices that provide information about sleep and activity) for 1 week and then completed tasks to measure emotional functioning, memory, and attention. On average, children slept less than 9 h per night, which is approximately 1 h less than the recommended duration for this age. Older children had shorter sleep durations, higher sleep efficiency, and later sleep onset times. Correlational analyses revealed that within this group of typically developing children, small variations in sleep were associated with statistically significant effects on daytime functioning. Specifically, shorter sleep duration was associated with increased negative affective response, and lower sleep efficiency was associated with poorer performance on a divided attention task. Study 2 involved experimental manipulation of sleep duration in the same sample of children. Following a week of typical sleep, each child was randomly assigned to go to bed 1 h earlier for 4 nights (Extended condition) or 1 h hour later for 4 nights (Restricted condition) relative to their typical bedtime. Each child then completed the opposite condition. Following each condition, emotional functioning, memory, and attention were assessed using objective and subjective measures. The sleep manipulation was effective: the children slept significantly longer in the Extended (*M*=9.3 h, *SD*=0.6) versus Restricted (*M*=8.1 h, *SD*=0.7) condition, and children were significantly sleepier in the Restricted condition according to parent, child, and research assistant report. Positive affective response, emotion regulation, memory, and aspects of attention were worse in the Restricted, compared to Extended condition. These studies provide evidence that modest variations in sleep can have substantial effects on daytime functioning in children. Clinical implications are discussed, including the importance of identifying sleep problems and promoting healthy sleep habits in children.

List of Abbreviations Used

ADHD = attention-deficit hyperactivity disorder

ANT = Attention Network Test

ANT-I = Attention Network Test – Interaction

CBCL = Child Behavior Checklist

CCT = Children's Category Test

CCTT = Children's Color Trails Test

CPT = Continuous Performance Test

CVLT = California Verbal Learning Test

DSST = Digit Symbol Substitution Test

H = hours

IAPS = International Affective Picture System

M = mean

Min = minutes

mm = millimeters

MSLT = multiple sleep latency test

n = sample size

NES = Neuropsychological Evaluation System

PANAS-C = Child Version of the Positive Affect and Negative Affect Schedule

PFC = prefrontal cortex

PSG = polysomnography

RA = research assistant

SD = standard deviation

SLT = sleep latency test

TD = Typically Developing

WCST = Wisconsin Card Sorting Test

WRAML = Wide Range Assessment of Memory and Learning

y = years

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Chapter 1: Introduction

Sleep is an active and complex behaviour. Researchers are only beginning to understand its many functions, including repair and growth, restorative processes, and regulation of cognitive and emotional functioning. We know that sleep serves critical roles in physical and mental health, yet sleep loss plagues modern society and not only affects adults, but also children.

To cope with daily obligations and personal interests, individuals frequently sacrifice total sleep time, which may lead to an array of negative consequences. In a seminal meta-analysis, Pilcher and Huffcutt (1996) reported that when adults were exposed to short-term total sleep deprivation (≤45 h), long-term total sleep deprivation (>45 h), or partial sleep deprivation (sleep period of <5 h in a 24-h period) these participants functioned at a level comparable to the 9^{th} percentile of non-sleep-deprived adults on measures of mood, cognitive performance, and motor performance. Mood was most impaired by sleep restriction, followed by cognitive performance, and then motor performance.

Childhood is a time of major developmental changes. Since it is a crucial period for acquiring new knowledge and skills and for establishing sleep patterns, children may be particularly vulnerable to the effects of sleep loss. Sleep restriction in children may have long-term effects on a range of developmental processes, including cognitive and emotional functioning. The integrity of learning and memory processes is fundamental to academic performance and development of emotion regulation is critical for developing social relationships (Dahl & Lewin, 2002). There is mounting literature suggesting that inadequate or poor sleep affects daytime functioning in children, but few well-controlled, experimental studies have been performed.

Children today are getting less than the recommended amount of sleep. Iglowstein, Jenni, Molinari, and Largo (2003) found that children's sleep duration has markedly decreased over the past three decades. Furthermore, the National Sleep Foundation conducted a poll in 2004 which revealed that, on average, 8-12 year-old children are sleeping approximately one hour less than the minimum recommended amount (Meltzer & Mindell, 2006). In addition to inadequate quantity of sleep, there is also evidence suggesting children are getting poor quality sleep. For example, Sadeh, Raviv, and Gruber (2000) found a high prevalence of fragmented sleep among school-age children.

Furthermore, sleep problems are common in children, affecting approximately 25% (Owens, 2007). Behavioural insomnia (i.e., difficulties initiating and/or maintaining sleep) is the most common pediatric sleep disorder with estimates of one in five children experiencing this sleep problem (Meltzer, Johnson, Crosette, Ramos, & Mindell, 2010). Other disorders such as sleep apnea and sleep-related movement disorders have lower prevalence affecting 1-8% of children, while the estimates for parasomnias such as night terrors range from 5-35% of children (Meltzer et al., 2010).

The Measurement of Sleep

Within the area of pediatric sleep research, it is important to consider the variety of methods that exist for measuring sleep. Studies frequently use subjective report (typically self-report or parent-report). However, a more objective and accurate measurement of sleep such as actigraphy or polysomnography (PSG) can also be used. Actigraphy involves measurement of motor activity using a device that resembles a small wristwatch. The detected movements are translated to digital counts, which accumulate over a predetermined period (typically 1-min epochs) and are stored within the device. Data are downloaded to a computer, which uses algorithms to score wake and sleep (Sadeh & Acebo, 2002). PSG involves recording specific physiological variables during sleep (e.g., electroencephalogram, eye movements, muscle tone, and respiration). PSG permits sleep stage scoring and is considered the "gold-standard" for measuring sleep. It typically requires an individual to sleep in a laboratory, although home PSG is also possible. Actigraphy has been shown to provide valid and reliable estimates of sleep that are highly correlated with PSG measures, but it does not identify sleep stages (Sadeh & Acebo, 2002). Due to the invasiveness and expense of PSG, actigraphy is frequently used to measure sleep when sleep stage scoring is not required.

Effects of Poor Quantity and Quality Sleep in Children

Approximately 30 years ago Carskadon and colleagues conducted seminal studies examining the effects of sleep loss in children. In addition to finding impairments in some areas of daytime functioning following sleep restriction, they also found that children may not recover from sleep restriction as rapidly as adults (Carskadon, Harvey & Dement, 1981a). Since that time, a number of observational, cross-sectional, and longitudinal studies, as well as a few well-controlled experimental studies, have been published and the emerging results indicate that sleep plays a critical role in daytime functioning (Dahl, 2005). However, the specific aspects of daytime functioning that are most vulnerable to sleep restriction are less clear. This dissertation focuses on the areas of sleepiness, emotional functioning, memory, and attention.

Poor Sleep and Sleepiness

Not surprisingly, sleepiness is the clearest and most consistent result of sleep restriction (Carskadon et al., 1981a; Fallone, Acebo, Arnedt, Carskadon, & Seifer, 2001). In both children and adults, there are two main processes that affect sleepiness: circadian rhythms and homeostatic sleep drive. These two processes form the two-process model first proposed by Borbély (Borbély, 1982). Circadian rhythms regulate the timing of the sleep/wake cycle according to an internal clock while homeostatic determinants include the amount of time since the individual last slept and the amount of sleep debt accrued. These two processes work together to regulate the timing of sleep and wakefulness, but can also be distinguished independent from one another (Carskadon, 2011).

Environmental, psychological, and/or biological factors can also affect the expression of sleepiness (Fallone, Owens, & Deane, 2002). Sleepiness can be masked by a variety of external (e.g., sensory input, exercise, caffeine) and internal (e.g., emotional state, motivation, hunger) factors (Fallone et al., 2002). For example, a child may argue that his math class makes him sleepy, when in fact sleepiness is not caused by dull curriculum. The curriculum, however, unmasks the psychological, behavioural, and physiological expression of underlying sleepiness that is the result of the two processes described above (Fallone et al., 2002).

Sleepiness is typically measured using subjective report such as self-report or parent-report questionnaires or the objective Sleep Latency Test (SLT). The SLT is the gold-standard measure of sleepiness. It requires the individual to attempt to fall asleep in a room that is conducive to sleep. Sleepiness is measured based on how quickly the individual falls asleep. Typically the SLT is administered multiple times through the day and is thus referred to as the Multiple Sleep Latency Test (MSLT). The MSLT requires

PSG, which, as explained above provides detailed sleep information, but is costly and typically requires the individual to remain in the laboratory throughout recording.

Sleepiness in children and youth is common. Many high school students and teachers surveyed suggest that falling asleep in school is a common behaviour (Wolfson & Carskadon, 1998). One study found that an 85-min delay in high school start times resulted in youth getting approximately 5 h more sleep per week and reduced sleeping in class (Wahlstrom, 2002). Much of the focus on sleepiness in children has targeted adolescent populations. However, there is also evidence to suggest that reductions in sleep time result in increased sleepiness in younger school-age populations (Carskadon et al., 1981a; Sadeh, Gruber, & Raviv, 2003). For example, Carskadon et al. (1981a) found that following one night of sleep restriction, sleep latencies dropped from an average of 15 min to an average below 5 min, indicating severe sleepiness. Other studies have shown that even moderate reductions in sleep result in increased sleepiness based on MSLT (Randazzo, Muehlbach, Schweitzer, & Walsh, 1998).

Poor Sleep and Emotional Functioning

Understanding the impact of sleep on emotional functioning in children is important because children are still developing their ability to regulate emotions (Dahl & Harvey, 2007). A number of correlational and naturalistic studies support the hypothesis that sleep plays a role in emotional functioning. However, the most direct evidence that sleep duration affects emotional functioning comes from experimental sleep restriction and extension protocols. The following sections focus on the naturalistic and correlational studies in this area and then describe the studies that have experimentally manipulated sleep and examined its effects on emotional functioning.

A number of naturalistic studies have examined sleep in children with a variety of clinical conditions. For the most part, these studies indicate that short and disturbed sleep is associated with both mood and anxiety disorders. For example, Hudson, Gradisar, Gamble, Schniering, and Rebelo (2009) found that 7-12 year-old children with anxiety, compared to children without anxiety, have significantly shorter self-reported sleep durations. Another study found that 83% of children with anxiety disorders experience at least one sleep complaint based on parent report (Alfano, Beidel, Turner, & Lewin, 2006). Johnson, Roth, and Breslau (2006) investigated the order of appearance of insomnia, anxiety, and depression in adolescents. Retrospective reports showed that anxiety disorders preceded insomnia in 73% of comorbid cases whereas insomnia preceded depression in 69% of comorbid cases.

Other research has examined the prevalence of emotional disturbance in children with sleep disorders. In children, both sleep-disordered breathing (Crabtree, Varni, & Gozal, 2004; Beebe et al., 2004) and periodic limb movement disorder (Gaultney, Merchant, & Gingras, 2009), both of which fragment sleep, are associated with depressive symptoms. Furthermore, Mitchell and Kelly (2007) examined children with mild sleep-disordered breathing before and after treatment by tonsillectomy. Both groups showed improvement in depressive symptoms as well as a number of behavioural measures after the surgical procedure. Unfortunately, with such studies, it is unclear whether the improvements in daytime functioning are directly related to the improvements in sleep, or if they are related to a reduction in other symptoms of these disorders (e.g., changes in oxygen flow to the brain).

Gregory and colleagues have produced a number of longitudinal studies demonstrating that sleep problems in early childhood predict later emotional problems. They found that persistent sleep problems at 5, 7, and 9 years of age predicted anxiety (but not depression) at 21 and 26 years of age (Gregory et al., 2005), that sleep problems at age 3-4 years predict anxiety at age 7 (Gregory, Eley, O'Connor, & Plomin, 2004), and that children whose parents reported that their children slept less than others were at an elevated risk for high scores on anxiety and depression scales (Gregory, Van der Ende, Willis, & Verhulst, 2008). Additionally, Fredriksen, Rhodes, Reddy, & Way (2004) found that sixth graders who reported obtaining less sleep also reported heightened levels of depressive symptoms and decreased self-esteem both at the initial assessment and at a follow-up assessment two years later. These studies suggest that sleep is involved in the maintenance of emotional functioning.

Subjective reporting of sleep and emotional problems make a significant contribution to the literature. Subjective measures can capture the subjective sense of having a problem with sleep (Gregory & Sadeh, 2011), which in some cases is not apparent using objective measures. Additionally, subjective report allows for much larger samples. For example, Smaldone, Honig, and Byrne (2009) had a sample of nearly 70,000 children. After controlling for child, family, and environment variables, they found that parents of children with inadequate sleep were more likely to report frequent child depressive symptoms.

Although subjective reporting has advantages, it also is a critical limitation of many studies examining sleep and emotional functioning in children. For example, subjective ratings can be problematic when the same individual rates both sleep and daytime functioning variables. If parents rate both sleep problems and associated traits, the individual's response patterns (e.g., tendency to be negative or tendency to rate extremes) could account for some of the associations reported (Gregory & Sadeh, 2011). For this reason, subjective report is increasingly convincing when the reports are from different raters (e.g., parent, child, teacher, and researcher). For example, one study examined nearly 6,000 8-9 year old children. They found that children's self-reported sleep problems predicted teacher reports of the children's emotional problems (Paavonen et al, 2002). There is also evidence that parents may not be aware of some of their children's sleep problems. For example, parents tend to overestimate their child's total sleep duration (Nixon et al., 2008). In addition, Owens, Spirito, McGuinn, & Nobile (2000) found that children self-identify more sleep problems than their parents.

Another limitation of subjective reporting is that many of the longitudinal epidemiologically-based studies assess sleep based on subjective measures that were not specifically designed to measure sleep, but do include a small number of items that ask about sleep problems. For example, the Child Behaviour Checklist (CBCL; Achenbach, 1991) is frequently used to assess a host of behavioural problems, including inattention, impulsivity, hyperactivity, and oppositionality. This questionnaire contains a few items about sleep as well (e.g., "sleep less than others"), and thus, has been used to measure sleep (Gregory & Sadeh, 2011). Unfortunately, these questions provide limited information about the type of sleep problem and, like other subjective measures, may be affected by individual's response patterns.

Objective measures such as actigraphy or polysomnography (PSG) provide more accurate measurement of sleep and address issues such as responder bias. Studies using objective measures to examine sleep and emotional functioning are limited in number. Bertocci et al. (2005) compared PSG recordings from 51 youth with Major Depressive Disorder to 42 healthy control subjects (aged 8-17 y). Although depressed youth reported significantly worse sleep in terms of quality and awakenings, PSG measures indicated no evidence of disturbed sleep in the depressed sample compared to controls. Also using PSG, Forbes et al. (2008) found that individuals with anxiety have poorer sleep (e.g., more night awakenings) than those with depression or controls. Another study found that children with anxiety slept for shorter periods than children in an age- and sex-matched control group (Rapoport et al., 1981). Sadeh et al. (1995) found that in 39 children receiving inpatient mental health treatment, children's self-ratings of depression, hopelessness, and low self-esteem were significantly correlated with sleep quality as measured by actigraphy. In summary, the studies using objective measures of sleep indicate that sleep in children with disorders of emotion regulation appears to be poorer than in typically developing (TD) children.

Very few studies have used objective measures to examine sleep and emotional functioning in non-clinical populations, but evidence is accumulating that even for otherwise healthy children, inadequate sleep may have serious outcomes (Smaldone et al., 2009). Aronen, Paavonen, Fjallberg, Soininen, and Torronen (2000) studied 49 healthy children and found significant associations between less total sleep time as measured by actigraphy and higher teacher ratings of externalizing behaviour, inattention, and social problems. Similarly, El-Sheikh, Buckhalt, Cummings, and Keller (2007) found that poor quality and quantity of sleep in 166 children was associated with emotional insecurity. Aside from these studies, little is known about how objectively measured sleep variables are related to emotional functioning in TD children. The need to explore the role of sleep in emotional functioning is underscored by the lack of studies using objective measures of sleep.

Although many researchers have suggested an association between problematic sleep and negative emotional functioning, experimentally manipulating sleep would allow researchers to make causal inferences. Based on a review of the literature, only one study (Talbot, McGlinchey, Kaplan, Dahl, & Harvey, 2010) experimentally manipulated sleep duration and examined its effects on emotional functioning in a TD pediatric population.

Talbot et al. (2010) had a group of early adolescents (n = 20; age 10-13 y), mid-adolescents (n = 24; age 13-16 y), and adults (n = 20; age 30-60 y) complete a within-participants sleep restriction design. Participants completed an affective functioning battery under conditions of sleep restriction (a maximum of 6.5 h total sleep time on the first night and a maximum of 2 h total sleep time on the second night) and rest (7-8 h total sleep time for two consecutive nights). In the sleep restriction condition compared to the rest condition, less positive affect was reported, but there was no change in negative affect as measured by the Child Version of the Positive Affect and Negative Affect Schedule (PANAS-C; Watson, Clark, & Tellegen, 1988). The PANAS-C lists 12 positive (e.g., happy) and 15 negative (e.g., upset) descriptors. For each descriptor, participants are asked to indicate how they feel on a 5-point Likert scale. Participants were also asked to list and rate topics about which they were worried and then complete a catastrophizing task which consisted of the experimenter asking the participant several questions about their most threatening worry (see Talbot et al., 2010 for details). Participants rated their anxiety before and after the catastrophizing task and also rated the likelihood that catastrophes that they reported would actually occur. Participants, across all age groups, reported more anxiety as a result of catastrophizing and they rated the likelihood of the catastrophes coming true as higher when sleep restricted, as compared to when rested.

Additionally, one published abstract found higher levels of reported negative emotions (anger, sadness, and fear) following sleep restriction in 11 to 15 year old children (Leotta, Carskadon, Acebo, Seifer, & Quinn, 1997). This study used an affective response task which involved viewing pictures and using a visual analog scale to rate emotional responses to the pictures. Although the studies by Talbot et al. (2010) and Leotta et al. (1997) suggest a causative role for sleep in regulating emotional functioning, more research is needed.

Poor Sleep and Cognitive Functioning

Several naturalistic and correlational studies have tied inadequate quantity and quality of sleep to cognitive impairments. To date, most of the research on cognitive functioning and sleep in children has been based on surveys indicating that irregular sleep-wake patterns are associated with poor academic achievement (e.g., Epstein, Chillag, & Lavie, 1998) or correlational studies finding early school start times are correlated with poor academic performance (e.g., Wolfson & Carskadon, 1998). For example, one study (Wahlstrom, 2002) followed 12,000 youths for two years before and three years after an 85-min delay in school start times. They found that later school start times resulted in decreases in tardiness, increases in graduation rates, improved academic performance, and higher morale. Others have found that children with academic problems and/or attention problems in school are more likely to have sleep problems compared to children that are not experiencing such problems (Corkum, Davidson, & MacPherson, 2011; Weissbluth, Davis, Poncher, & Reiff, 1983).

A few naturalistic studies have found that sleep problems such as sleep apnea are correlated with impaired performance on cognitive tasks (Beebe et al., 2004). Additionally, treating sleep-related breathing problems improves academic performance (Gozal, 1998). With such studies, however, it is difficult to determine to what extent cognitive impairments are due to poor sleep versus other symptoms of the disorder (e.g., lowered oxygen consumption during sleep).

A few researchers have used objective measures of sleep to examine the relationships between sleep quantity and efficiency and cognitive variables in TD children. These studies have found correlations among poor sleep quality as measured by actigraphy and impaired attention (Sadeh, Gruber, & Raviv, 2002; Gruber et al., 2007) and memory (Steenari et al., 2003). Additionally, Steenari et al. (2003) found short sleep duration was also correlated with poorer performance on complex memory tasks. However, the lack of studies using objective measures of both sleep and cognition indicates more research is needed in this area.

Again these naturalistic and correlational studies provide evidence for a relationship between sleep and cognitive functioning. However, experimental research is critical to understanding the daytime consequences of inadequate sleep, as causality can only be inferred from such studies. Unfortunately, studies that experimentally restrict sleep in children are limited. The few studies that do exist have somewhat conflicting results. The differences in results are not entirely surprising as these studies have used different amounts of sleep restriction (e.g., one full night of sleep deprivation versus a few nights of one-hour of sleep restriction), a variety of outcome measures (e.g., computerized tasks, self-report, parent-report, teacher-report), variation in sleep measures (e.g., actigraphy versus PSG), and within-participants versus between-participants designs.

Given the limited number of well-controlled experimental studies in the pediatric population and the value that each adds to the literature, all seven studies examining sleep restriction are reviewed in detail (see Table 1 for a summary). Additionally, three studies conducted by Beebe and colleagues are also included. These studies examine slightly older adolescent populations, but were deemed relevant and were therefore included in the chronologically-ordered list below.

1. Carskadon et al., (1981a) examined the effect of a full night of sleep deprivation in 12 children (67% males) between the ages of 11 and 15 in a within-participants design. Sleep deprivation was related to decrements in performance on all performance measures, but these decrements only reached statistical significance for two measures of performance: number of problems attempted on the Wilkinson Addition Test (Wilkinson, 1968) and number of words recalled on the Williams Word Memory Test (Williams, Gieseking, & Lubin, 1966). It was further noted that most of the decrements in test scores were due to participants falling asleep during the tasks. The other tasks examined in this study were a listening attention task to assess vigilance and a serial alternation task which required participants to tap two switches regularly and alternately at a steady pace.

2. In a separate study, Carskadon, Harvey and Dement (1981b) examined sleep, cognitive performance, and sleepiness in nine (33% males) 11-13 year olds using a

within-participants design. Sleep was restricted to 4 h time-in-bed for one night as compared to 10 h time-in-bed. Although sleep restriction resulted in increased daytime sleepiness, no significant effects of the sleep manipulation were seen in performance on an addition task (the Wilkinson Addition Test), a memory task (the Williams Word Memory Test), or a listening attention task.

3. Randazzo et al., (1998) randomly assigned eight participants (three males) to 5 h in bed overnight and eight participants (four males) to 11 h in bed in a between-participants design. All participants were between the ages of 10 and 14 y. The following day they examined psychomotor performance using the Digit Symbol Substitution Test (DSST; Randazzo et al., 1998) and the Steer Clear Computer Driving Test (Randazzo et al., 1998). The DSST involves matching symbols to numbers based on a key of nine numbers. The Steer Clear test is a 30-min computerized visual vigilance simulated driving task that requires participants to avoid hitting cows on a road. The sleep restricted group improved to a significantly lesser degree than the control group on the DSST whereas there was no significant difference on the Steer Clear test. In the same study, Randazzo et al. (1998) examined cognitive performance using the Wide Range Assessment of Memory and Learning (WRAML; Adams & Sheslow, 1990), the Torrance Tests of Creative Thinking (TTCT; Torrance, 1990), the Children's Category Test (CCT; Boll, 1993), the Wisconsin Card Sorting Test (WCST; Heaton, 1991), and the California Verbal Learning Test (CVLT; Delis, Kramer, Kaplan, & Ober, 1994). Significant treatment differences were found in three of four variables of verbal creativity on the TTCT and on one of three variables of the WCST. There were no significant differences in the expected directions on any of the other measures. The authors concluded that even

one night of sleep restriction can impair aspects of higher cognitive function in children (i.e., verbal creativity, learning new abstract concepts, and abstract thinking). However, routine performance is relatively maintained, which was attributed to motivation overcoming sleepiness-related impairment for these tasks.

4. Fallone et al., (2001) examined the effects of one night of sleep restriction (4 h of time-in-bed; *n* = 45; 49% males) versus optimized sleep (10 h of time-in-bed; *n* = 37; 21 males) in school-age participants 8 to 15 yrs using a between-participants design. To assess response inhibition, the researchers used an 8-min task called the Gordon System Standard Delay Task (Gordon, 1983), and to assess sustained attention, the researchers used a 9-min continuous performance task called the Gordon System Vigilance Task 1/9 Mode. They found sleep restriction was associated with shorter daytime sleep latency based on MSLT and increased subjective sleepiness. Although research assistants (RAs) reported that the children demonstrated increased sleepy and inattentive behaviours, they did not report increased hyperactive-impulsive behaviours. Furthermore, sleep restriction did not lead to impaired performance on the response inhibition or sustained attention tasks.

5. Sadeh et al., (2003) examined the effects of sleep manipulations on children between the ages of 9 and 12 years using a mixed within- and between-participants design. Cognitive functioning was assessed using the Neuropsychological Evaluation System (NES; Arcia, Ornstein, & Otto, 1991). The NES includes a finger tapping test, a simple reaction time test, a continuous performance test, a symbol digit substitution test, a visual digit span test, and a serial digit learning test. This study consisted of a 6-day protocol (Sunday to Friday). Day 1 and 2 participants were asked to follow their typical

sleep schedules. Baseline testing was performed on the morning of day 1 or 2. On day 3 participants were randomly assigned to an optimized (1 hour earlier bedtime) or a restricted (1 hour later bedtime) condition for the subsequent 3 nights. On day 6, participants were again tested. For the analysis, participants were divided into three groups: a sleep-optimized group (those that were able to extend their sleep by an average of 30 min for the three nights; $n = 21$), a sleep-restriction group (those that were able to restrict their sleep by an average of 30 minutes for the three nights; $n = 28$), and a no-change group (those that were unable to extend or restrict their sleep for an average of 30 minutes for the three nights; $n = 23$). Results revealed that children in the optimized sleep group significantly improved their performance from baseline to post-intervention on a short-term verbal memory test (the digit forward memory test) and their reaction time on a measure of sustained attention (the continuous performance test; CPT), whereas performance of the other groups did not change. In addition, performance on the simple reaction time test did not change in the optimized sleep group, whereas performance of the other two groups deteriorated.

6. Fallone, Acebo, Seifer, and Carskadon (2005) conducted a home-based, within participants study wherein 74 participants (53% males, 6-12 years of age) followed 3 week-long sleep schedules: self-selected (followed their normal school-night schedule), optimized (no fewer than 10 h per night), and restricted (8 h for first and second graders and 6.5 h for those in third grade or a higher grade). At the end of each study condition, teachers completed questionnaires to evaluate academic problems, hyperactive-impulsive behaviours, internalizing, oppositional-aggressive, sleepiness, total attention problems, and mean severity of attention problems. Restricting sleep was also associated with

increased ratings of academic problems relative to baseline and optimized conditions and increased mean severity of attention problems relative to baseline. The authors concluded that these results provide experimental support for the negative effects of sleep loss on academic functioning in children and suggested that core effects of insufficient sleep in children are likely to appear in the form of slower processing speed and impaired memory function.

7. Gruber et al., (2011) examined the effects of sleep restriction on neurobehavioural functioning in children (7-11 years of age) using the CPT. The CPT is a 15-min computerized task that measures attention. Participants included 32 TD children (63% males) and 11 children with attention-deficit hyperactivity disorder (ADHD; 64% males). Children were asked to go to sleep 1 h later than usual for six nights. Sleep was monitored using actigraphy and sleepiness was evaluated using questionnaires. They found restricting sleep led to poorer scores on 2/3 of the CPT outcome measures in both children with and without ADHD.

Additional Studies: Beebe et al. conducted three studies examining sleep restriction in slightly older populations, adolescents between the ages of approximately 14 and 17 years. Using a similar protocol to Fallone et al. (2005), Beebe et al. (2008) found that when 19 (60% male) participants were restricted to 6.5 h of time in bed versus 10 h of time in bed, parents reported participants displayed significantly greater problems with sleepiness, attention, oppositionality/irritability, behaviour regulation and metacognition. Participant self-report indicated similar, but less robust results. Again using the same sleep manipulation protocol, Beebe, DiFrancesco, Tlustos, McNally, and Holland (2009) found that regions of the brain that are normally active during an attention-demanding working memory task in those that were well-rested became even more active, while brain areas that are normally suppressed showed even greater suppression in order to maintain performance following chronic sleep restriction. The findings are limited, however, as this study only included 6 participants (67% males). Finally, Beebe, Rose, and Amin (2010) examined how sleep restriction affects performance in a simulated classroom (*n* = 16; 56% male). Participants followed the same protocol described above. Findings indicated that when participants were sleep-restricted, participants had lower quiz scores, more inattentive behaviours, and lower arousal levels.

Together the studies reviewed above provide evidence that certain areas of cognitive functioning are impaired by poor or inadequate sleep. These results are consistent with the adult literature on sleep loss and cognitive functioning (see Walker, 2008 for review). However, there is inconclusive evidence in the pediatric literature to indicate the particular areas of cognitive functioning that are most vulnerable to sleep restriction. Two areas that have been highlighted as being especially vulnerable are memory and attention. The literature reveals that although many studies have found impairments in these two domains of cognitive functioning as a result of sleep restriction, there are some studies that have not found any impairments in these domains. Thus, it is important to gain more insights as to which particular aspects of attention and memory are most vulnerable to sleep restriction.

The pediatric literature includes few attempts to identify the mechanisms by which sleep loss can affect emotional and cognitive functioning. More extensive attempts to explain the role of sleep on these areas of daytime functioning have been proposed within the adult literature. To help guide thinking about these issues in the pediatric population, the three main hypotheses explored in the adult literature are reviewed.

Theoretical Perspectives on how Sleep Promotes Emotional Stability and Cognitive Functioning

There are three general hypotheses in the adult literature about how sleep restriction affects emotional regulation and cognition: the vigilance hypothesis, the neuropsychological hypothesis, and the controlled attention hypothesis (for review see Lim & Dinges, 2010). Like the pediatric literature, the adult literature has been biased toward studies examining cognitive as opposed to emotional functioning, resulting in limited hypotheses explaining how sleep regulates emotional functioning.

The Vigilance Hypothesis

A number of authors have suggested that decrements in performance are simply due to a decrease in arousal and vigilance. Supporters of this hypothesis suggest that sleep loss affects nearly all cognitive capacities in a global manner through lowered vigilance and alertness (Killgore, 2010). Balkin, Rupp, Picchioni, and Wesensten (2008) even going so far as to suggest that "…sleep loss impacts a wide array of cognitive abilities. In fact, the array is so extensive that it is reasonable to posit that sleep loss exerts a nonspecific effect on cognitive performance."

The Neuropsychological Hypothesis

Harrison and Horne (2000) proposed a "neuropsychological" model based on recent neuroimaging and clinical data. They suggested that sleep deprivation may negatively affect performance due to a decrease in activity in the prefrontal cortex (PFC). Thus, according to the neuropsychological hypothesis, tasks that place heavy demands on the PFC are most vulnerable to sleep restriction.

The PFC consists of cortex lying in front of the primary and secondary motor cortex, and includes the dorsolateral and orbital areas, frontal eye fields, and Broca's area. Not all of the functions of the PFC are known, but key functions include the maintenance of wakefulness and non-specific arousal and the recruiting of various cortical areas required to deal with tasks (Horne, 1993). Other functions include decision making, innovative thinking, response inhibition, revising plans, selectively attending, and effective communication (Harrison & Horne, 2000). PFC impairment can also lead to disorders of affect, such as apathy and indifference (Horne, 1993). Horne (1993) suggests that compensatory efforts can maintain performance on tasks that are less demanding on the PFC, but it is more challenging to counteract the effects of sleep loss on PFC-related tasks.

Supporters of this hypothesis suggest that impairment in complex cognitive tasks is not merely a result of failure of more basic skills such as those due to lowered arousal, vigilance, and sleepiness, but instead failure on these tasks is specifically linked to the demands the task places on the PFC (Harrison & Horne, 2000). As explained by Lim and Dinges (2010), this model is described as neuropsychological since sleep restriction appears to result in a reversible lesion in the PFC, which is detectable by tests sensitive to these deficits in brain-injured patients. Interestingly, PFC areas are critically involved in both regulating mood and performing cognitive tasks. Thus, these sleep-deprivation impairments may share similar pathophysiological bases and may be related (Franzen, Siegle, & Buysse, 2008).

The Controlled Attention Hypothesis

Somewhat in contrast with the neuropsychological hypothesis, some studies have revealed that highly demanding tasks such as Baddeley's Logical Reasoning Test are unaffected by sleep restriction (Magill et al., 2003; Smith & Maben, 1993). These results led to theories such as the "controlled attention" model (Pilcher, Band, Odle-Dusseau, & Muth, 2007). These authors suggest that tasks that are monotonous, boring, and/or intrinsically less engaging are more affected by sleep restriction because greater top-down control is needed to sustain optimal performance. Pilcher et al. (2007) suggested that tasks be classified based on whether they encourage attentive behaviours, with tasks that are low on this dimension being the most affected by sleep restriction.

The three hypotheses described above are not mutually incompatible. For example, Lim and Dinges (2010) suggest that the vigilance and controlled attention hypotheses can be viewed as different explanations of the same set of phenomena and the neuropsychological hypothesis accounts for the effects above and beyond what can be explained by the other two hypotheses. For example, sleep restriction may affect specific domains (such as those that place heavy demands on the PFC) to a greater degree than the effects produced by global impairments in vigilance (Killgore, 2010).

It is unclear how these three theories extend to the pediatric literature. A few of the pediatric sleep restriction studies have suggested that more complex tasks appear to be most susceptible to sleep restriction (Randazzo et al., 1998) and that the effects of sleep restriction may be domain specific (Gruber et al., 2011), which is most in line with the neuropsychological hypothesis. However, limited attempts have been made to explain *how* sleep restriction affects emotional and cognitive functioning in children.

Overview of Dissertation and Objectives and Hypotheses

Correlational and naturalistic studies point to concerning relationships between poor sleep and emotional and cognitive difficulties. However, such studies do not allow causal inferences. Studies employing experimental manipulation of sleep are needed to allow stronger causal conclusions, especially with respect to emotional functioning in children, for which there are very few experimental studies.

The main objective of this dissertation was to examine the relationships between sleep and daytime functioning (i.e., emotional functioning, memory, and attention) in children. More specifically, the goals were to: 1) examine how sleep duration and sleep efficiency correlate with sleepiness, emotional functioning, memory, and attention, and 2) examine how restricting versus extending sleep duration affects daytime functioning in children. These goals were addressed through the two manuscripts included in Chapters 2 (Study 1) and 3 (Study 2) of this dissertation. The first study employs a correlational design to examine objectively measured sleep in children and explores the relationships between sleep quantity and quality and daytime functioning. The second study seeks to disentangle the bidirectional relationships by providing a within-participants, experimental restriction and extension of sleep duration to allow greater confidence that reduced sleep is the factor causing the daytime functioning impairments.

Table 1.1

Summary of the Studies Examining the Effects of Sleep Restriction on Cognitive Functioning.

Study	Participants/Age	Design	Sleep Restriction Protocol	Findings
Carskadon, Harvey, & Dement, 1981a	12 participants (11-15 y; 67% males)	Within-participants	No sleep for 1 night compared to 10 h time in bed for 1 night	Objective (MSLT) and subjective sleepiness increased. Performance on addition and memory tasks were impaired in sleep restriction condition.
Carskadon, Harvey, & Dement, 1981b	9 participants (11-13 y; 33% males)	Within-participants	4 h time in bed for 1 night compared to 10 h time in bed for 1 night	Objective sleepiness (MSLT) increased. No significant changes on cognitive tasks.
Randazzo, Muehlback, Schweitzer, & Walsh, 1998	16 participants (10-14 y; 44% males)	Between-participants (8 per group)	5 h in bed for 1 night compared to 11 h in bed for 1 night	Sleep restriction impaired performance on 3 measures of creativity and a measure of reasoning. Nine other measures of cognitive performance were not affected.
Fallone, Acebo, Arnedt, Carskadon, & Seifer, 2001	82 participants (8-15 y; 49% males)	Between-participants (37 sleep-extended; 45 sleep-restricted)	4 h time-in-bed compared to 10 h time-in-bed	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	77 participants (9-12 y; unknown sex distribution)	Mixed within- and between-participants (21 sleep-extended; 28 sleep-restricted; 23 no sleep change)	2 nights of normal sleep and 3 nights of ±1 h difference in normal sleep duration	Extended sleep led to improved memory function and CPT performance, and maintained performance on a simple reaction time test.

Study	Participants/Age	Design	Sleep Restriction Protocol	Findings
Fallone, Acebo, Seifer, & Carskadon, 2005	74 participants (6-12 y 53% males)	Within-participants	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	Sleep restriction increased teacher-reported sleepiness, academic problems, and inattention.
Gruber, Wiebe, Montecalvo, Brunetti, Amsel, & Carrier, 2011	43 participants (7-11 y; 64% males); 32 TD and 11 children with ADHD	Within-participants	1 h less than typical time-in-bed for 6 nights compared to typical time-in-bed	Sleep restricted led to poorer CPT scores on 2/3 of CPT measures in TD children and children with ADHD.

Note. ADHD = attention deficit hyperactivity disorder; CPT = continuous performance test; h = hours RA = research assistant; TD = typically developing; *y* = years old;

Chapter 2: Sleep Quantity and Quality and its Relationship with Daytime Functioning in Children

Abstract

This study examined sleep and its relationship with daytime functioning in 32 typically developing children (8-12 y). Participants wore actigraphs for 1 week and then completed tasks to measure emotional functioning, memory, and attention. Results revealed that children were sleeping less than 9 h per night, which is approximately 1 h less than the recommended duration. Older children had shorter sleep durations, higher sleep efficiency, and later sleep onset times. Examination of the relationships between sleep and daytime functioning revealed that within this typically developing group of children, small variations in sleep were significantly associated with emotional functioning and attention. The results highlight the need to increase awareness about the importance of sleep in children.

Introduction

Increasingly later bedtimes, but unchanged wake times, have led to a marked decrease in children's total sleep duration over the past three decades (Iglowstein, Jenni, Molinari, & Largo, 2003). In fact, a National Sleep Foundation poll (National Sleep Foundation, 2004) found that 8-12 year old children are sleeping much less than the recommended amount (Meltzer & Mindell, 2006). In 2006, insufficient sleep in children was declared a major public health concern by an international pediatric task force (Mindell et al., 2006).

In addition to quantity of sleep, it is also important to consider quality of sleep. Poor sleep quality is common among school-aged children (Sadeh, Raviv, & Gruber, 2000). Furthermore, sleep disorders, which often result in both inadequate quantity and quality of sleep, affect approximately 25% of children (Owens, 2007). Of these sleep problems, behavioural insomnia, which includes difficulties initiating and/or maintaining sleep, is the most common pediatric sleep disorder, affecting approximately one in five children (Meltzer, Johnson, Crosette, Ramos, & Mindell, 2010).

Unfortunately, the negative consequences of poor sleep (both quantity and quality of sleep) are frequently overlooked. Evidence is mounting to suggest that inadequate and disrupted sleep impairs emotion and cognition (Sadeh, 2007); aspects that are critical to children's daily functioning. The high prevalence of children experiencing inadequate and disrupted sleep is concerning and highlights the importance of furthering our understanding of the role of sleep in daytime functioning in children.

Most of the literature in this area examines associations between subjective measures of sleep (e.g., parent report or child report) and daytime functioning. Subjective measures of sleep are problematic because there is evidence that they can be unreliable. For example, Nixon et al. (2008) found that parents overestimated their child's total sleep duration and Owens, Spirito, McGuinn, & Nobile (2000) found that children identified more sleep problems than did their parents. Obtaining accurate self reports about sleep is even more problematic among younger children. Additionally, responder bias can be a problem when subjective measures are used. For example, if parents rate both sleep problems and associated traits, responder bias could account for some of the associations reported between sleep and daytime functioning (Gregory & Sadeh, 2011).

Objective measures such as actigraphy or polysomnography (PSG) provide more accurate measurement of sleep, but these are rarely employed in studies examining relationships between daytime functioning and sleep. Actigraphy involves the measurement of motor activity using a device that resembles a small wristwatch, whereas PSG involves recording specific physiological variables during sleep (e.g., electroencephalogram, eye movements, muscle tone, and respiration). Actigraphy has the advantage of allowing children to sleep in their home environments, thus maintaining a high level of ecological validity. Actigraphy has been shown to provide valid and reliable estimates of individuals' sleep and wake periods that are highly correlated with the "gold-standard" PSG measures, but does not permit sleep stage scoring (Sadeh & Acebo, 2002). PSG is more invasive, involving placement of multiple electrodes on the body and typically requiring sleeping in the unfamiliar environment of a sleep laboratory.

The high prevalence of short and poor sleep in pediatric groups highlights the need for more research to understand the consequences. Although a number of studies have demonstrated relationships among poor sleep and impaired emotional and cognitive functioning, most have employed subjective measures of sleep. When examining the literature on the relationship between sleep and daytime functioning, it is important to consider the limitations of subjective measures of sleep. The following sections review the literature examining the role of sleep in emotional and cognitive functioning.

Understanding the impact of sleep on emotional functioning in children is particularly important because children are still developing their ability to control emotions (Dahl & Harvey, 2007). A number of studies that link pediatric sleep problems with emotional dysregulation suggest that sleep plays a role in emotional functioning. For example, Reid, Hong, and Wade (2009) found that among young children, sleep problems were as strong a correlate of child emotional problems as some well-established risk factors, including parenting factors and maternal depressive symptoms. Paavonen et al. (2002) found that subjective reports of more severe sleep disturbances were positively correlated with high ratings of teacher-reported internalizing symptoms (e.g., cries, worries, fearful, miserable). Others have found that children with emotional disorders such as depression and anxiety have high rates of subjectively reported sleep problems (Hudson, Gradisar, Gamble, Schniering, & Rebelo, 2009; Johnson, Roth, & Breslau, 2006). However, when sleep is measured objectively in clinical populations, these relationships are less clear. Some have found higher rates of sleep problems in clinical populations (Forbes et al., 2008; Sadeh et al., 1995), while others have not found such relationships (Bertocci et al., 2005; Puig-Antich et al., 1982).

The majority of studies examining sleep and emotional functioning are based on cross-sectional data, but a few longitudinal studies suggest that poor sleep precedes emergence of emotional problems. Fredriksen, Rhodes, Reddy, & Way (2004) conducted a study in which they obtained self-reports of sleep at sixth, seventh, and eighth grades for over 2000 students. They found habitual sleep amount at the initial assessment predicted future depression and poor self-esteem ratings. Similarly, Gregory, Rijsdijk, Lau, Eley, and Dahl (2009) found that sleep problems at age 8 y predicted depression at age 10 y. A meta-analysis indicated that sleep problems during infancy are linked to emergence of childhood mood-related symptoms (Hemmi, Wolke, & Schneider, 2011). Thus, results from both cross-sectional and longitudinal studies support the conclusion that poor sleep is associated with a wide range of emotional problems. However, much of the literature in this area is based on self- or parent-reports of sleep duration and quality, with limited use of objective measures of sleep.

Aronen, Paavonen, Fjallberg, Soininen, and Torronen (2000) found significant relationships between short sleep duration as measured by actigraphy and higher teacher ratings of psychiatric symptoms. Similarly, El-Sheikh, Buckhalt, Cummings, and Keller (2007) measured sleep using actigraphy and found that children with frequent sleep disruptions were more emotionally insecure than those with fewer sleep disruptions. More research is needed to examine how objectively measured sleep variables are related to emotional functioning in typically developing children. Poor sleep may have serious outcomes even for otherwise healthy children.

Similar to the research examining sleep and emotional functioning, most of the research on cognitive functioning and sleep in typically developing children is based on surveys indicating that poor sleep is associated with poor academic achievement (e.g., Epstein, Chillag, & Lavie, 1998; Wolfson & Carskadon, 2002). A few studies involving experimental manipulation of sleep length in children have been published. These studies indicate that sleep restriction leads to impaired cognitive functioning; however, the domains most affected by sleep restriction remain unclear. As noted by Fallone, Acebo, Seifer, and Carskadon (2005), two closely linked domains of cognition that are important to children's daily function; namely, memory and attention, appear to be particularly vulnerable to sleep restriction (Fallone, Acebo, Arnedt, Seifer, & Carskadon, 2001; Fallone et al., 2005; Gruber et al., 2011; Sadeh, Gruber, & Raviv, 2003).

The research in this area has mainly focused on inadequate sleep duration, which has been tied to problems with attention and memory. Few researchers have examined how sleep efficiency (i.e., the number of minutes of sleep divided by the number of minutes in bed) is related to cognitive functioning. Using actigraphy, Steenari et al.

(2003) and Sadeh, Gruber, and Raviv (2002) found that lower sleep efficiency was correlated with poorer performance on complex memory tasks. Similarly, Sadeh et al. (2002) and Gruber et al. (2007) found that children with poor sleep efficiency, compared to those with good sleep efficiency, performed significantly worse on an attention task.

The experimental studies indicate that reducing children's sleep may lead to impairments in attention and memory. However, less is known about how habitual sleep duration in typically developing children is related to attention and memory. Furthermore, there is some evidence that sleep efficiency may have a stronger association than sleep duration with attention and memory performance (Sadeh et al., 2002; Steenari et al., 2003). Thus, further exploration of the role of objectively measured sleep duration as well as sleep efficiency in daytime functioning of typically developing children is needed.

The objectives of this study were to describe sleep in 8 to 12 year-old children and to explore the relationships among sleep and emotional functioning, memory, and attention using objective measures of sleep. It was predicted that children would be getting less than the recommended amount of sleep and that older children would have shorter sleep durations than younger children, due to later sleep onset, but stable morning awakening. In terms of sleep and daytime functioning, we predicted that shorter sleep duration and lower sleep efficiency would be correlated with more negative emotions, fewer positive emotions, and poorer performance on tests of memory and attention.

Methods

Participants

Healthy typically developing children of either sex aged 8-12 y were recruited. Exclusion criteria were: a chronic illness, a history of neurological impairments (e.g., epilepsy), a history of psychiatric illness, a known learning disability, major sleep complaints, use of medication that would likely affect sleep during the month prior to the study, crossing more than two time zones in the month prior to the study, regularly sleeping less than 8 h or more than 12 h nightly, or regularly taking naps (i.e., more than one per week).

Participants in this study also participated in a sleep manipulation study wherein their sleep duration was manipulated. The data described in the current paper were gathered during the baseline week of the sleep manipulation study. Thirty-six children meeting inclusion criteria were studied. Four children were excluded from the study: three had erratic sleep schedules during the recording week (i.e., greater than 3 h differences in bedtimes and/or wake times), making it difficult to define their typical time in bed, and 1 child experienced a death in the family during the study. Thus, data are reported for 32 participants, 14 males (M = 9.6 years old, SD = 1.3) and 18 females (M = 10.6 years old, SD = 1.3).

Four parents identified their children as multi-racial, with the remainder of the sample identified as Caucasian. One mother was widowed, two sets of parents were divorced, and the rest were married. Mothers' average age was 39.5 y (SD = 5.6y), while fathers' average age was 42.2 y (SD = 6.6 y). All 32 mothers indicated that they had completed high school, 8 mothers completed courses in college, and 22 attended university. Fathers' highest level of education was reported as: grade 10 ($n = 2$), completed high school ($n = 3$), some college-level course ($n = 4$), and some university-level courses ($n = 22$).

Procedure

This project was approved by the Research Ethics Board of the IWK Health Centre, Halifax, Nova Scotia, in conformity with the Canadian Tricouncil Policy Statement: Ethical Conduct for Research Involving Humans. Participants were recruited using a variety of methods, including word-of-mouth and posting recruitment advertisements at various local community centres, universities, hospitals, and on internet sites directed at parents.

Participants interested in the study contacted the principal investigator who described the details of the study and used a brief screening questionnaire to ascertain inclusion/exclusion criteria. Participants and their parent(s) who met inclusion/exclusion criteria were asked to come to our laboratory to complete the consent process as well as the Sleep Evaluation Questionnaire (Mindell & Owens, 2003).

Following the consent process, participants were given an actigraph and daily sleep diaries. Participants were instructed to wear the actigraph 24 h per day for one week and their parents were asked to complete the sleep diary nightly. Participants were asked to remove the actigraphs only if they bathed, swam, or engaged in sports where it might get damaged. Participants were told to follow their typical sleep schedules, with the exception of waking up at their usual weekday wake-up time on the Saturday of their testing session. Efforts were made to ensure that the week represented a typical sleep pattern for the individual, such as asking parents to indicate on the sleep diary whether or not each night of sleep was typical and examining the degree of variability in the participants' sleep over the course of the week. At the end of the week, they were asked to return to the laboratory for their testing session. The sleep diary and actigraphy data from the first week (Sunday night through Saturday morning) were used to calculate the participant's typical bedtime and wake time. The testing session took approximately 90-120 min, and involved completing various tasks measuring emotional functioning, memory, and attention. The tasks (described below) were presented in the following order: memory tasks, affective response task, reaction time task, and sustained and divided attention tasks. Participants were provided with compensation of a $10 movie store gift card and the parent received $10.

Measures

Screening

Participants were initially screened over the phone with a list of relevant inclusion/exclusion questions. They also completed the *Sleep Evaluation Questionnaire* (Mindell & Owens, 2003) following the consent session. This questionnaire requires parents to answer questions about their child's sleep history, current sleep problems, medical and psychiatric sleep history, and school performance as well as demographic questions.

Sleep Measures

Sleep parameters were estimated using Octagonal Basic Motionlogger Actigraphs (Ambulatory Monitoring, Inc. Ardsley, New York). These actigraphs provided measures of sleep duration (number of min from sleep onset to awakening), sleep efficiency (the number of min of sleep divided by the number of minutes in bed), sleep onset time (first min of sleep followed by at least 15 min of uninterrupted sleep), and time of awakening (last min of sleep that was preceded by at least 15 min of uninterrupted sleep). Actigraphy has been shown to provide valid and reliable estimates of sleep variables (Sadeh & Acebo, 2002). In addition, participants' parents were asked to complete the *Sleep Diary* (Corkum, 1996) for each night. Sleep diaries provided information about when the child was in bed, which was used to assist in interpreting the actigraphy data.

Emotional Functioning Measures

There is no clear consensus on the best approach to obtain measures of children's emotions (Chambers & Johnston, 2002) and there are very few existing tasks to measure children's emotional functioning. An Affective Response Task (ART) was designed to measure emotion in children using methods from Leotta, Carskadon, Acebo, Seifer, & Quinn (1997). This task has been found to be sensitive to the effects of sleep restriction and validated for use with pediatric populations (Leotta, 1999) and similar tasks have been used to examine the effects of sleep restriction on emotional functioning in adults (Franzen, Siegle, & Buysse, 2008).

This task required the participant to look at 33 pictures (3 practice pictures and 30 task pictures) from the International Affective Picture System (IAPS), a set of visual stimuli used in investigations of emotions (Lang, Bradley, & Cuthburt, 2008). These stimuli include a variety of images depicting, for example, pollution, puppies, and roller coasters. Following the presentation of each picture, children were asked to report their affective response on a visual analog scale (100 mm line) for each of the following affective states: happy, sad, angry, disgusted, scared, and interested. Endpoints of each line were anchored on the left side by a neutral face with the word "neutral" and on the right side by a face representing the emotion with the word “very”. Positive affective responses were evaluated by a composite score combining values for ‘happy’ and ‘interested’, whereas negative affective responses were a composite score of values for ‘sad’, ‘angry’, ‘disgusted’, and ‘scared’.

Cognitive Functioning Measures

Memory was assessed using a Digit Span task (modified from the Wechsler Intelligence Scale for Children; Fourth Edition; Wechsler, 2003) and the Finger Windows (modified from the Wide Range Assessment of Memory and Learning; Second Edition; Sheslow & Adams, 2003) tasks. For the Digit Span task, participants were asked to repeat sequences of numbers, whereas for the Finger Windows tasks they had to point out patterns of visual sequences. Performance was based on the child’s ability to repeat the sequences and patterns in the same order (short-term memory) as well as in reverse order (working memory) as that presented by the research assistant (RA). Scores were based on percentage of sequences correctly recalled, resulting in a possible range of 0 to 100. The Digit Span task has been found to have good reliability (.78-.91) in children aged 6-16 years (Wechsler, 2003) and the Finger Windows task has been found to have good internal consistency (.81-.83) for children aged 6-13 (Sheslow & Adams, 2003).

A 20 min computerized task, the *Attention Network Test-Interaction* (ANT-I; Callejas, Lupianez, & Tudela, 2004; Fan, McCandliss, Sommer, Raz, & Posner, 2002), was used to assess alerting, orienting and executive attention. For each trial, the participant was instructed to press a certain key to indicate the direction an arrow pointed (for review see Callejas et al., 2004; Fan et al., 2002). Reaction time (ms) was calculated for correct responses only. Scores were derived in the following way: alerting scores were based on the difference between trials with and trials without a warning tone, orienting scores were based on the difference between trials with a valid cue and those with an invalid cue, and executive attention scores were derived from the difference between congruent and incongruent trials. The ANT (an earlier version of the ANT-I) has been reported to have good test-retest reliability and has been validated for use with children (Fan et al., 2002). Reliability estimates for the ANT-I are only beginning to emerge. A recent study found that the reliability of the network scores for young adults is generally greater with the ANT-I than with the ANT and that the network scores of the ANT-I are robust against practice effects (Ishigami & Klein, 2010).

Finally, the Children's Colour Trails Test (CCTT; Williams et al., 1995), a two-part (CCTT-1 and CCTT-2) standardized, paper-and-pencil instrument, was used to measure sustained and divided attention. The CCTT-1 requires the participant to rapidly draw a line through circles numbered 1 through 15 in consecutive order. For the CCTT-2, each number is printed twice, once inside a pink coloured circle and once inside a yellow coloured circle. The participant is asked to rapidly draw a line through consecutively numbered circles, maintaining the sequence of numbers but alternating between pink and yellow coloured circles. The CCTT-1 measures sustained attention, perceptual tracking, and graphomotor skills. Due to the additional requirement of alternating colour and number sequences, the CCTT-2 requires the same three skills as well as divided attention, sequencing skills, and inhibition-disinhibition. As a shorthand description, we refer to the CCTT-1 as a measure of sustained attention and the CCTT-2 as a measure of divided attention. For both the CCTT-1 and the CCTT-2, performance was based on the time required to complete the task. The CCTT has been shown to have good test-retest reliability (moderate range) and adequate validity (Llorente, Voigt, Williams, Frailey, Satz, & D'Elia, 2009).

Results

Prior to analyses, relevant assumption checks were conducted[1]. Descriptive statistics are provided, followed by an analysis of relationships between sleep variables and age, and lastly correlational analyses examining the relationship between sleep measures and emotional functioning, memory, and attention. In order to reduce Type I error due to multiple comparisons, a relatively conservative alpha cut-off value was used ($\alpha = .01$).

Descriptive Statistics

Data from thirty-two participants[2] were included in the final analyses. Average sleep duration (min from sleep onset until wake time) was 530.7 (SD = 32.7) min (or M = 8.8 h). Average sleep efficiency (percentage of time in bed spent sleeping) was 85.5 (SD = 9.0). Participants' mean sleep onset time was 21:57 (SD = 45 min), while their mean time of awakening was 6:52 (SD = 36 min).

Baseline Sleep, Age, and Sex

Pearson bivariate correlations were performed to examine the relationship among age, sex and sleep variables. As expected, age was negatively correlated with sleep duration (r = -.511, p = .003). It was positively correlated with sleep efficiency (r = .452, p = .009) and sleep onset time (r =.495, p = .004), but was not correlated with time of awakening (r =.134, p = .464). Since age was correlated with these sleep variables, we controlled for age in all subsequent analyses.

There were no significant sex differences for most parameters studied. For sleep duration, however, the difference approached significance, with males sleeping longer than females ($F_{(1,30)} = 5.90$, $p = .021$). However, males were also younger on average than females. Since age is known to affect sleep parameters, it was added as a covariate to the analysis and the difference no longer approached significance ($F_{(2,29)} = 2.39$, $p = .133$). Thus, sex does not appear to affect the sleep parameters examined.

Sleep and Emotional Functioning

Relationships of both sleep duration and sleep efficiency with affective response, both positive and negative, were examined. Partial bivariate correlations controlling for age revealed that there was a significant negative relationship between sleep duration and negative affective response ($r = -.504$, $p = .004$), indicating that those with shorter sleep durations show higher levels of negative affective responses. Sleep duration was not significantly correlated with positive affective response, and sleep efficiency was not correlated with either positive or negative affective responses.

Since there was a significant relationship between sleep duration and negative affective response, the relationships between sleep duration and the subscales of negative affective response (sad, angry, scared, and disgusted) were explored (Table 2.1). Partial correlations, with age as a covariate, revealed those with shorter sleep durations reported higher levels of sadness ($r = -.518$, $p = .003$) and anger ($r = -.579$, $p = .001$). Furthermore, both fear ($r = -.387$, $p = .032$) and disgust ($r = -.354$, $p = .050$) tended to be associated with shorter sleep durations, but these relationships only approached significance with the alpha value set at .01.

Sleep and Memory and Attention

Relationships among sleep duration and sleep efficiency and performance on the memory and attention tasks were examined using partial bivariate correlations (Table 2.2). Due to procedural and technical problems, two participants did not complete the CCTT tasks and two others did not complete the ANT-I tasks. For this reason, 28 rather than 32 participants were included in the analyses examining sleep and cognitive functioning. Analyses revealed that sleep efficiency was negatively correlated with divided attention ($r = -.508$, $p = .007$), indicating that those with low sleep efficiency took longer to complete the divided attention task (CCTT-2) than those with high sleep efficiency. There were no other significant relationships among the sleep variables and measures of cognitive functioning.

Discussion

This study examined the impact of habitually occurring differences in sleep quantity and quality in a sample of typically developing school-aged children between the ages of 8 and 12 y. Results revealed that children in this age group are sleeping approximately one hour less than the recommended duration. Older children had shorter sleep durations, higher sleep efficiency, and later sleep onset times. Examination of the relationships between sleep and daytime functioning revealed that even within this typically developing group of children, small variations in sleep were associated with statistically significant effects on daytime functioning. Specifically, results revealed relationships between short sleep duration and increased negative affective response as well as poor sleep efficiency and impaired performance on a divided attention task. Sleep characteristics were not significantly associated with positive emotion, performance on memory tasks, and performance on some attention tasks.

Our descriptive findings were similar to those of other studies in this area, with the average sleep duration being over an hour less than the amount recommended. This finding supports other studies that suggest children are not getting adequate sleep (Sadeh et al., 2000 & 2002; Steenari et al., 2003). For example, Sadeh et al. (2000) found that on average 4th graders were sleeping approximately 8.7 h, while 6th graders were sleeping even less (8.2 h). The average sleep onset time and morning wake time of participants in this study were similar to those reported by Sadeh et al. (2000). The average sleep efficiency of our sample (85.5%) was similar to that of Steenari et al. (2003) who found sleep efficiency to be 86.5% in a sample of 60, 6-13 year-old children.

We found that age was negatively correlated with sleep duration, indicating, consistently with past work, that older children sleep less. For example, Sadeh et al. (2000) found that 2nd graders had longer sleep durations than 4th graders, who had longer sleep durations than 6th graders. The reduction in sleep duration typically is a result of progressively later bedtimes, while wake times remain the same. This is consistent with our finding that older children were falling asleep later than younger children. Interestingly, like Steenari et al. (2003), older children in our sample slept more efficiently than younger children. If these children were not getting adequate sleep, perhaps greater sleep efficiency was due to partial sleep restriction. Experimental sleep restriction studies have found that sleep efficiency increases following sleep restriction (Devoto, Lucici, Violani, & Bertini, 1999). It has been suggested that sleep efficiency changes may be compensatory mechanisms that regulate sleep in response to reductions or extensions in sleep duration. However, others have not found differences in sleep efficiency related to age (Sadeh et al., 2000). Furthermore, although Gruber et al. (2011) and Sadeh et al. (2003) found changes in sleep quality when children were moderately sleep restricted, these ‘compensatory mechanisms’ were not powerful enough to reduce impairments in daytime functioning.

There is conflicting evidence as to whether or not sex affects sleep parameters in school-aged children. For example, Sadeh et al. (2000) found that girls had longer sleep durations, but there was no difference in sleep efficiency, whereas Steenari et al. (2003) found that girls had more efficient sleep, but did not find differences in sleep duration. After controlling for age, our results revealed no sex differences among the sleep parameters examined (sleep duration, sleep efficiency, sleep onset time, and morning wake time).

Emotional Functioning

Short sleep duration was related to high levels of negative affective response. Contrary to prediction, positive affective response was not related to sleep duration, suggesting that negative affective response is more affected by shorter habitual sleep duration compared to positive affective response. There was no relationship between sleep efficiency and either positive or negative affective responses. Our results are consistent with a number of studies that have demonstrated that shorter sleep durations are associated with increased levels of negative emotional symptoms. For example, Smaldone, Honig, and Byrne (2009) found that after controlling for child, family, and environment variables, parents of children with inadequate sleep were more likely to report frequent child depressive symptoms. Giannotti, Flavia, Cortesi, Sebastiani, and

Ottaviano (2002) found that adolescents that characterized themselves as evening-types and had shorter sleep durations as well as poorer subjective sleep were more "emotionally upset" than morning-types.

Only one study has experimentally manipulated sleep in typically developing children to assess its effects on emotional functioning. Talbot, McGlinchey, Kaplan, Dahl, and Harvey (2010) found that under conditions of sleep restriction, compared to when rested, adolescents and adults reported less positive affect, but no difference in negative affect, as measured by the Positive Affect and Negative Affect Schedule (PANAS; Watson, Clark, & Tellegen, 1988). Participants then completed a catastrophizing task, which consisted of the experimenter asking the participant several questions about the participants' most threatening worry. Participants reported more anxiety as a result of catastrophizing when sleep deprived, as compared to when rested.

Additionally, one abstract (Leotta et al., 1997) describes experimentally manipulating sleep in typically developing children to examine emotional functioning. They found that reducing sleep duration led to an increase in negative affective response (anger, sadness, and fear) but no change in positive affective response. These preliminary results should be interpreted cautiously, but they support the idea that sleep is important in regulating emotion.

Most studies that examine relationships among sleep and emotional functioning focus on clinical populations such as individuals with sleep disorders or individuals with emotional disorders. The results of this study indicate similar correlations exist among typically developing children. Together, the results of the current study and the available literature suggest that sleep duration plays an important role in regulating emotional functioning.

Memory and Attention

Lower sleep efficiency was correlated with poorer scores on the CCTT-2, which measures divided attention, sequencing, and inhibition-disinhibition.. There was no relationship between sleep efficiency and the other measures of memory and attention and no relationship between sleep duration and performance on any of the cognitive tasks. Our finding that sleep efficiency, but not sleep duration, is significantly correlated with performance on an attention task (CCTT-2) is consistent with previous research (Sadeh et al., 2002, Gruber et al., 2007). The divided attention task was one of the more complex tasks in our protocol. Like other complex cognitive tasks, this task is said to involve skills subserved by the prefrontal cortex (Williams et al., 1995), which is one area of the brain that may be particularly sensitive to impaired sleep (Dahl, 1996; Drummond & Brown, 2001; Horne, 1993).

Although we found a relationship between sleep efficiency and performance on the CCTT-2, there were a number of aspects of memory and attention that were not correlated with sleep efficiency or duration. It is possible that these domains of memory and attention are not affected by differences in sleep. However, there are a number of factors that may have played a role in determining this outcome, which are discussed in detail below.

Firstly, excluding children with sleep problems as well as any learning, behaviour or mental health issues, resulted in reduced variability in sleep parameters as well as in cognitive performance among our typically developing sample of children. Greater variability in the sample may have permitted detection of other relationships, as in past studies which found that poor sleep efficiency was associated with impairments in a variety of working memory and attention tasks (Gruber et al., 2007; Sadeh et al., 2000; Steenari et al. 2003).

The order of the testing session is also important to consider. Since the memory tasks were the first tasks completed, it is likely that children were more alert and motivated and thus potentially more resistant to the effects of poor sleep. The CCTT-2 may have been more sensitive to disrupted sleep because it was near the end of the testing protocol, at which point the children were likely fatigued. Those with poorer sleep efficiency may have had more difficulty attending at the end of the session, while those with better sleep efficiency remained able to focus.

Finally, it is also important to consider how task engagement and motivation may have affected performance. The ANT-I consisted of two blocks of 96 trials wherein simple stimuli are presented. RAs reported needing to frequently remind most children to attend to this task during its completion, suggesting that the participants had difficulty sustaining attention throughout this task, regardless of sleep condition. Perhaps longer and less engaging tasks make the effects of sleep differences more difficult to detect than tasks that are shorter and more engaging to children. Future research should examine how task engagement and motivation interact with variations in sleep duration.

Strengths, Limitations, and Future Directions

Important strengths of this study were: (1) we used an objective measure of sleep, (i.e., actigraphy) thus allowing us to examine the role of both sleep duration and sleep efficiency in daytime functioning, while permitting an at-home protocol; (2) we used objective measures of memory and attention; and (3) this study is one of very few to objectively examine the role of sleep in emotional functioning in a group of typically developing children.

The cross-sectional nature of this study was both a strength and limitation. This design provided insight into habitual sleep parameters and their relationship with daytime functioning in a group of typically developing children. However, no causal inferences can be made from our research; rather, experimental manipulations of sleep duration or efficiency are needed. Further exploration using experimental protocols that manipulate sleep duration (e.g., restricting time in bed) and/or sleep efficiency (e.g., using multiple forced awakenings) appears to be a promising approach.

A further limitation of this study was use of child reports of affective response. Changes in facial expression have been shown to reflect changes in some mood states (Ekman & Friesen, 1975) so systematic coding of facial expression during the testing session might be a useful approach for more reliably assessing some mood state differences.

Clinical Implications and Conclusions

This study examined a group of healthy children and found that even within this group, small variations in sleep duration and sleep efficiency have statistically significant effects on aspects of emotional functioning and attention. One would anticipate that the more extreme variations in sleep that occur in the general population would have even more profound effects on daytime functioning.

Reduced sleep in children appears to be the norm in our society, but it is not likely in the children's and families' best interests (Wiggs, 2007). Given that poor sleep efficiency was found to be associated with impairments in cognitive functioning and that short sleep duration was associated with increased levels of negative affective response, it is particularly concerning that as a society we do not place more value on sleep. As children move toward adolescence, there are increasing biological and psychosocial influences that interfere with sleep (Dahl & Lewin, 2002), which are likely to further contribute to sleep problems. The high prevalence of short sleep duration and poor sleep quality combined with growing evidence of negative consequences of these sleep problems highlights the need to increase awareness about sleep and sleep problems in children.

Footnotes

[1]Prior to analyses, relevant assumption checks were conducted. Since outliers can have profound effects on the value of the correlation coefficient (Hill & Lewicki, 2007), scatterplots and histograms were examined for all variables. Both sets of graphs allowed us to target possible outliers and check whether or not the data were normally distributed. These checks revealed that performance on the ANT-I Executive Attention network did not have a normal distribution due to outliers. Analyses were conducted with outliers removed and results did not change significantly. The assumption of linearity was explored through examination of scatterplots. Curvature in the relationships was not evident to a degree that would suggest non-linear relationships among the variables. Thus, the analyses included data from all participants.

[2]The actigraphs failed to record data for two female participants. For part of a larger study we had actigraphy data for these participants when their sleep was restricted by one hour and extended by one hour. We used the averages from these two sleep conditions to estimate baseline sleep variables for these participants and verified that these estimates were in agreement with sleep diary data. Data were analysed with and without these participants. Results were similar so we retained these data in the final analyses.

Table 2.1

Partial Correlations (Controlling for Age) among Sleep Variables and Negative Affective Responses

Measure	Sleep Duration
Sadness	-.518 (*p*=.003)
Anger	-.579 (*p*=.001)
Fear	-.387 (*p*=.032)
Disgust	-.354 (*p*=.050)

Note. Values represent r values (*p* values)

Table 2.2

Partial Correlations (Controlling for Age) among Sleep Variables and Memory and Attention Variables

Measure	Sleep Duration	Sleep Efficiency
Short-Term Memory (digit span & finger windows)	-.08 (*p*=.71)	.09 (*p*=.66)
Working Memory (digit span & finger windows)	-.28 (*p*=.16)	.11 (*p*=.57)
Alerting Attention (ANT-I)	-.14 (*p*=.50)	.15 (*p*=.44)
Orienting Attention (ANT-I)	.17 (*p*=.39)	.14 (*p*=.48)
Executive Attention (ANT-I)	-.09 (*p*=.66)	.12 (*p*=.57)
Sustained Attention (CCTT-1)	-.02 (*p*=.92)	-.34 (*p*=.08)
Divided Attention (CCTT-2)	.01 (*p*=.94)	-.51 (*p*=.007)

Note. Sleep duration and sleep efficiency values represent *r* values (*p* values). ANT-I = Attention Network Test – Interaction. CCTT = Children's Color Trails Test.

Chapter 3: Manipulating Sleep Duration alters Emotional Functioning, Memory, and Attention in Children

Abstract

Daytime consequences of sleep loss have been well documented in adults, but the pediatric literature includes mostly correlational studies, with few well-controlled, experimental studies. A few studies have manipulated sleep experimentally in school-aged children to examine effects on emotional and cognitive functioning, but more well-controlled, experimental studies are needed. Thirty-two children (8-12 y) wore actigraphs for 3 weeks. During the baseline week, actigraphic data were used to estimate the child's typical daily sleep duration. During the second week, the child was randomly assigned to go to bed either one hour earlier (Extended condition) or one hour later (Restricted condition) than their typical bedtime. Each child then completed the opposite schedule during the third week of the study. After each of the 3 weeks, emotional functioning, memory, and attention were assessed using objective and subjective measures. The sleep manipulation was effective; the children slept significantly longer in the Extended (M = 9.3 h, SD = 0.6) versus Restricted (M = 8.1 h, SD = 0.7) condition and children were significantly sleepier in the Restricted condition according to parent, child, and research assistant report. Results revealed impaired functioning in the Restricted relative to Extended condition on measures of positive affective response, emotion regulation, memory, and aspects of attention. However, some aspects of emotional functioning and attention were not affected by the sleep manipulation. Results suggest that even a modest degree of cumulative sleep restriction can have negative consequences for children's daytime functioning. Moreover these findings support the need to emphasize the importance of promoting healthy sleep habits for children.

Introduction

A number of reports suggest that children's total sleep duration has decreased markedly over the past three decades (Iglowstein, Jenni, Molinari, & Largo, 2003). A poll of over 600 American parents of school-aged children found that these children slept 9.0-9.5 h nightly (National Sleep Foundation, 2004), although they are estimated to need 10-11 h of sleep (Meltzer & Mindell, 2006). Given the prevalence of reduced sleep among children, it is important to understand its impact on different domains of daytime functioning. The daytime consequences of sleep loss have been well documented in adults, but well-controlled studies addressing this issue in the pediatric population are scarce. The limited pediatric literature suggests that sleep restriction affects many domains of daytime functioning, including areas of emotional and cognitive functioning.

Although the experimental literature examining sleep and emotional functioning is sparse, a number of correlational studies suggest a relationship between poor sleep and increased emotional problems (Fredriksen, Rhodes, Reddy, & Way, 2004; Gregory, Rijsdijk, & Eley, 2006). In addition, numerous studies have found that pediatric sleep disorders associated with disrupted sleep are associated with symptoms of emotional dysregulation (Kurnatowki, Łapienis, & Kowalska, 2008). Longitudinal studies suggest that poor sleep precedes the emergence of emotional problems in children; e.g. future depression and low self-esteem ratings (Fredriksen et al., 2004) and higher scores on anxiety, depression and aggressive behaviour scales (Gregory, Van der Ende, Willis, & Verhulst, 2008).

The published experimental literature relating sleep reduction to daytime functioning in typically developing school-age children is limited to one study and one abstract. Talbot, McGlinchey, Kaplan, Dahl, and Harvey (2010) restricted sleep in adolescents to 6.5 h for the first night and 2 h for the following night. When the participants were sleep restricted, compared to rested, they reported less positive affect, but there was no change in negative affect. Using an affective response task, Leotta, Carskadon, Acebo, Seifer, and Quinn (1997) found 8-12 year-old children reported higher levels of negative emotions (anger, sadness, and fear) following sleep restriction. More studies involving experimental manipulations of sleep duration are needed to permit strong causal inferences.

Most studies in the pediatric literature relating sleep and cognitive functioning are correlational. For example, studies indicate that early school start times, which result in shortened sleep duration (Wahlstrom, 2002), are linked to poor academic performance (e.g., Wolfson & Carskadon, 1998). Additionally, poor sleep has been linked to impaired attention (Gruber et al., 2007; Sadeh, Gruber & Raviv, 2002) and memory (Steenari et al., 2003).

Seven studies involving experimental manipulation of sleep length in elementary-school-aged children have been published. Among these studies, six reported negative effects of sleep reduction on some aspects of cognitive functioning, but not on others, while one did not report any significant impairment (Carskadon, Harvey & Dement, 1981a). The studies reporting impaired functioning after restricted sleep identified deficits in a number of domains, including addition tasks and word memory tasks (Carskadon, Harvey & Dement, 1981b), verbal creativity, learning new abstract concepts, and abstract thinking (Randazzo, Muehlbach, Schweitzer, & Walsh, 1998), RA-reported inattention (Fallone, Acebo, Arnedt, Seifer, & Carskadon, 2001), simple reaction time

(Sadeh, Gruber, & Raviv, 2003), teacher-reported academic problems and severity of attention problems (Fallone, Acebo, Seifer, & Carskadon, 2005), and vigilance and sustained attention (Gruber et al., 2011). Although there is mounting evidence to suggest that sleep affects cognitive functioning, the particular areas of cognitive functioning that are most affected remain unclear.

Memory and attention are two closely related domains of cognitive functioning that are especially important to children's daytime functioning. Both are correlated with sleep duration (Gruber et al., 2009; Steenari et al., 2003) and are particularly vulnerable to experimental sleep restriction (Carskadon et al., 1981a; Fallone et al., 2001; Fallone et al., 2005; Gruber et al., 2011; Sadeh et al., 2003). A few studies, however, have reported that sleep loss does not impair performance on some tests of memory and attention (Carskadon et al., 1981b; Fallone et al., 2001; Randazzo et al., 1998). Studies examining a wider variety of memory and attention tasks are needed to identify the aspects of memory and attention that are most sensitive to alterations in sleep duration.

The goal of this study was to assess the effects of manipulating sleep duration on emotional functioning, memory and attention in school-aged children. We generated a relatively modest difference in sleep duration by extending sleep for four consecutive nights (1 h earlier bedtime: Extended sleep condition) or restricting sleep for four consecutive nights (1 h later bedtime: Restricted sleep condition) using a within-participant, cross-over design, with the protocol conducted in the participant's home. These manipulations resulted in sleep duration differences that might realistically occur spontaneously among children. Based on previous research, we predicted that children in the Restricted sleep condition would show impaired daytime functioning relative to when they were in the Extended sleep condition. Specifically, we expected that sleep restriction would increase negative emotions, decrease positive emotions, and impair emotion regulation, mood, memory, and attention.

Methods

Participants

Participants were school-aged children who were selected based on the following exclusion criteria: they were not able to participate if they had a chronic illness, a history of neurological impairments (e.g., epilepsy), a history of psychiatric illness, or a known learning disability. With regard to sleep history, those who had major sleep complaints (e.g., frequent night time awakenings), had used medication that would likely affect sleep during the month prior to the study, had crossed more than two time zones in the last month, regularly slept less than 8 h or more than 12 h nightly, or regularly took naps (e.g., more than one per week) were excluded.

Of 36 participants initially enrolled, 32 completed the entire protocol, including baseline, Restricted and Extended sleep weeks. Four participants withdrew following the baseline period (three had erratic sleep schedules with bedtimes shifting by more than 3 h from night to night and one withdrew following the death of a family member). The 32 participants who completed the study were 8-12 years old (M = 9.8 y, SD = 1.4), and included 14 boys (M = 9.1 y, SD = 1.3) and 18 girls (M = 10.3 y, SD = 1.3). Half completed the Restricted sleep protocol and half the Extended sleep protocol first. Their average sleep duration at baseline (sleep onset until wake time, determined using actigraphy, see below) was 8.8 h (SD = 0.5) and their average sleep efficiency was 85.5% (SD = 9.0).

Four parents identified their children as multi-racial, while 28 were identified as Caucasian. Mothers' average age was 39.5 y (*SD* = 5.6), while fathers' average age was 42.2 (*SD* = 6.6). Within our sample, all 32 mothers indicated that they had completed high school, 8 mothers completed courses in college, and 22 attended university. The highest level of education reported for the fathers was high school (n=5), college (n=4), and university (n=22). Two sets of parents were divorced, one mother was widowed, and the rest were married.

Procedure

This project was reviewed and approved by the Research Ethics Board of the IWK Health Centre, Halifax, Nova Scotia in conformity with the Canadian Tricouncil Policy Statement: Ethical Conduct for Research Involving Humans. Participants were recruited using a variety of methods, including word-of-mouth and advertisements posted at local community centres, universities, hospitals, and on internet sites directed at parents. Participants interested in the study contacted the principal investigator who described the details of the study and administered a brief screening questionnaire. Participants and their parent(s) who met inclusion/exclusion criteria were asked to come to our laboratory to complete the consent process as well as the Sleep Evaluation Questionnaire (Mindell & Owens, 2003).

A three-week at-home sleep restriction/extension protocol was used, which required participants to come to the laboratory on four separate occasions. Following the consent process, participants were given an actigraph (see below) and a daily sleep diary. For the three-week duration of the study, parents were instructed to complete the sleep diary each day and participants were instructed to wear the actigraphs. Participants were asked to wear the actigraph at all times, with the exceptions of removing it if they bathed, swam, or engaged in sports where it might get damaged. Participants were told to follow their typical sleep schedules for the first week. At the end of the week, they were asked to return to the laboratory on a Saturday morning for their first testing session. The session took approximately 90-120 min and involved completing various measures of emotional functioning, memory, and attention, including objective tasks and self-report questionnaires. Meanwhile, parents completed questionnaires to assess their child's attention and emotion regulation. Once the child left the laboratory, a research assistant (RA), who administered the tests to the participants, completed questionnaires to provide their observations of the child's sleepiness, mood, and attention. Participants were provided with compensation of $10 in movie store gift cards each week and the parent received $10 each week.

The sleep diary and actigraphy data from the first week were used to calculate each participant's typical daily bedtime and wake time during the week. Using these data, bedtimes were adjusted to create two different sleep schedules: one that required a 1 h later bedtime, relative to the individual's baseline schedule (Restricted condition), and one that required a 1 h earlier bedtime relative to the individual's baseline schedule (Extended condition). Participants were randomly assigned to have either the Restricted condition first followed by the Extended condition, or vice-versa. Participants maintained their usual sleep schedules Saturday through Monday nights, and sleep schedule manipulations were imposed for four nights (Tuesday through Friday nights) during the second and third weeks of the study. Participants returned to the laboratory for test sessions at the same time as their baseline tests on each Saturday morning following the sleep manipulation weeks. The schedule of events during the testing session was: child-reported sleepiness scale; short-term and working memory tasks; child-reported sleepiness scale; affective response task; child-reported sleepiness scale; computerized alerting, orienting, and executive attention task (block 1); break; child-reported sleepiness scale; computerized alerting, orienting, and executive attention task (block 2); sustained and divided attention tasks; child-reported emotion regulation and attention questionnaires.

Measures

Participants were initially screened over the phone using a list of inclusion/exclusion criteria questions. They then completed the *Sleep Evaluation Questionnaire* (Mindell & Owens, 2003) at the laboratory following the consent session. This questionnaire requires parents to answer questions about their child's sleep history, current sleep problems, and medical and psychiatric sleep history, as well as demographic questions.

To measure sleep duration, *Octagonal Basic Motionlogger Actigraphs* (Ambulatory Monitoring, Inc. Ardsley, New York) were used. An actigraph resembles a wristwatch and is worn on the non-dominant wrist; it uses an accelerometer to measure activity as an indirect measure of sleep and waking. Actigraphy has been shown to provide valid and reliable estimates of individuals' sleep and wake periods that are highly correlated with the 'gold-standard' polysomnography (PSG) measures (Sadeh & Acebo, 2002). In addition, participants' parents were asked to complete the daily *Sleep Diary* (Corkum, 1996). Sleep diaries provided information about when the child was in bed, which was used to assist in interpreting the actigraphy data.

One question in the sleep diaries was also used to obtain parental reports of child sleepiness. This question asked parents to assess their child's sleepiness upon awakening using a 5-point Likert scale with anchors of 1 = alert to 5 = lethargic. Child self-report of sleepiness was measured using the *Child's Pictorial Sleepiness Scale* (Maldonado, Bentley, & Mitchell, 2004). This scale displays five cartoon faces representing degrees of sleepiness. The child was asked to circle the face that best matched how he/she felt at a particular time (1 = picture of an alert face; 5 = picture of a very sleepy face). It was administered four times throughout the testing session. RAs completed one question to assess the child's sleepiness during the session, using a scale of 1 = alert to 5 = tired.

Parent-reported emotion regulation was measured using the *Emotion Questionnaire* (Rydell, Thorell, & Bohlin, 2007; EQ-P), a 40-item questionnaire that assesses parents' views of children's emotional reactions with regard to anger, fear, positive emotions/exuberance, and sadness in response to statements depicting everyday situations. Items are ranked on a 5-point scale where 1 = "*Does not apply at all*" and 5 = "*Applies very well.*" For this study, only the 24-item Emotion Regulation subscale was used. This measure has been shown to have adequate reliability and validity (Rydell et al., 2007). Child-reported emotion regulation was assessed using the 29-item *Emotion Questionnaire for Children* (Rydell et al., 2007; EQ-C). There are 29 items pertaining to emotion regulation (e.g., "When I am angry I calm down pretty quickly"). Items are rated on a 4-point scale where 1 = "*Does not apply to me at all*" and 4 = "*Applies to me very well.*" This measure has been shown to have adequate reliability and validity (Rydell et al., 2007). RAs reported on the child's mood using a positive mood subscale of the *Emotional Disorders Rating Scale* (*EDRS*; Kaminer, Feinstein, Seifer, Stevens, &

Barrett, 1990). This 1-item subscale ranges from 1= “So-so mood. Neither good nor bad” to 5 = “Extremely good. Appeared terrific, great, on top of the world.”

Using methods from Leotta et al. (1997, 1999) an Affective Response Task (ART) was designed to examine emotion. This task has been found to be sensitive to the effects of sleep restriction and validated for use with pediatric populations (Leotta, 1999). It included 33 pictures from the International Affective Picture System (IAPS), a set of visual stimuli used in investigations of emotions (Lang, Bradley, & Cuthburt, 1999). These stimuli include a variety of images depicting, for example, pollution, puppies, and roller coasters. Three practice pictures were presented followed by 30 test pictures. Following the presentation of each picture, children were asked to report their affective response according to six 100-mm line visual analog scales representing happy, sad, angry, disgusted, scared, and interested. Endpoints of each line were represented by a neutral face and the word “neutral” on the left side and a face representing the emotion and the word “very” on the right side. The measure of positive affective response was a composite mean score of ‘happy’ and ‘interested’, whereas negative affective response was assessed using a composite score of ‘sad’, ‘angry’, ‘disgusted’, and ‘scared’. The range of possible scores for both positive and negative affective response was 0 to 100.

Memory was assessed using two tasks: the Digit Span (modified from the *Wechsler Intelligence Scale for Children, Fourth Edition*; Wechsler, 2003), and Finger Windows (*Wide Range Assessment of Memory and Learning 2*; Sheslow & Adams, 2003). In the Digit Span task, participants were asked to remember sequences of numbers, while in the Finger Windows task, they were required to point out patterns of visual sequences. Short-term memory scores were based on children’s abilities to repeat the sequences in the same order as presented by the RA, whereas working memory tasks required participants to repeat the sequences in reverse order. Scores were based on percentage of sequences correctly recalled, resulting in a possible range of 0 to 100. These tasks have been found to have adequate psychometric properties (Sheslow & Adams, 2003; Wechsler, 2003).

The Conners' Parent Rating Scale-Revised (Long Form; CRS-R:L; Conners, 1998) is a standardized behaviour rating system that is completed by parents to assess problem behaviours in children. It has adequate psychometric properties as demonstrated by good internal reliability coefficients, high test-retest reliability, and effective discriminatory power (Conners, 1998). It consists of 80 items that comprise a number of subscales. For this study, the 9-item DSM-IV Criteria for Inattentive Type Attention-Deficit/Hyperactivity Disorder (ADHD) subscale was used to measure parent-reported attention. Child-reported attention was measured using the *Self Report of Symptoms Scale* (SRSS). This measure was developed in our laboratory and contains a 9-item Inattention subscale that is also based on DSM-IV criteria. A RA read the questions to the child and the child was asked to indicate how frequently a behaviour (e.g., "Rushed through your school work and didn't pay close attention to what you were doing") occurred on a 3-point scale ranging from "Never" to "Usually". RAs rated child attention according to the Attention subscale of the *Child Attention Problems Scale* (CAPS), a scale developed in our laboratory. The Attention subscale consists of the 9 DSM-IV items (e.g., "Is easily distracted") listed as criteria for ADHD, Inattentive Type. The RA was asked to circle the number that best describes the child's behaviour during the testing session according to a 4-point scale ranging from "Never or Rarely" to "Very Often".

A computerized task, the *Attention Network Test-Interaction* (ANT-I; Callejas, Lupianez, & Tudela, 2004), was used to measure alerting, orienting, and executive attention. The ANT-I is a modification of the original adult ANT (Fan, McCandliss, Sommer, Raz, & Posner, 2002). The participant is instructed to press the "c" key if the target stimulus (an arrow) points left and the "m" key if the arrow points right. During each trial, the following events occur: First, a cross appears at the central fixation point. On half of the trials, an auditory tone is presented after a variable duration (400-1600 ms). On two thirds of the trials, an asterisk is presented after 400 ms and the target arrow is presented 50 ms later, either on the same ('valid') or opposite ('invalid') side. Half of the trials include presentation of flanker arrows (two arrows on each side of the target arrow). The arrow(s) remains on the computer screen until the participant responds or until 3000 ms have elapsed. Reaction time was calculated for correct responses only. The task includes one block of 24 practice trials and two blocks of 96 experimental trials. The experimental trials were separated by a 5 min break.

When either all five arrows point in the same direction or the target arrow is presented in the spatial location congruent with the direction to which it points (e.g., arrow presented on left side of fixation and points left), trials are considered 'congruent'. Incongruent trials occur when either the target arrow points in the opposite direction of the flanking arrows or when the spatial location is incongruent with the direction to which the target arrow points (e.g., arrow presented on right side and points left).

Functioning of the alerting network is measured by subtracting the reaction times on trials with a tone preceding the target from those without a tone. The orienting network is assessed by subtracting reaction time on trials with a valid asterisk cue from those with an invalid asterisk cue. The executive network is assessed by examining the difference in reaction time between congruent trials and incongruent trials.

The task took approximately 20 min to complete. The ANT (an earlier version of the ANT-I) has been reported to have good test-retest reliability and has been validated for use with children (Fan et al., 2002). Reliability estimates for the modified version used in this study, the ANT-I, are only beginning to emerge. However, a recent study found that the reliability of the network scores is generally greater with the ANT-I than with the ANT and that the network scores of the ANT-I were robust against practice effects (Ishigami & Klein, 2010).

The Children's Colour Trails Test (CCTT; Williams et al., 1995), a standardized, two-part, paper-and-pencil task was used to assess sustained (CCTT-1) and divided (CCTT-2) attention as measured by time required to complete each task as measured in seconds. The sustained attention task (CCTT-1) requires participants to rapidly draw a line from numbers 1 through 15 in consecutive order. For the divided attention task (CCTT-2) each of the 15 numbers is printed twice, once in a pink coloured circle and once in a yellow coloured circle. Participants are told to alternate between yellow and pink circles while drawing the line from number 1 to15. The CCTT has been shown to have good test-retest reliability (moderate range) and adequate validity (Llorente, Voigt, Williams, Frailey, Satz, & D'Elia, 2009).

Results

To ensure that the sleep manipulation had the desired effect, sleep duration during the Extended sleep protocol was compared to that during the Restricted protocol using a paired samples t-test. As anticipated, average sleep duration in the Restricted condition

(M = 484.6 min, SD = 38.9) was significantly shorter ($t_{(31)}$=12.6, p<.001) than in the Extended condition (M = 558.0 min, SD = 36.8). Furthermore, comparing sleep durations within participants, they slept 28.2-140.2 min longer in the Extended condition (M = 73.4 min; SD = 33.9) than in the Restricted condition.

Paired samples t-tests indicated that children were sleepier in the Restricted condition according to parental report ($t_{(31)}$=3.41, p=.002), child report (first administration of the sleepiness scale) ($t_{(31)}$=3.39, p=.002), and RA report ($t_{(31)}$=3.43, p=.008). Within the Extended condition, there was a significant difference between the second and third assessment of child-reported sleepiness ($t_{(31)}$=3.24, p=.003). As seen in Figure 1, there were significant differences in self-reported sleepiness in the Extended versus Restricted condition early during the testing session (the first two times that the sleepiness scale was administered; $t_{(31)}$=3.39, p=.002; $t_{(31)}$=3.30, p=.002, respectively), but there were no significant differences later during the test session (third and fourth times that the scale was administered; $t_{(31)}$=1.18, p=.247; $t_{(31)}$=.87, p=.394, respectively).

The Effects of Sleep Manipulation on Daytime Functioning Variables

To examine the effects of sleep manipulation on emotional functioning, memory, and attention, we conducted repeated-measures multivariate analysis of variance (MANOVA). Before the analyses were conducted, checks of the relevant statistical assumptions were performed[1]. For the primary analyses, one MANOVA was performed to examine emotional functioning and a separate MANOVA was performed to examine attention and memory. For both analyses, condition (Extended vs. Restricted) was the within-participant factor. The dependent variables used to examine emotional functioning included: positive affective response (ART), negative affective response (ART), parent-reported emotion regulation (EQ-P), child-reported emotion regulation (EQ-C), and RA-reported mood (EDRS). For the second MANOVA, the following dependent variables were analyzed: short-term memory (Digit Span Forward and Finger Windows Forward), working memory (Digit Span Backward and Finger Windows Backward), alerting attention (ANT-I), orienting attention (ANT-I), executive attention (ANT-I), sustained attention (CCTT-1), divided attention (CCTT-2), parent-reported inattention (CRS-R:L), child-reported inattention (SRSS), and RA-reported inattention (CAPS).

When the multivariate results suggested a significant difference between the Extended and Restricted conditions, univariate analyses were conducted to determine which variables were contributing to the effect. Although MANOVA tests controlled for experimentwise (Type 1) error at the multivariate level, no correction was made for multiple univariate tests. This decision was in keeping with other studies in this area (e.g., Randazzo et al., 1998, Sadeh et al., 2003). An alpha level of .05 was used to determine statistical significance.

Effects of Sleep Manipulation on Emotional Functioning

The first MANOVA revealed significant differences ($F_{(1, 27)} = 3.09$, $p = .023$, partial $\eta^2 = .37$) in emotional functioning. This result suggests that 36.8% of the variation in emotional functioning was attributable to the influence of the sleep manipulation. This significant effect prompted examination of five separate repeated-measures ANOVAs, of which two were significant. Participants showed more positive affective response ($F_{(1,31)} = 5.05$, $p = .032$) and better parent-reported emotion regulation ($F_{(1,31)} = 7.62$, $p = .010$) in the Extended compared to Restricted condition. The other three ANOVAs revealed no significant differences in negative affective response, child-reported emotion regulation, or RA-reported mood. The mean and standard deviation of the raw scores as well as effects sizes for each outcome variable are presented in Table 3.1.

In addition, parents were asked the following question "Do you have any comments about your child's learning, emotions, behaviour, or sleep the past few days." Qualitative reports indicated that many parents noticed changes in their child's mood and emotional state. In fact, statements related to emotional functioning were listed more often than statements about sleepiness or inattentive behaviours. For example, the following were statements written by participants' parents in the Restricted condition: "He had occasional temper outbursts", "She has been more reactive in situations that she couldn't control", " more argumentative", "more subdued", "more emotional", "cried more often", "easily frustrated". These types of statements were not made during the Extended condition.

Effects of Sleep Manipulation on Memory and Attention

The MANOVA examining the effects of sleep on attention and memory functioning also revealed significant differences ($F_{(1,18)} = 3.65$, $p = .011$, partial $\eta^2 = .657$), suggesting that 65.7% of the variance in cognitive functioning was attributable to the sleep manipulation. Of the ten univariate ANOVAs, three were significant. There was a significant difference in short-term memory ($F_{(1,27)} = 4.67$, $p = .040$), working memory ($F_{(1,27)} = 7.97$, $p = .009$), and parent-reported inattention ($F_{(1,27)} = 15.26$, $p = .001$), with lower scores on memory tasks and decreased attention in the Restricted compared to Extended condition. The difference on the divided attention task of the CCTT-2 approached significance ($F_{(1,27)} = 4.17$, $p = .051$). No significant differences were found for reaction time on alerting, orienting or executive attention (ANT-I)[2], sustained attention (CCTT-1), RA-reported inattention, and child-reported inattention. The means and standard deviations of the raw scores for each outcome variable are presented in Table 3.2.

Discussion

This study examined the effects of modest, cumulative sleep restriction over several days on emotional functioning, memory, and attention in children. Our sleep manipulation was successful in achieving an average of >1 h difference in sleep duration during the Extended compared to Restricted condition. In addition, reports from the parent, child, and RA were consistent in indicating that children were sleepier in the Restricted condition. Our results confirmed our hypothesis that manipulating sleep duration would affect aspects of emotional functioning, attention, and memory; however, this was not consistent across all measures.

Sleepiness

The most frequent and consistent finding in pediatric sleep restriction studies is that sleep restriction increases sleepiness (Carskadon et al., 1981a; Fallone et al., 2001). Our findings support previous reports (Sadeh et al., 2003) suggesting that even modest, cumulative sleep restriction increases sleepiness. While reports by parent and child could have been confounded by their knowledge of the current sleep condition, the RAs were blind with respect to the participant's current sleep protocol. The consistency of their evaluations with the other reports demonstrates that this sleep manipulation was adequate to generate overt, readily detectable changes in children's sleepiness. Thus, even as few as four nights of modest sleep restriction (1 h per night) can increase daytime sleepiness in children.

In the Restricted condition, self-reports of sleepiness were consistent over the 2 h testing session. However, in the Extended condition, lower sleepiness scores at the beginning of testing increased during the second half of the test morning (Figure 1). This observation may be related to the children confounding increasing tiredness and boredom with sleepiness as a result of the >1.5 h testing session. Similarly, Carskadon et al., (1981a) found that self-reported sleepiness increased following a battery of performance tests. However, they also found that objective multiple sleep latency test (MSLT) scores remained fairly stable, despite the increase in self-reported sleepiness.

Based on the discrepancy between MSLT and self-report of sleepiness observed by Carskadon et al. (1981a), it is likely that the increase in sleepiness reported during the second half of our test battery by children in the Extended condition actually reflects increasing fatigue and/or boredom, rather than neurobiologically defined sleepiness. There was no increase in sleepiness ratings over the course of the test battery in the Restricted condition.

Emotional Functioning

Participants expressed less positive affective responses to stimuli presented, and parents reported children had more difficulty regulating their emotions when they were in the Restricted compared to Extended condition. Furthermore, qualitative data derived from an open-ended question given to parents suggest that most parents in our study saw negative changes in their children's mood and emotion regulation when they were sleep restricted. These results demonstrate a causal relation between changes in sleep duration and changes in emotion regulation and are consistent with the only other experimental study in this area (Talbot et al., 2010). Additionally, results are consistent with a number of correlational studies showing that sleep problems and child emotional problems occur together (El-Sheikh et al., 2007; Gregory et al., 2006). For example, higher levels of depressed mood have been reported in short-sleeping children (Smaldone, Honig, & Byrne, 2009).

Longitudinal studies have found that poor sleep precedes the emergence of depressive symptoms (Fredriksen et al., 2004; Gregory et al., 2008), and that infant sleep problems are linked to later emergence of mood-related (internalizing) symptoms during childhood (Hemmi, Wolke, & Schneider, 2011). Others have reported improvements in emotional problems following treatment for sleep difficulties (Goldstein, Post, Rosenfeld, & Campbell, 2000; Walters, Mandelbaum, Lewin, Kugler, England, & Miller, 2000). In these studies, however, it is unclear whether effects are on negative emotions, positive emotions or both. The current investigation did not examine clinical populations, however, it is important to consider our results in the context of such studies. In our study, modest changes in sleep duration over a few days affected positive, but not negative, emotions. It should be noted that we used the same set of pictures for both conditions and these were not very disturbing. Whether more extreme or sustained changes in sleep or the use of more strongly negative images would demonstrate broader effects of sleep loss on emotional regulation needs to be evaluated.

Sleep condition did not produce significant changes in either RA assessments of the children's mood or children's self-report of emotion regulation. It is likely that our RA report measure (a single item with a 5-point scale) did not have adequate sensitivity to detect a change in mood. Although the children were sleepy, they remained highly cooperative during testing (as also reported by Carskadon et al., 1981a). Perhaps the controlled laboratory environment and working one-on-one with an adult reduced the probability of observing the mood changes that were reported by parents in the more varied and unstructured home environment.

Since parents reported much greater impairment in the Restricted condition, the lack of self-reported impairment in children may reflect an inability to adequately reflect on and assess their own ability to regulate emotional state. Similarly, Beebe et al., (2008) found that adolescent self-report following sleep restriction was a less robust measure than either teacher or parental report. In addition, we administered these questionnaires at the end of the testing session, when children reported being very 'sleepy' (which may also reflect being tired as a result of testing), regardless of which sleep condition they were in. Perhaps children would be more able to attend to and reflect upon emotional regulation and attention if assessed earlier in the testing protocol.

Memory and Attention

Short-term and working memory as well as some aspects of attention were impaired during Restricted sleep relative to Extended sleep, which is consistent with a previous finding that sleep extension for 3 days led to improved performance on a short-term memory task (Sadeh et al., 2003). Correlational studies have also suggested that sleep disturbances are associated with impaired working memory performance (Steenari et al., 2003). In contrast, Carskadon et al. (1981b) and Randazzo et al. (1998) found that performance on verbal memory tasks was unaffected by a single night of sleep restriction. However, significant impairments were detected on a word memory task after 38 h of sleep deprivation (Carskadon et al., 1981a).

Parents in this study reported problems with children's attention during the Restricted protocol, while the result of the divided attention task showed a trend (p=.051) in the same direction. These results are consistent with those reached from teacher reports of children undergoing moderate, cumulative sleep restriction, which indicated that they had increased academic problems and impaired attention (Fallone et al., 2005), and with evidence that sleep-restricted children show more inattentive behavior in the laboratory (Fallone et al., 2001). Similarly, children with poor sleep quality were reported to show poorer attention (Gruber et al., 2009) and those undergoing sleep restriction showed impairments in sustained attention and vigilance (Gruber et al., 2011). It is noteworthy, however, that Fallone et al. (2001) did not find deficits in computerized tasks that measure sustained attention and response inhibition, despite evidence for more inattention in the laboratory.

Although our results suggest that sleep restriction impairs attention on some measures, this finding was not true for the attention networks of the ANT-I or the sustained attention task of the CCTT. Three factors that may have contributed to these results are: (1) our modest manipulation of sleep duration did not affect certain aspects of attention; (2) fatigue and lack of motivation may have masked the effects of the sleep manipulation; and (3) poor psychometrics of the measures may have affected our ability to detect differences.

The literature suggests that less complex cognitive tasks are more resistant to sleep restriction (Randazzo et al., 1998), which may explain why alerting, orienting, and sustained attention were not affected by our sleep manipulation. This explanation, however, is unlikely to explain why executive attention, which is said to require a higher level of cognitive functioning (Fan et al., 2002), was unaffected.

Fatigue may have caused participants to perform more poorly on tasks administered toward the end of the session, thus masking the effects of sleep manipulation. This explanation is supported by the finding that participants reported equal levels of sleepiness by the end of the testing sessions, regardless of sleep manipulation condition. Additionally, motivation likely contributed to our results, particularly for the ANT-I task. RAs reported needing to frequently redirect children to this task, regardless of sleep condition. Perhaps the monotony and length of the task, paired with a high level of fatigue, reduced its sensitivity to detect effects of sleep restriction. This hypothesis is in contrast to the adult literature, which suggests that long tasks requiring prolonged vigilance are the most likely to deteriorate with acute sleep loss (e.g., Samkoff & Jacques, 1991). Although participants had trouble attending to this task, our results revealed that, for the most part, the measure worked as expected (see footnote).

Finally, it is also important to consider the psychometric properties of the measures used in this study. In particular, little is known about the reliability of the ANT-I task for pediatric populations. Ishigami and Klein (2011) suggest that the reliability of the ANT-I for adult populations is “generally lower than is ideal for many purposes” (p. 27). Low reliability may explain why these networks were not affected by the sleep manipulation.

Strengths, Limitations, and Implications

The main strengths of this study include: (1) it is only the second study to assess how cumulative, moderate manipulation of sleep duration affects emotional functioning in children, and one of few to examine how it affects memory and attention; (2) manipulation of sleep was moderate to mimic sleep changes that often occur spontaneously in children's everyday life; (3) a within-participant design was used to avoid between-group differences; (4) both subjective and objective measures of daytime functioning were used; and (5) use of actigraphy provided objective measures of sleep in an ecologically valid environment.

Additional studies are needed to address limitations of this study. First, we used subjective measures to assess sleepiness and emotional functioning. In future studies, conclusions reached could be strengthened by adding objective (physiological) measures to assess these functional areas, such as MSLTs to assess sleepiness, and blinded, systematic coding of facial expression to assess emotional status (e.g., Ekman & Friesen, 1975). Secondly, the effects of sleep manipulations on attention were less clear, possibly due to lack of motivation, fatigue, or poor psychometric properties of certain tasks. Future research should explore how motivation and fatigue affect performance during an extended battery of tests.

This study indicates that even modest sleep restriction, accumulated over four days, leads to deficits in areas that are critical to daytime functioning in children. One can assume that chronic sleep restriction would result in much greater impairments. Our results suggest that problems with emotional functioning, memory, or attention may be a symptom of inadequate sleep; thus, children experiencing difficulties in these areas should be screened for sleep problems. Furthermore, this study highlights the need to educate health care professionals, educators, parents, and children about the importance of sleep and healthy sleep habits and the potential negative consequences of inadequate sleep.

Footnotes

[1]Prior to analyses, all relevant assumption checks were conducted. These checks revealed that a few participants had standardized residuals greater than 3 on a few variables. There were a few variables that violated the assumption of no univariate outliers. Variables with standardized residuals greater than 3.3 violate this assumption (Tabachnick & Fidell, 2001). One participant had a standardized residual of 3.36 on orienting attention in the restricted condition and a different participant had a standardized residual of 3.43 on child-reported inattention in the restricted attention. Analyses were conducted with outliers removed and results were not significantly affected. Parent-reported inattention and child-reported inattention violated the assumption of sphericity (p=.037). However, whether Greenhouse Geisser or Huynh-Feldt were examined there were no significant changes (i.e., p = .001 for parent-report and p > .7 for child report). Additionally, a few variables were not normally distributed. With sufficient sample size (i.e., minimum of 20 cases per cell), the MANOVA is robust to this violation of this assumption (Mardia, 1971). However, to be more confident in our results, analyses were conducted with outliers removed as well as with variables transformed. For example, a new variable was created that was a function of the old variable by taking the square root on variables with skew greater than 1.5 or kurtosis greater than 3.9. If this transformation did not effectively reduce skew and kurtosis, logarithm transformations were performed). Results were not significantly affected. Thus, the analyses included data from all participants and variables used in the final analyses were not transformed.

[2]Additional analyses were conducted to assess the general characteristics of performance on the ANT-I task. For these analyses, Restricted and Extended conditions were not

compared, but rather performance was examined within each of these conditions. As expected, paired-samples t-tests revealed that children responded significantly faster on trials when a tone was presented, compared to when no tone was presented, in both the Restricted ($p<.001$) and Extended ($p<.001$) conditions. Furthermore, participants also responded significantly faster for congruent versus incongruent trials in both conditions ($p<.001$). Finally, participants responded significantly slower on the invalid, compared to valid trials in the Extended ($p<.05$), but not the Restricted ($p=.093$), condition.

Table 3.1

Means and Standard Deviations for Emotional Outcome Measures in Extended versus Restricted Sleep Conditions

Measure	Extended	Restricted	F	*P*	η^2
Positive Affective Response (ART)	33.38 (18.13)	31.26 (17.68)	5.05	.032	.14
Negative Affective Response (ART)	14.33 (13.53)	14.86 (13.71)	.61	.442	.02
Parent-Reported Emotion Regulation (EQ-P)	4.11 (.53)	3.80 (.66)	7.62	.010	.20
Child-Reported Emotion Regulation (EQ-C)	2.80 (.49)	2.77 (.56)	.31	.583	.01
RA-Reported Mood (EDRS)	3.53 (.98)	3.28 (.89)	2.39	.133	.07

Note. Values shown are means (standard deviations). η^2 = partial eta squared. ART = Affective Response Task; EQ-P = Emotion Questionnaire (Parent); EQ-C = Emotion Questionnaire (Child); EDRS = Emotional Disorders Rating Scale. ART scores are the averaged sum of the mean score on a 100mm visual scale. EQ-P values are scores on the Emotion Regulation Scale (range: 1-5). EQ-C values are scores on the Emotion Regulation Scale (range: 1-4). EDRS values are raw means (range: 1-5).

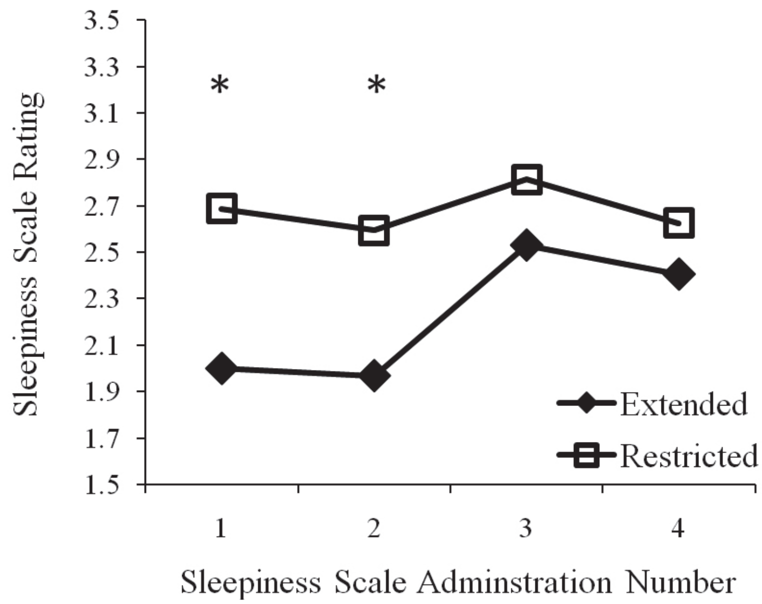
Table 3.2

Means and Standard Deviations for Cognitive Outcome Measures in Extended versus Restricted Sleep Conditions

Measure	Extended	Restricted	F	*P*	η^2
Short-term Memory (Digit Span & Finger Windows)	56.73 (9.75)	53.425 (10.07)	4.67	.040	.15
Working Memory (Digit Span & Finger Windows)	44.32 (10.41)	39.50 (11.40)	7.97	.009	.23
Alerting Attention (ANT-I)	97.70 (67.16)	115.26 (125.37)	.61	.442	.02
Orienting Attention (ANT-I)	32.43 (85.85)	30.97 (104.26)	.00	.950	.00
Executive Attention (ANT-I)	98.59 (89.76)	85.83 (74.81)	.55	.551	.01
Sustained Attention (CCTT-1)	42.11 (26.22)	47.96 (29.44)	1.77	.194	.06
Divided Attention (CCTT-2)	71.61 (36.93)	80.89 (41.34)	4.17	.051	.13
Parent-Reported Inattention (CRS-R:L)	3.93 (4.54)	7.55 (6.76)	15.26	.001	.36
Child-Reported Inattention (SRSS)	4.93 (3.21)	5.03 (3.63)	.17	.681	.01
RA-Reported Inattention (CAPS)	1.60 (1.96)	2.63 (3.35)	3.04	.093	.10

Note. Values shown are means (standard deviations). η^2 = partial eta squared. ANT-I = Attention Network Test – Interaction. CCTT = Children's Color Trails Test. Digit Span and Finger Windows scores are the percentage of sequences correctly recalled. ANT-I scores are difference scores measured in ms. CCTT scores are raw scores measured in seconds. CRS-R:L values represent scores on the Inattentive Type Attention-Deficit/Hyperactivity Disorder subscale (range: 1-9). SRSS values represent scores on the Inattention subscale (range: 1-9). CAPS values represent scores on the Attention subscale (range: 1-4).

Figure 1. Mean child-reported sleepiness ratings in the Extended versus Restricted Conditions during testing sessions.* = significant difference between Extended and Restricted conditions ($p < .05$).



Chapter 4: Discussion

Overview of Results

The goals of this dissertation were to: 1) examine how sleep duration and sleep efficiency correlate with emotional functioning, memory, and attention, and 2) examine how restricting versus extending sleep duration affects daytime functioning in TD children. These goals were addressed through two studies. The first study examined sleep in children and explored the relationships between sleep quantity and quality and daytime functioning. Results revealed that children slept less than the recommended duration for their age. Older children in the study had later sleep onset times, shorter sleep durations, and better sleep efficiency than younger children. Children with shorter sleep durations had greater negative affective responses, and those with lower sleep efficiency performed worse on a divided attention task. In the second study, children underwent experimental extensions and restrictions of sleep duration relative to their individual baselines. Results indicated that sleepiness, positive affective response, emotion regulation, memory, and aspects of attention were worse in the Restricted, compared to Extended condition. However, some aspects of emotional and cognitive functioning were not affected by our sleep restriction protocol.

Sleep in Children

Study 1 revealed that children in our sample were not getting the recommended amount of sleep. In fact, on average children slept an hour less than the minimum recommended amount. These findings are supported by other research in this area (Sadeh et al., 2003; Randazzo et al., 1998). It is challenging, however, to know how much sleep children actually need as we do not know to what extent variation in habitual sleep duration is a reflection of interindividual variability in biological sleep need, or to what extent it reflects variation in accumulated sleep debt (Dinges, 2005).

Daytime functioning may help provide insights into whether or not a child is obtaining an appropriate quantity and quality of sleep. However, determining 'optimal daytime functioning' is also challenging (Wiggs, 2007). Sadeh et al. (2003) suggest that experimenting with extending and restricting sleep and tracking the changes in the child's daytime functioning may be the most appropriate approach to determining a child's optimal sleep need. The results of Sadeh et al. (2003) demonstrated that extending sleep beyond children's typical sleep duration led to improvements in cognitive functioning, suggesting that children were not getting enough sleep to function at their optimum level. There is also evidence to suggest that many young adults are not obtaining adequate sleep. For example, Klerman and Dijk (2005) found that young adults with shorter, compared to longer, habitual sleep durations fell asleep more quickly and frequently during MSLT, indicating they carry a higher sleep debt. These results suggest the interindividual variation in sleep duration may be a reflection of variation in self-selected sleep restriction or wake extension rather than a variation in sleep need.

Furthermore, research indicates that children sleep more when given the opportunity. For example, Wolfson and Carskadon (1998) found significant differences in adolescents' total sleep duration during the week compared to during the weekends. In a similar manner, later school start times result in children getting several hours more sleep per week than peers who start earlier (Wahlstrom, 2002). Additionally, in the current investigations, Study 1 indicated that those with longer sleep durations had lowered negative affective responses and performed better on a divided attention task and

Study 2 revealed that participants were able to extend their sleep duration when assigned to the Sleep Extension condition. Although conclusive evidence is not available, these results suggest that our youth are not getting adequate sleep.

Age and Sleep

The findings in Study 1 with respect to age effects on sleep are consistent with the literature. For example, Sadeh et al. (2000) found that 2nd graders had longer sleep duration than 4th graders, who had longer sleep durations than 6th graders. This reduction in sleep duration has been attributed to increasingly later bedtimes, but consistent (or in some cases earlier) school start times for older children. The results of the current investigation are in agreement with this suggestion, as the older children were falling asleep later than the younger children, yet there was no difference in their morning wake time.

Two important contributors to increasingly later bedtimes, and resulting shorter sleep durations, over the past few decades are likely technology and caffeine. Television viewing habits have been associated with sleep disturbances in school-age children. Increased television viewing amounts and increased television viewing at bedtime have been associated with sleep disturbances including bedtime resistance, sleep onset delay, and anxiety around sleep, and a resulting decrease in sleep duration (Owens, Maxim, McGuinn, Nobile, Msall, & Alario, 1999). Similarly, Li, Jin, Shenghu, Jiang, Yan, and Shen (2007) found that having a television in the bedroom was associated with later bedtimes, later awakening times, and shorter sleep duration in school-aged children. Additionally, Pollak and Bright (2003) found that caffeine use is associated with shorter sleep durations in children and Mindell, Meltzer, Carskadon, and Chervin (2009) found that children who consumed at least one caffeinated beverage per day slept approximately 20 min less than children without daily caffeine intake. Thus, it is concerning that nearly 50% of school-aged children have televisions in their bedrooms and over 40% of school-aged children consume at least one caffeinated beverage daily (Mindell et al., 2009). Given the high prevalence of inadequate sleep, educating our youth on the effects of technology and caffeine on sleep is an important step to improving sleep in children and adolescents.

In terms of sleep efficiency, similar to Steenari et al. (2003), results of the present investigation revealed that older children slept more efficiently than younger children. Perhaps greater sleep efficiency was due to partial sleep restriction. Experimental sleep restriction studies have found that sleep efficiency increases following sleep restriction (Gruber et al., 2011; Sadeh et al., 2003). It has been suggested that sleep efficiency changes may be compensatory mechanisms that regulate sleep in response to reductions or extensions in sleep duration. However, others have not found differences in sleep quality measures related to age. For example, Sadeh et al. (2000) examined sleep percentage (the percentage of the sleep period that was true sleep time) and number of night wakings (that lasted 5 min or longer and that were preceded and followed by at least 15 min of uninterrupted sleep) and did not find relationships between these variables and age. Thus, there may be some compensatory mechanisms at play, but they may not be sufficient to ameliorate daytime functioning impairments.

Sleepiness

Increased sleepiness is the most frequent and consistent effect of poor quantity and quality sleep in children (Carskadon et al., 1981a; Fallone et al., 2001). Results from

Study 2 showed that when children were sleep restricted, compared to sleep extended, self-, parent-, and RA-report indicated that the children were significantly sleepier. These results demonstrated that even as few as four nights of modest sleep restriction led to overt, readily detectable changes in children's sleepiness.

If children are regularly getting approximately an hour less sleep than they require, it is important to consider that sleepiness is likely widespread in youth and, thus, a significant problem. Furthermore, children appear to require more time than adults to recover from sleep restriction (Carskadon et al., 1981a). Sleepiness is best addressed through improved sleep (Mindell et al., 2009) and improved sleep is most likely achieved through educating children, parents, and professionals about healthy sleep habits.

In addition to finding that sleep restriction led to increased sleepiness, the results of Study 2 raised interesting questions regarding sleepiness and fatigue. During the Restricted condition, self-reports of sleepiness were consistent over the 2 h testing session. However, in the Extended condition, lower sleepiness scores at the beginning of testing increased during the second half of the test morning. This observation may be related to the children confounding increasing fatigue and boredom with sleepiness as a result of the lengthy testing session.

Carskadon et al. (1981a) found that self-reported sleepiness can vary in relation to daytime activity, with sleepiness ratings increasing toward the end of a battery of performance tests. In that report, Carskadon et al. also found that objective MSLT scores remained fairly stable throughout the day despite the increase in self-reported sleepiness. Fallone et al. (2001) also noted no significant difference in subjective sleepiness scores between a sleep-extended and sleep-restricted group at certain times of the day even though MSLT scores suggested those in the restricted condition were physiologically sleepier.

Based on the discrepancy between MSLT scores and self-report of sleepiness observed by Carskadon et al. (1981a) and Fallone et al. (2001), it is likely that the increase in sleepiness reported during the second half of our test battery by children in the Extended condition actually reflects increasing fatigue and/or boredom, rather than neurobiologically defined sleepiness. To help clarify whether children are experiencing task-related fatigue versus sleepiness, it would be valuable in future studies to include MSLT during sleep-restriction protocols (Fallone et al., 2002). Furthermore, although not as informative as the MSLT, shorter testing protocols and longer and/or more frequent breaks between tests may also be helpful.

Sleep and Emotional Functioning

Both studies found significant relationships between sleep and emotional functioning. In Study 1, shorter spontaneous sleep durations were associated with increased negative affective response, but there was no relationship between spontaneous sleep duration and positive affective response. There were significant relationships between short sleep durations and increased sadness and anger, while the relationships between short sleep durations and fear and disgust approached significance. Study 2 demonstrated that the sleep restriction protocol decreased positive affective response and parent-reported emotion regulation, but did not alter negative affective response, child-reported emotion regulation, or RA-reported mood.

Most studies examining sleep and emotional functioning have been naturalistic and correlational. Furthermore, most have focused on negative, as opposed to positive, emotional symptoms. For example, Smaldone et al. (2009) found that, after controlling for child, family, and environment variables, parents of children with inadequate sleep were more likely to report frequent child depressive symptoms as well as disagreements involving heated arguing and violent family conflict style, among other factors. These results are consistent with the findings from Study 1 that short spontaneous sleep duration is significantly associated with increased sadness and anger. Similarly, Aronen et al. (2000) studied 49 children using actigraphy and found significant associations between shorter total sleep duration and higher teacher ratings of externalizing, attention, and social problems. Additionally, El-Sheikh et al., (2007) found that poor quality and quantity of sleep in 166 children was associated with emotional insecurity. Like the results of the current investigation, these studies suggest short habitual sleep duration is associated with increased negative emotions.

The results of Study 1 indicate that even within a group of healthy, TD children, relationships between short sleep duration and negative affective response exist. It is surprising and concerning that these associations exist among a relatively homogenous group of well-functioning children. This result emphasizes the strength of the relationship between habitual short sleep durations and negative affective response.

Although correlational studies such as the one presented in Study 1 are important and valuable, causation cannot be determined. Study 2 examined the effects of experimentally manipulating sleep on emotional functioning in a pediatric population. Results were consistent with the only other study in this area (Talbot et al., 2010), revealing that restricting sleep decreased positive affective response, but did not significantly change negative affective response. Additionally, the current investigation revealed that sleep restriction impairs parent-reported emotion regulation.

The finding that even small differences in spontaneous sleep durations were correlated with sadness and small reductions in sleep duration reduced positive affect and reduced ability to regulate emotion hint at how more severe sleep abnormalities may contribute to the emergence of, or perpetuate, depression and other affect regulation disorders. The current investigation did not examine clinical populations; thus our ability to extend our findings to clinical populations is limited. However, it is important to consider the results of the current investigation in the context of studies that have examined clinical populations.

Many longitudinal studies indicate that short sleep duration is associated with the later emergence of emotional problems. For example, Fredriksen et al., (2004) found that habitual sleep amount predicted higher ratings of depression and lower ratings of self-esteem. Similarly, Gregory et al., (2008) found that children who were reported by their parents to sleep less than others were at an elevated risk for high scores on anxiety and depression as well as aggressive behaviours scales. Additionally, a meta-analysis indicated that sleep problems during infancy are linked to emergence of childhood mood-related symptoms (Hemmi et al., 2011). Short sleep duration may be a particularly important risk indicator of later emotional difficulties, but it is less clear whether this relationship is due to increased negative emotions, decreased positive emotions, or a combination of the two.

Questions also exist as to whether or not sleep restriction affects individuals with emotional disorders differently. Based on the literature, it is likely that children with anxiety may be especially vulnerable to inadequate or poor sleep while children that are habitually short sleepers may be at risk for depressive symptoms (Johnson et al., 2006). The results of Study 1 are in line with this literature, suggesting that even within a group of TD children, those with shorter sleep durations express more sadness. The results of the current investigation should be cautiously extended toward clinical populations, but may be useful to guide future research questions in this area. Additionally, the result that sleep loss dampens positive affective response (Study 2) indicates that it is likely that sleep loss would worsen depressive symptoms. Furthermore, if individuals with poor sleep are prone to more negative affective response and then are sleep restricted, one would expect that the results would be even more impairing. That is, their negative affective response is heightened while at the same time their positive affective response flattened. Additionally, within the context of the results of Study 1, perhaps poor sleep is a marker of phenotype vulnerability that later expresses itself as a clinical syndrome. Thus, these results may reflect an underlying mechanism that is related to both sleep and affect.

Although a number of measures of emotional functioning were associated with sleep, in Study 2, sleep condition did not produce significant changes in RA assessments of mood or children's self-report of emotion regulation. It is likely that our RA report measure did not have adequate sensitivity to detect a change in mood. Furthermore, the controlled laboratory environment and working one-on-one with an adult likely reduced the probability of observing the mood changes that were reported by parents in the more varied and less structured home environment.

Since parents reported significant impairments in the Restricted condition, the lack of self-reported impairment in children may reflect an inability to adequately reflect on and assess their own ability to regulate emotional state. Similarly, Beebe et al. (2008) found that adolescent self-report following sleep restriction was a less robust measure than either teacher or parental report. Additionally, administering these questionnaires at the end of the testing session, when children reported being very ‘sleepy’ may have resulted in children having difficulty attending to and reflecting on the questions.

Although RA-reported mood and child self-report of emotion regulation were not significantly affected by our manipulation of sleep duration, the results of both Study 1 and Study 2 indicate that sleep plays an important role in regulating emotional functioning, including negative affective response, positive affective response and emotional regulation, in children. This investigation emphasizes the importance of sleep duration in optimal emotional functioning.

Sleep and Cognitive Functioning

Both Study 1 and Study 2 revealed significant relationships among sleep and cognitive functioning. Study 1 revealed that children with poor sleep efficiency were more likely to have difficulties with divided attention tasks, but no relationship was found between sleep duration and other aspects of attention and memory. Study 2 revealed that experimentally shortening sleep duration negatively affected short-term memory, working memory, divided attention (CCTT-2), and parent-reported inattention. The attention networks on the ANT-I task, performance on the sustained attention task of the CCTT-1, RA-reported inattention, and child-reported inattention were not affected by the sleep restriction protocol.

Few studies have examined relationships among sleep efficiency and cognitive functioning. Obtaining a measure of sleep quality is challenging with subjective measures, and thus sleep quality is typically only assessed when objective sleep measures are used. Consistent with previous results (Sadeh et al., 2002, Gruber et al., 2007), Study 1 revealed that poor sleep efficiency was correlated with impaired cognitive performance, specifically poor performance on the divided attention task (CCTT-2). Relationships among sleep duration and sleep efficiency and memory were not found in Study 1. It is possible that the relative ease of our memory tasks made them less sensitive to varying sleep durations and qualities. Steenari et al. (2003) found that performance on only the most complex memory tasks was associated with sleep duration. Furthermore, the current investigation only included children that did not have problematic sleep or learning problems. These exclusion criteria may have limited our abilities to find relationships among these variables. All studies examining sleep quality and cognitive functioning in children have been correlational or naturalistic. Experimentally fragmenting sleep (i.e., waking children during the night) would result in decreased sleep efficiencies and would further our understanding of the causative role of sleep efficiency in cognitive functioning.

Although no studies have examined the effect of experimentally fragmenting sleep and its effects on cognitive functioning in children, seven studies have looked at the effects of experimentally restricting sleep duration on cognitive functioning in school-aged children. Among these studies, six reported negative effects of sleep reduction on some aspects of cognitive functioning, but not on other aspects (Carskadon, Harvey, & Dement, 1981a; Fallone, Acebo, Arnedt, Carskadon, & Seifer, 2001; Fallone, Acebo, Seifer, & Carskadon, 2005; Gruber, Wiebe, Montecalvo, Brunetti, Amsel, & Carrier, 2011; Randazzo, Muehlback, Schweitzer, & Walsh, 1998; Sadeh, Gruber, & Raviv, 2003), while one did not report any significant impairment (Carskadon et al., 1981b). The studies reporting impaired functioning after sleep loss identified deficits in a number of domains: addition tasks and word memory tasks (Carskadon et al., 1981a); verbal creativity, learning new abstract concepts, and abstract thinking (Randazzo et al., 1998); teacher-reported academic problems and severity of attention problems (Fallone et al., 2005); RA-reported inattention (Fallone et al., 2001); simple reaction time (Sadeh et al., 2003), and vigilance and sustained attention (Gruber et al., 2011).

Consistent with past literature (Fallone et al., 2001 & 2005; Gruber et al., 2011; Sadeh et al., 2003), the current investigation revealed that experimental sleep restriction leads to impaired memory and attention. In Study 2, short-term memory, working memory, and parents' reports of children's attention were all worse in the Restricted condition. Additionally, performance on the divided attention task showed a trend in the same direction. These results are consistent with those reached from teacher reports of children undergoing moderate, cumulative sleep restriction, which indicated that they had increased academic problems and impaired attention (Fallone et al., 2005), and with evidence that sleep-restricted children show more inattentive behaviour in the laboratory (Fallone et al., 2001).

Although our results suggest that sleep restriction impairs attention on some objective measures, this finding was not true for the ANT-I attention networks or the sustained attention task. Similarly, a few studies have reported that sleep loss does not impair performance on some tests of memory and attention (Carskadon et al., 1981b;

Fallone et al., 2001; Randazzo et al., 1998). It is important to consider factors that may explain why certain aspects of memory and attention were not found to be impaired following sleep restriction. Factors that may have played a role in these results include study design (sample size, between- versus within-participants, amount and duration of sleep restriction) and task characteristics (task engagement, psychometric properties).

Firstly, the design of many of the studies in this area have included modest sample sizes and used between-participants designs. For example two of the studies that did not find deficits in memory and attention included sample sizes of 16 or fewer participants (Carskadon et al., 1981b; Randazzo et al., 1998). Small sample sizes are problematic for various reasons including variability in performance on cognitive functioning tasks. Carskadon et al. (1981a) reported that decrements in performance did not reach statistical significance on some measures due to the wide variability of the performance tests scores, particularly when participants were sleep deprived.

Another potential problem with small samples and between-participants designs that is frequently overlooked is interindividual variability in sensitivity to sleep loss. Within the adult literature, Van Dongen, Baynard, Maislin, and Dinges (2004) suggested that interindividual differences in neurobehavioural impairment from sleep loss in adults provides evidence of trait-like differential vulnerability; neurobehavioural impairment from sleep loss was significantly different among adult individuals, but stable within individuals. A thorough literature review revealed that no published studies have examined interindividual variability in sensitivity to sleep loss in children; however, one would expect similar if not more variable effects compared to adults. Small sample sizes increase the risk of having a sample that could be more or less extreme than the average population.

In addition to small sample sizes, a number of studies have used between-participants designs (Fallone et al., 2001; Randazzo et al., 1998; Sadeh et al., 2003). Due to the variability in children's sleep needs and cognitive skills, between-participants designs may not have the sensitivity to detect changes related to sleep loss, particularly in studies that examine moderate sleep loss.

Amount and duration of sleep restriction is also likely to affect task performance differently. For example, accumulated sleep restriction may affect daytime functioning differently than one night of sleep restriction. Carskadon et al. (1981b) and Randazzo et al. (1998) had similar amounts of sleep restriction to that imposed in Study 2, but only across one night. Their sleep restriction protocols did not affect memory and attention, whereas that of the current investigation did. Studies should compare whether spreading sleep restriction across multiple nights results in similar impairments compared to limiting sleep restriction to one night (i.e., does four nights of one hour of sleep restriction yield effects similar to those of one night of four hours of sleep restriction?).

In addition to the study design, it is also important to consider how task characteristics can mask the effects of sleep restriction. For example, tasks that are lengthy and less engaging may be less sensitive to impairments related to sleep restriction. The computerized performance measure used in the current investigation, the ANT-I, did not detect impairments in attention related to sleep restriction and was not correlated with sleep duration or sleep efficiency. Similarly, Fallone et al. (2001) used 8- and 9-minute computerized tasks to assess sustained attention and response inhibition and did not detect impairments related to sleep restriction although teacher-report indicated impairments in attention. Randazzo et al. (1998) examined the Steer Clear task, which is a 30-minute computerized task, and found that it was not affected by sleep restriction. Others, however, have found sleep-restriction-related impairments on lengthy computerized tasks such as the 15-minute CPT (Gruber et al., 2011). It is important to consider whether results from our investigation, as well as those of others, are due to the aspects of attention (e.g., executive attention) not being affected by sleep restriction or whether other factors such as task engagement masked the effects.

In Study 1 and 2, RAs reported needing to frequently redirect children to the ANT-I task, regardless of sleep condition. Perhaps the monotony and length of the task, and resulting lack of task engagement, reduced its reliability and, therefore, its sensitivity to detect effects of sleep restriction. Unfortunately, little is known about the psychometric properties of this task for use in pediatric populations. A recent study revealed that network scores of the ANT-I were robust against practice effects in adults, but their reliability was generally low (Ishigami & Klein, 2010). More research is needed to establish the reliability of this task for use with children. It may be a useful strategy for future researchers to add assessments of motivational state to their protocols to assess task engagement. Furthermore, these results emphasize the importance of using measures with well-established psychometric properties.

This investigation demonstrates that adequate quantity and quality of sleep are important to optimizing certain aspects of memory and attention. However more research examining why only certain aspects of these domains appear to be affected by changes in sleep duration is required.

Theoretical Perspectives on how Sleep Promotes Emotional Stability and Cognitive Functioning

As described previously, there are three hypotheses that have been suggested to account for the effects of sleep loss on daytime functioning: the vigilance hypothesis, the neuropsychological hypothesis, and the controlled attention hypothesis. These hypotheses were initially proposed to explain sleep-related cognitive impairments. However, as will be described, there is evidence to suggest that they may account for sleep-related emotional impairments as well.

The Vigilance Hypothesis

The Vigilance Hypothesis states that impairments in performance following sleep restriction are due to decreased general arousal and vigilance (Pilcher et al., 2007). Few researchers have described how the vigilance hypothesis applies to emotional functioning. One could hypothesize that general lowered arousal might lead to a decrease in emotional response (Minkel, Htaik, Banks, & Dinges, 2011), which is consistent with our result that sleep restriction reduces positive affective response, but does not increase negative affective responses. Others have attributed sleep-loss-related changes in emotional regulation to decreases in ‘cognitive energy’ (Zohar, Tzischinsky, Epstein, & Lavie, 2005). That is, sleep loss is said to deplete cognitive energy, resulting in positive events being associated with dampened positive emotion and negative events being associated with heightened negative emotion.

A number of memory and attention measures were affected by sleep restriction in Study 2, and in Study 1, lower sleep efficiency was correlated with poorer performance on the divided attention task. According to the vigilance hypothesis, these effects could be explained by generally lowered arousal and vigilance due to sleep restriction or inefficient sleep. However, some tasks were not affected (e.g., the ANT-I networks and the sustained attention task) suggesting that other explanations should also be considered.

The Neuropsychological Hypothesis

The Neuropsychological Hypothesis states that sleep deprivation negatively affects performance through a decrease in activity in the prefrontal cortex (PFC), a structure involved in regulation of both emotional and cognitive functioning. Proponents of this hypothesis suggest that deficits in complex cognitive tasks are not a result of failure of more basic skills due to lowered arousal and vigilance, but are specifically linked to the cortical demands of these tasks (Harrison & Horne, 2000).

The PFC interacts with the amygdala and hippocampus to regulate emotional expression and sleep loss has been demonstrated to reduce PFC activity (Meerlo, Mistlberger, Jacobs, Heller, & McGuinty, 2009). The reduction in PFC activity could account for changes in emotional regulation via this circuit. The involvement of the PFC in mood regulation includes inhibiting limbic structures that are important to generating and recognizing affect such as the amygdala and the hippocampus (Davidson et al., 2000; Hariri, Bookheimer, & Mazziotta, 2000; Urry et al., 2006). Neuroimaging studies in adults indicate that sleep restriction leads to greater amygdala response to negative emotional stimuli (Sterpenich et al., 2007) and that following sleep deprivation adults have weaker connectivity between the amygdala and the medial PFC (Yoo, Hu, Gujar, Jolesz, & Walker, 2007), resulting in problems moderating emotional responses. Similarly, we found that short sleep durations were associated with increased negative affective response and restricting sleep led to decreased ability to regulate emotional responses.

Based on this hypothesis, impairments in the more complex cognitive tasks such as working memory, executive attention, and divided attention are predicted. Our results partially support his hypothesis. In support of this hypothesis, both working memory (p = .009) and divided attention (p=.051) were impaired following sleep restriction in Study 2. However, executive attention was not affected by the sleep restriction protocol and neither executive attention nor working memory was correlated with sleep variables in Study 1. Our interpretation of this result was that there may have been specific task characteristics and/or participant characteristics that influenced the sensitivity of the task to sleep-related impairments.

The Controlled Attention Hypothesis

Supporters of this hypothesis suggest that monotonous and less engaging tasks are more severely affected by sleep restriction because greater levels of top-down control are necessary to sustain optimal performance on these tests. A proponent of this hypothesis might suggest that children had more difficulty regulating their emotions following sleep deprivation due to the requirement of top-down control of emotion. For example, Yoo et al. (2007) suggested that sleep deprivation increased negative emotions due to a failure of top-down, prefrontal control. Like the Neuropsychological Hypothesis, this hypothesis suggests that sleep loss would lead to increased emotional responses and more difficulty regulating emotions.

As noted by Pilcher et al. (2007), a person's ability to maintain attention is necessary to successfully complete many different types of tasks. Supporters of the controlled attention model believe that tasks that encourage high attentive behaviour (strong task engagement) would be affected least by sleep restriction. However, in contrast, our results suggest that the ANT-I, which was a monotonous and less engaging task, was not affected by sleep restriction. Perhaps a moderate amount of task engagement is necessary for a task to be sensitive to the effects of sleep restriction. The results of this dissertation do not provide substantial support for this hypothesis.

Summary of Theoretical Perspectives

Support for and against all of these hypotheses can be found in the literature. At this point, due to the inconsistencies in the adult literature, there is not a coherent theory that fully explains the role of sleep in daytime functioning. Furthermore, given the limited pediatric research in this area, these hypotheses should be used to help guide how we think about these issues in pediatric populations.

The extent to which sleep restriction affects daytime functioning likely depends on several factors such as a general decline in vigilance, the degree to which cognitive functions depend on emotion-processing networks, and the specific cortical regions involved in the cognitive processes (Killgore, 2010). We interpret the current literature and our findings as indicating that a certain level of task engagement is required for a task to be sensitive to sleep restriction. Performance on tasks that meet, but do not exceed this level, will be vulnerable to impairments due to decreased vigilance. Additionally, tasks that meet the necessary level of task engagement and require the greatest PFC involvement are likely to be the most vulnerable.

Clinical and Societal Implications

This dissertation demonstrated that children are not getting the amounts of sleep recommended and that poor sleep impairs various aspects of emotional and cognitive functioning. The high prevalence of poor sleep and multitude of negative consequences make it especially concerning that as a society we do not place more value on sleep. In order to reduce inadequate sleep and its resulting negative effects, it is important to improve awareness of developmentally appropriate sleep and healthy sleep habits.

Educating children, parents, and professionals on the topic of sleep should involve encouragement of healthy sleep habits and discouragement of unhealthy sleep habits. The literature has repeatedly demonstrated that the use of technologies prior to bedtime, electronics in the bedroom, and caffeine have serious negative consequences on sleep quality and quantity. Furthermore, positive aspects of sleep hygiene such as having a consistent bedtime routine are related to longer sleep durations and better sleep (Mindell, et al., 2009). As children move toward adolescence, there are increasing biological and psychosocial influences that interfere with sleep (Dahl & Lewin, 2002), which are likely to further contribute to sleep problems. Thus, targeting children prior to adolescence and instilling healthy sleep habits prior to adolescence is likely to be beneficial. Gruber et al. (2011) recommended that initial efforts to educate the public be directed toward the education system. In fact, Gruber and colleagues are currently evaluating a program they are implementing in elementary schools in Quebec.

Additionally, education should lead to increased awareness and early identification of sleep problems, which can lead to effective treatment resulting in improved daytime functioning. The National Sleep Foundation's 2004 (National Sleep Foundation, 2004) poll results indicated that approximately 70% of parents of young children reported that their child had one or more sleep problems a few nights per week, but less than 15% reported this information to their pediatrician. In order to recognize and treat sleep problems, it is critical that parents and health care providers routinely discuss sleep issues. Additionally, children should be regularly screened for potential sleep problems, particularly children who have academic or emotional difficulties.

Strengths, Limitations, and Future Directions

This dissertation makes a significant contribution to the literature examining sleep and daytime functioning in children. This investigation has a number of strengths, including: (1) use of actigraphy to provide objective measures of sleep in an ecologically valid environment; (2) it is the first study to examine the effects of moderate, cumulative sleep restriction on emotion regulation and affective response in children; (3) use of objective measures of cognitive performance to examine specific domains of cognitive functioning (i.e., memory and attention); (4) moderate manipulation of sleep to mimic sleep changes that often occur spontaneously in children's everyday life; and (5) use of a within-participant design to avoid problems related to between-group research designs.

The effects of sleep on daytime functioning in children has been largely neglected to date and there are many exciting possibilities for future research. Additional studies are needed to address limitations of this investigation. First, we used subjective measures to assess sleepiness and emotional functioning. In future studies, conclusions reached could be strengthened by adding objective (physiological) measures to assess these functional areas, such as the MSLT to assess sleepiness, and blinded, systematic coding of facial expression to assess emotional status.

The issue of multiple comparisons and experiment-wise errors is important to consider. In Study 1, a stringent alpha was used in order to reduce experiment-wise errors. In Study 2, however, no corrections were made for multiple comparisons, but these concerns were tempered by the fact that many of the same significant differences were identified using multiple independent measures (i.e., parent-, child- and RA-reported sleepiness). Future researchers should carefully consider the number of dependent variables in relation to their sample size to reduce the experiment-wise error rate.

Many studies examining the effects of sleep restriction in pediatric populations have included relatively small sample sizes. Given the variability in task performance as well as interindividual variability in sensitivity to sleep loss, it will be important for future studies to include large sample sizes. Furthermore, the variability described above also provides support for conducting within-participants designs. Such designs require greater commitments from families, but reduce the between-group variability. It is also important to note that although this dissertation consisted of two studies, the participants in the two studies were the same children.

A study that follows a similar protocol to that of Study 2, but additionally has a week of typical sleep to which participants are randomly assigned, would reveal whether such results are deficits due to sleep restriction, improvements due to sleep extension, or a combination of both. Such studies may also help us to estimate how much sleep children need. For example, comparison of the typical sleep week to the extended sleep week could answer questions regarding whether more sleep leads to improved daytime functioning. Such studies are challenging, however, as they require an additional visit to the laboratory, placing even greater demands on participating families.

Varying the methods of altering sleep will be an important area of future exploration. For example, examination of the effects of experimental sleep fragmentation on children’s daytime functioning is an intriguing area of future research. Other studies should compare whether spreading sleep restriction across multiple nights results in similar impairments compared to limiting the sleep restriction to one night.

Future research should examine how reduced sleep affects children with varying conditions. In particular, children with emotional, learning, and attention problems may be especially vulnerable to the effects of sleep restriction. Aside from Gruber et al. (2011) who examined the effects of sleep restriction in children with ADHD, pediatric sleep restriction studies have focused on TD children.

Conclusions

Sleep loss is a common condition in our society (Pilcher & Huffcutt, 1996; National Sleep Foundation, 2004). Unfortunately, there is now overwhelming evidence that this is not only true for adults, but for children as well. Furthermore, evidence is mounting to suggest that sleep restriction in the pediatric population has marked negative effects. This dissertation makes a significant contribution to the literature examining sleep and daytime functioning in children. Results revealed that inadequate quantity and quality of sleep are associated with various impairments in daytime functioning including increased sleepiness, decreased positive affective response, increased negative affective response, and deficits in memory and attention.

This dissertation revealed concerning associations between sleep and daytime functioning in a relatively homogenous group of well-functioning children. Furthermore, it demonstrated that a moderate amount of sleep restriction over just a few days impaired aspects of some measures of emotional functioning, memory and attention. The high prevalence of poor sleep and the multitude of negative consequences emphasize the need for increased public awareness about the importance of sleep and the value of early identification and treatment of sleep problems.

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