Relationship between Sleep and Obesity among Children in the Guelph Family Health Study

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ABSTRACT

RELATIONSHIP BETWEEN SLEEP AND OBESITY AMONG CHILDREN IN THE GUELPH FAMILY HEALTH STUDY

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The purpose of this study was primarily to examine the cross-sectional and longitudinal associations between sleep measures (duration, quality, and variability) with markers of obesity risk (BMI, BMIz, waist circumference, body composition and blood pressure) among child participants in the Guelph Family Health Study. Additionally this study aimed to examine the extent to which children participants who receive the Guelph Family Health Study intervention improve their sleep quantity, quality and variability, compared to a control group. Sleep was measured using wrist Actigraphy for 2-7 nights. There were 46 and 30 participants included in the primary and secondary objective respectively. Children were between the ages of 18 months and five years old and the majority identified as Caucasian. Results showed no significant associations in the cross-sectional analyses between sleep measured and markers of obesity risk. In the longitudinal analyses, increases sleep efficiency from baseline to 6-months were associated with lower BMI z-scores at 6-months and lower sleep variability was associated with lower BMI and BMI z-scores at 6-months after adjusting covariates. Greater decreases in sleep variability were also associated with lower waist circumference at 6-months however this association did not remain after adjusting for covariates. In the secondary objective, no significant associations were found between intervention groups with regard to sleep measures. This study provides preliminary evidence suggesting an important role of sleep quality and sleep variability as predictors of obesity risk in preschool children.
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List of Abbreviations

BIA = Bioelectrical Impedance Analysis
BMI = Body Mass Index
BMIz = Body Mass Index Z-Scores
BP = Blood Pressure
CAM = Cardiac Autonomic Modulation
CI = Confidence Interval
CRP = C-Reactive Protein
EEG = Electroencephalogram
FM = Fat Mass
GEE = Generalized Estimating Equations
GFHS = Guelph Family Health Study
WHO = World Health Organization
HV = Home Visit
LDL = Low-Density Lipoprotein x
MVPA = Moderate to Vigorous Physical Activity
PA = Physical Activity
PYY = Peptide YY
REM = Rapid Eye Movement
SES = Socioeconomic Status
WASO = Wake After Sleep Onset
WC = Waist Circumference
1.0 Introduction

While research has shown a decreasing trend in sleep duration in the general public in recent decades, less is known about sleep trends in younger children (Matricciani et al., 2012; Jean-Louis et al., 2014). Identifying these trends is important because sleep impairments have been associated with negative health outcomes such as obesity, diabetes and cardiovascular disease (Meier-Ewert et al., 2004). Although limited, there has been research conducted which suggests that sleep and obesity are associated in preschool children (See Tables 1 & 2). The underlying mechanism responsible for the relationship between sleep and obesity is unclear. Hormonal changes in leptin and ghrelin (Spiegel Tasali, Penev & Van Cauter, 2004), environmental influences (Nedeltcheva et al., 2009) and the role of cytokines (Vgontzas et al., 2004) and circadian rhythms (Markwald et al., 2013) have all been associated with the sleep and obesity relationship in adult samples.

The association between sleep quantity and BMI is the most widely studied relationship in the literature. Several studies have identified cross-sectional and longitudinal relationships between parent-reported short nighttime sleep duration and higher BMI in preschool children (See Table 1). Limitations to these studies are that none have been conducted in the Canadian context and none have used objective measures of sleep such as Actigraphy. In addition to sleep quantity, sleep quality (Mamun et al., 2007) and sleep variability (Kjeldsen et al., 2014) have also been associated with obesity and weight status in children. Research involving sleep quality and sleep variability are less common because these measures are more difficult to assess through parent report. Furthermore, because childhood obesity has been correlated with sleep problems, it has been recommended for obesity prevention and intervention studies to target sleep (Kuhl, Clifford & Stark, 2012). This approach has been shown to be effective in children.
(Dawson-McClure et al., 2014), however most obesity-related interventions focus on diet and physical activity alone.

To date, no Canadian study has observed the relationship between sleep and obesity in preschool children, therefore the present study addresses this gap as well as several other methodological limitations in the literature. The primary objective was to examine the cross-sectional and longitudinal associations between sleep measures (duration, quality, and variability) with markers of obesity risk (BMI, BMIz, waist circumference, body composition and blood pressure) among child participants in the Guelph Family Health Study. Sleep measures were assessed using wrist Actigraphy and obesity and weight status markers were assessed by the study coordinator and research assistants at the University of Guelph. It was hypothesized that in the cross-sectional analysis lower total sleep time, lower sleep efficiency and higher sleep variability will be associated with higher BMI, BMIz, waist circumference, blood pressure and fat mass. Furthermore, it was hypothesized that in the longitudinal analysis increases in total sleep time, increases in sleep efficiency and decreases in sleep variability from baseline to 6-months would be associated with lower BMI, BMIz, waist circumference, blood pressure and fat mass at 6-months.

The secondary objective was to examine the extent to which child participants who receive the Guelph Family Health Study intervention improve their sleep quantity, quality and variability, compared to a control group. It was hypothesized that greater improvements in sleep quantity, quality and variability would be seen in participants receiving the Guelph Family Health study intervention, compared to participants in the control group.

The following section provides a comprehensive review of the literature surrounding the relationship between sleep and obesity in preschool children including: Sleep recommendations
and their importance in children, types of sleep, how sleep and obesity have been associated in the literature, suggested mechanisms responsible for this relationships, and how sleep has previously been incorporated in obesity interventions.
2.0 Review of the Literature

2.1 Importance of Sleep

Sleep is important as it allows the body to go through several essential physiological processes. The mechanisms of the sleep-wake cycle encompass a combination of sleep homeostasis and circadian rhythms (National Sleep Foundation, 2011). These two influences control conditions such as blood pressure, body temperature, acid-base balance, and hormone levels. Therefore, inadequate sleep can impair the restorative processes the body goes through during sleep. Consequences of inadequate sleep or impaired sleep could include impaired memory and attention, motor and emotional control, and immune and endocrine function (National Sleep Foundation, 2011). Negative health outcomes associated with these impairments include chronic diseases such as obesity, diabetes and cardiovascular disease (Meier-Ewert et al., 2004).

2.2 Sleep Recommendations

The National Sleep Foundation has recently updated their recommendations for sleep duration across all ages, based on a multidisciplinary expert panel and systematic literature review (Hirshkowitz et al., 2015). It is recommended that toddlers (children between 1 and 2 years old) and preschoolers (children between 3 and 5 years old) sleep between 11 to 14 hours and 10 to 13 hours per 24 hour period, respectively (Hirshkowitz et al., 2015). New additions to these recommendations include ranges which “may be appropriate” for each age group to acknowledge individual variation in sleep durations. For toddlers the additional ranges which may be appropriate are shorter durations of 9-10 hours and longer durations of 15-16 hours. For preschoolers the additional ranges which may be appropriate are shorter durations of 8-9 hours and longer durations of 14 hours. Durations outside of these ranges are “not recommended”
because they have been associated with adverse health outcomes (Hirshkowitz et al., 2015). In adults, both short and long sleep durations have been associated with adverse health outcomes such as type 2 diabetes (Cappuccio, D’Elia, Strazzullo, & Miller, 2010a), early mortality (Cappuccio, D’Elia, Strazzullo, & Miller, 2010b), and weight gain (Chaput, Despres, Bouchard, & Tremblay, 2008).

Along with sleep duration, another important area of sleep research includes sleep quality. Sleep quality is not clearly defined, however it extends beyond the quantity of sleep to encompass parameters such as nighttime awakenings (how many times and for how long an individual wakes during the night), sleep initiation (what time an individual falls asleep), sleep efficiency (the proportion of total time in bed to total time spent sleeping), wake after sleep onset (or WASO, total time spent awake after sleep initiation), and latency (time between getting into bed and falling asleep). There are currently no standards or recommendations for sleep quality measures and research exploring sleep quality, particularly among children, is limited. However, researchers hypothesize that the quality of one’s sleep will influence sleep duration (Hirshkowitz et al., 2015). Interestingly, in a sample of 523 children (6 to 12 years old) longer Actigraphy-measured sleep duration was not associated with higher sleep quality (Michels, Verbeiren, Ahrens, De Henauw, & Sioen, 2014).

Additionally, sleep variability is another sleep parameter which has been measured and associated with obesity risk in the literature. Sleep variability is most often measured with regards to variability in sleep duration, measured using intra-subject standard deviation. Variability in other sleep variables, such as sleep quality variables has also been explored. A higher sleep variable standard deviation is representative of greater night-to-night variability in that sleep variable.
2.3 Sleep Trends and Habits

There is growing evidence suggesting that people are sleeping less than previous generations. Evidence to support this claim in adults is substantial, although there is limited and somewhat conflicting evidence available for younger children. Jean-Louis et al. (2014) used results from the National Health Interview Survey to confirm that self-reported sleep duration has decreased in adults over 18 years from 1977 to 2009. There is also evidence that sleep duration has decreased by 0.75 minutes per year over the past hundred years in children between 5 and 18 years from nations across the globe (Matricciani, Olds, & Petkov, 2012). Furthermore, a study in Switzerland observing sleep trends in sleep duration in children between 1 and 16 years old across three birth cohorts from 1974 to 1993 revealed a decreasing trend in sleep duration across cohorts (Iglowstein, Jenni, Molinari, & Largo, 2003). Interestingly, this trend was most prominent in infants and younger children and was attributed to later evening bedtimes.

Although most of the literature suggests a decline in sleep duration in past decades, there is also evidence to support the contrary. For example, Hofferth (2009) described that children aged 6 to 12 years experienced an increase by 2% in sleep duration from 1997 to 2003, based on a United States representative sample from the Panel Study of Income Dynamics.

Declining sleep duration has been attributed to several lifestyle factors (Pollock, 1993). Much attention has been placed on the role of televisions, computers and other electronics on children’s sleep. Of particular significance is a Canadian cross sectional study by Chaput et al. (2014), which concluded that in children 9 to 11 years old, the presence of more electronic screens in a child’s bedroom was significantly inversely associated with actigraphy measured sleep efficiency (but not duration), and directly associated with higher BMI z-score, waist circumference and percent body fat. Furthermore, in early life parental influences can be
particularly important on development healthy sleep-wake patterns. Jiang et al. (2009) show that Chinese children between 3 and 4 years were more likely to have shorter sleep duration if they had primary caregivers who slept later or less. Additionally, variability in bedtime and its association with socioeconomic status and parents’ work schedules may also be significant in influencing sleep-wake patterns of younger children. Acebo and colleagues found that children whose parents hold occupations with irregular hours and those with fluctuating social and financial pressures may experience more nighttime variability in sleep patterns (Acebo et al., 2005).

2.4 Sleep Measurement

Sleep can be measured in several ways. Polysomnography is the gold standard of sleep assessment, and involves overnight monitoring of the brain and body by an electroencephalogram (EEG) test. This test can track an individual’s cycle through the sleep stages (REM and nonREM) and identify any disruptions in one’s sleep (National Sleep Foundation, 2014). Because this test monitors brain activity directly, it is currently the most accurate measure of sleep behaviour. However, a key limitation of this technique is that it must be performed in a lab, therefore removing the individual from his or her typical sleeping environment. This can be particularly problematic for studies involving children where the objective is to compare what time they went to bed versus what time they fell asleep. The typical bedtimes and wake up times in a lab may not reflect the childrens’ home environment. A second limitation of this technique is that it is costly and requires a specialist; therefore it can be impractical for use in studies involving many participants. Third, polysomnography would not capture any daytime naps children may have. Video monitoring of childrens’ sleep is another method of assessing sleep behaviour, however this method also would exclude daytime naps.
Additionally, video monitoring involves complex data analysis including subjective judgment of whether or not a child is sleeping. Neither polysomnography nor video monitoring have been used to assess sleep in existing research involving children less than 5 years old (See Table 1).

Another method of assessing sleep behaviour is accelerometry. This method identifies sleep/wake activity through wear of a wrist, hip or ankle accelerometry device that measures an individual’s body motion. This technique is more time and cost effective as compared to polysomnography and videosomnography because several participants can wear the activity monitors at the same time for several days in a row. Furthermore, these devices can be worn in the participants’ home environment; therefore their activity results will more accurately reflect their usual daily and nightly sleep behaviours compared to polysomnography. A specific kind of accelerometry is Actigraphy which is used in the context of sleep measurement. Actigraphy is the term that will be used throughout this thesis. As outlined in Table 1, two studies examining the sleep-obesity relationship in children under 5 years old used Actigraphy to measure sleep (Carter, Taylor, Williams, & Taylor, 2011; Klingenberg, 2012). However, sleep duration was the only variable assessed in these studies, even though Actigraphy has the capability to measure other variables such as bedtime, wake time, and sleep quality parameters. Several other studies in older children have used Actigraphy to measure sleep in relation to obesity risk markers and are further explained in the next section. For example, a cross sectional study in Ottawa, Canada by Chaput et al. (2014) observed the relationship between the presence of electronic screens in childrens’ (ages 9-11 years) bedrooms and sleep and markers of obesity risk. Sleep was measured using Actigraphy and results showed that the presence of screens was associated with higher adiposity and lower sleep efficiency but not sleep duration. These results highlight the importance of objectively measured sleep for assessment of sleep quality in addition to sleep.
duration, to capture a more comprehensive assessment of children’s sleep. Actigraphy-measured sleep in children under 5 years old also has limitations. First, although actigraphy is more cost effective than polysomnography when conducting larger scale studies, it is still more expensive than questionnaires (discussed below) and therefore is not used widely in larger scale, longitudinal studies (Chen, Beydoun, & Wang, 2008). Additionally, actigraphy has not been used extensively in the pediatric population, especially in children younger than 5 years old, therefore there are currently no practice standards with regards to recording and scoring sleep parameters (Meltzer, Montgomery-Downs, Insana & Walsh, 2012). Consequently, there is little consistency across the pediatric literature with regards to actigraphy practices. A review of the use of actigraphy in the pediatric population by Meltzer et al. (2012) identified that across studies there is a consistent report of high sensitivity (correctly identifies sleep) and low specificity (correctly identifies wake). Consequently, the authors suggest proceeding with caution with using actigraphy to measure wake after sleep onset in this population. Included in this same review are concerns about the validation of scoring methods, specific sleep variables and algorithms because of the scarcity of literature available in the pediatric population.

Questionnaires and sleep diaries are other methods of sleep assessment used to measure sleep duration and quality. This method is even more cost-effective than actigraphy because they can be widely distributed to many participants. However, there are several limitations in using questionnaires and sleep diaries to measure sleep in young children. First, when children are too young to report for themselves, parents typically report their children’s sleep. Several studies have shown that compared to actigraphy-measured sleep, parent-reported sleep under or over reports certain sleep parameters. For example, Kushnir and Sadeh (2013) examined how well actigraphy and parent reported sleep correspond among children between 4 and 6 years old.
Results showed that compared to actigraphy, parents reported earlier sleep onset times and overestimated children’s total sleep duration. Additionally, parents also underestimated the number of times children were waking up in the night in comparison to actigraphy. Similarly, Lam, Mahone, Mason and Scharf (2011) examined the consistency and agreement between actigraphy and parent log and attempted to determine if one method is preferable for specific types of sleep parameters. Findings indicated that parents overestimated nighttime sleep duration and sleep offset times and underestimated nighttime awakenings compared to actigraphy. Interestingly, results did not show significant differences between parent reports and actigraphy measures of weekend nap duration, suggesting that parent reports may accurately capture children’s napping behaviour (Lam et al., 2011). In addition to potential inaccuracy due to parental reporting, another limitation in using questionnaires or sleep diaries to measure sleep is the associated participant burden. Furthermore, across the literature there are many different questionnaires and sleep logs that have been used and not all are validated for use in the pediatric population. Consequently, comparison between studies is challenging.

2.5 Obesity and Types of Sleep

2.5.1 Sleep Duration and Obesity in Children

Due to ethical reasons involving sleep restriction in children, there has been limited experimental research studying the impact of different sleep conditions and obesity risk outcomes among children. There is growing literature exploring the relationship between sleep and obesity among children using cross-sectional and longitudinal approaches, however this area of research is still limited in children under 5 years old and measures of sleep and obesity risk are mostly limited to self-report (or parent report) and BMI, respectively. Table 1 summarizes the
limited available research and suggests a positive relationship between short sleep duration and obesity in children under 5 years old.

The majority of research exploring the association between sleep and obesity has been cross-sectional. Several reviews of cross-sectional studies have identified a significant direct association between short sleep duration and obesity risk measures in children. Table 2 outlines several reviews demonstrating a relationship between sleep and obesity in children. A Canadian study observing children 5 to 10 years old by Chaput, Brunet and Tremblay (2006), found that, compared to children who reported sleeping 12-13 hours a night, those that reported sleeping between 10.5-11.5 hours were 1.42 times more likely to be overweight/obese (using BMI as a measure of overweight/obesity status) and those that slept between 8-9 hours were 3.45 times more likely to be overweight or obese. In addition to sleep duration, this study also examined the relationships between other potential risk factors of obesity including familial income, parental education, parental obesity, physical inactivity, and TV watching. Results showed that short sleep duration was the most significant predictor of obesity (Chaput et al., 2006). In another Canadian study, Chaput et al. (2011) used actigraphy to assess sleep duration in children 8-10 years old and found a U-shaped association between sleep duration and BMI z-scores, body fat, weight and waist circumference. In other words, both short (less than 10 hours of sleep) and long (greater than 12 hours of sleep) sleep were associated with obesity markers, however only short sleep duration remained significantly associated with obesity markers after adjustment for covariates. A study specifically looking at children between 3 and 4 years old, in China, found that children, who slept less than 9.4 hours per night, were more likely to be obese (using BMI as a measure of obesity status) than children who slept greater or equal to 11 hours, based on parental reports of sleep duration (Jiang et al., 2009). In Japan, Sekine et al. (2002) identified a
dose response relationship between sleep and duration and obesity in children 2-4 years old. Using BMI as a marker of obesity, results showed that compared to children sleeping 11 hours or more, parent reported sleep duration of 10-11, 9-10 and less than 9 hours were at an increased odds of obesity with odds ratio of 1.20, 1.34, and 1.57 respectively (Sekine et al., 2002).

Similarly, a US national study of 8550 four year old children demonstrated that children who experienced greater than 10.5 hours of sleep per night (mother-reported), were less likely to be obese (classified by BMI). Von Kries and colleagues (2002) looked at both BMI and fat mass in relation to sleep duration in 6862 five to six year old children in Bavaria, Germany. They identified a cross-sectional relationship between sleep duration and obesity at body fat. Specifically, they found that children who slept longer than 10.5 hours had less than half the risk of being obese or having high body fat (von kries et al., 2002).

In addition to cross-sectional research, there is also longitudinal evidence of a relationship between sleep and obesity in children. Several reviews have been conducted to summarize the available longitudinal literature on the temporal development of the relationship between sleep and obesity risk in early childhood through adolescence and adulthood (See table 2 for an outline of existing reviews). Fatima, Doi, and Mamun (2014) performed a systematic review and meta-analysis of prospective associations between short sleep and overweight and obesity in children and adolescents. Results from the meta-analysis revealed that children and adolescents who sleep for a shorter duration have approximately twice the odds of becoming overweight or obese compared with those who sleep for a longer duration. Furthermore, younger children (0.5-2.5 years old at baseline) were shown to be at greater risk, compared to older children (6-10 years old at baseline). This review found that 19 of the 22 included studies measured sleep by self or parent report and BMI was the only measure used to assess obesity.
risk. Additionally, a review by Liu, Zhang and Li (2012) shows the relevance of sleep in early childhood and risk of obesity and overweight development in later childhood. All four longitudinal studies included in this review reported a significant association between short sleep duration and later obesity or overweight status. Of these longitudinal studies, 3 used parent or self-report to assess sleep and 3 used BMI as the only measure of obesity risk. Noteworthy is a national USA longitudinal study by Bell and Zimmerman (2010), which found that children 0-4 years old with short sleep duration (parent-reported) at baseline were 1.80 times more likely to become overweight or obese at 5-9 years old, compared to those with longer sleep durations. This prospective association was not found in children 5-13 years old at baseline, with a follow-up five years later. Therefore, these results suggest that the time prior to 5 years old is a critical window when nighttime sleep is especially important for overweight and obesity prevention (Bell & Zimmerman, 2010). Similarly in another longitudinal study by Snell, Adam and Duncan (2007), sleep timing and sleep duration were observed in relation to BMI in children 3-12 years old at baseline, and then at 5-year follow-up. Results showed that self or parent-reported shorter sleep duration, later bed times and earlier wake-up times were all associated with higher BMI and increased odds of being overweight at follow-up. Interestingly, these associations were stronger for younger children (3-7.9 years at baseline) compared to older children (8-12.9 years at baseline) (Snell et al., 2007). A recent longitudinal study conducted in Massachusetts showed somewhat conflicting results. Taveras et al. (2014) followed children from infancy until age 7 measuring maternal reported sleep duration and markers of obesity including BMI Z-score, fat mass, and waist and hip circumference. Results showed that there were consistent associations between sleep curtailment and markers of obesity through infancy, early-, and mid-childhood. These results contrast previous work suggesting that there is a critical window prior to 5 years
old by showing that sleep curtailment across childhood may be a significant risk factor for becoming overweight or obese. However, the study by Taveras et al. (2014) only measured children up to age 7, so were unable to compare how this association may differ for older children.

Conversely, Klingenberg and colleagues (2013) found no associations in a study observing both the cross-sectional and longitudinal relationship between sleep duration and markers of obesity in Danish children. Parent reported sleep duration measures were taken at 9 months, 18 months and 3 years. Additionally, sleep duration was also measured by Actigraphy at 3 years. Obesity markers measured at each time point include body composition, BMI z-score, triceps skin-fold and subscapular skin-fold. No longitudinal associations were found between sleep duration and obesity markers. Additionally, there were no cross-sectional associations found between sleep duration and obesity at the 3-year time point. Although no significant associations were found in this study of young Danish children, there is still a possibility of short sleep duration having a longer-term effect on adverse obesity markers (Klingenberg et al., 2013).

### 2.5.2 Sleep Quality and Obesity in Children

As previously discussed, sleep quality is another sleep parameter studied in relation to obesity risk in the literature. However, less is known about the relationship between sleep quality compared to duration, because sleep quality is more accurately assessed through more objective measures of sleep such as Actigraphy. While measures of sleep quality vary, a common measure is sleep efficiency which represents the percentage of time spent asleep to the time spent in bed. McNeil et al. (2015) suggests that sleep quality rather than sleep quantity, may be more strongly linked to obesity risk. McNeil et al. (2015) used Actigraphy to measure sleep duration and quality in 9-11 year old children and found that only poor sleep efficiency was inversely
associated with weight, waist circumference, percentage body fat, BMI z-score and waist to height ratio. In another Actigraphy-measured sleep study, Gupta, Mueller, Chan and Meininger (2002) observed the cross-sectional relationship between total sleep time and sleep disturbance (used as a measure of sleep quality) with obesity with BMI and percent body fat. Results showed that in this sample of 11-16 year old children (n=383) sleep disturbance was not directly associated with obesity, but was directly associated with physical activity. Specifically, physical activity decreased by 3% for each hour increase in sleep disturbance. Therefore, these results suggest a possible indirect relationship between sleep quality and obesity in adolescents. In a longitudinal study in Brisbane, Australia by Mamun and colleagues (2007), sleep problems in early life (6 months and 2-4 years) were observed in relation to BMI at 21 years. Sleeping difficulties were measured through a parent-reported questionnaire. Results showed that among the 2494 participants, those who experienced sleep difficulties at age 2-4 years were more likely to be obese or have a higher BMI at age 21.

Contrastingly, Martikainen et al. (2011) observed the cross-sectional relationships between sleep and cardiovascular function in 8 year old children and found no significant associations. This study measured sleep quantity and quality (sleep efficiency) using Actigraphy and measured cardiovascular function by blood pressure and cardiovascular reactivity (assessed using a psychosocial stress test).

### 2.5.3 Bed Timing and Sleep Variability and obesity in Children

In addition to sleep duration and quality, bed timing has also been associated with adverse obesity measures. Golley, Maher, Matricciani and Olds (2013) observed the cross-sectional relationship between self-reported sleep timing and BMI in children between 9 and 16
years. Results showed that children who went to bed later and woke up later had higher BMI scores than those who went to bed earlier and woke up earlier.

Sleep variability has also been measured in the literature with regards to obesity related markers and behaviours. First, two studies have observed the association between sleep variability and certain eating behaviours. Kjeldsen et al. (2014) examined the relationship between sleep variability and dietary risk factors for obesity in a sample of 676 children between 8 and 11 years old in Denmark. A sleep variability score was calculated for each participant from the mean sleep duration and the number of days measured. Sleep behaviour was measured using waist actigraphy for 8 nights and diet was measured using a web-based Dietary Assessment Software for Children. Results showed that sleep duration variability was positively associated with intake of sugar-sweetened beverages (p=0.03). This association was maintained even after adjusting for age, sex, pubertal status, height, weight, screen time, moderate-to-vigorous PA, highest education of the parents, the number of parents born in Denmark and sleep duration (Kjeldsen et al., 2014). In a similar study conducted in adolescent participants, He et al. (2015) examined the relationship between sleep variability and energy and snack intake. Sleep was measured using wrist actigraphy for 7 nights and a food frequency questionnaire was used to assess daily average total energy, protein, fat, and carbohydrate intake and number of snacks consumed. Results showed that higher sleep variability was associated with increased caloric intake, total fat intake, total carbohydrate intake and higher snack consumption. Furthermore, this study also measured sleep duration and found no significant associations between sleep duration and energy or snack consumption (He et al., 2015).

Also in adolescents, Rodriguez-Colon et al. (2015) examined the association between sleep patterns and cardiac autonomic modulation (CAM; a risk factor for cardiovascular disease)
in the United States. Sleep duration variability and sleep efficiency variability were measured using wrist actigraphy for 7 days. CAM was measured by heart rate variability, with a lower heart rate variability representing a greater risk for cardiovascular disease. Results showed that both increased sleep duration variability and sleep efficiency variability were associated with lower heart rate variability and higher heart rate (Rodriguez-Colon et al. 2015). Consequently, these results suggest an important role of a regular sleep pattern in preventing cardiovascular disease risk in an adolescent population. In another cross-sectional study, Spruyt, Molfese and Gozal (2011) examined the effects of sleep duration regularity on BMI and metabolic regulation in a sample of 308 American children between 4 and 10 years old. Sleep was measured using wrist actigraphy for one week and blood glucose, insulin, lipids and C-reactive protein (CRP) were used to measure metabolic regulation. Results showed that obese (BMI>1.65) children showed more variability in sleep duration on weekends compared to school days. Additionally, higher sleep duration variability was associated with altered insulin, and low-density lipoprotein (LDL) and CRP in overweight (BMIz>1.04) children.

The current gap in the literature surrounding sleep variability in children, is that there have not been any studies directly observing the relationship between sleep variability in children younger than 5 years old and markers of obesity commonly measured in other sleep related studies such as BMI, waist circumference and body composition.

2.5.4 Significance of Napping in Children

In addition to nighttime sleep duration and sleep quality, there is also limited research exploring the role of napping and obesity risk among children younger than 5 years old and results are inconsistent. In a longitudinal study by Touchette et al. (2008), the associations between sleep patterns (parent-reported questionnaire) at 2.5 years old and BMI at 6 years old
were examined in a sample of Canadian children. Results showed that napping at 2.5 years was not significantly associated with subsequent obesity at age 6. In another longitudinal study by Bell and Zimmerman (2010) in the United States, results showed that parent-reported napping at 0 to 4 years old was not associated with subsequent obesity five years later. The third study was a cross-sectional study in China, which explored the association between nap duration and obesity in children between 3 and 4 years old (Jiang et al. 2009). Napping was measured using a parent reported questionnaire and obesity was measured by BMI. Results did not show a significant associated between napping of any duration and obesity (Jiang et al. 2009). Conversely, a study by Agras, Hammer, McNicholas and Kramer (2004) found that children between 3 and 5 years old who slept (parent-reported sleep), over a 24-hour period, 30 minutes less were more likely to become overweight at 9.5 years old. The 30 minute difference was attributed to daytime sleep, because nighttime sleep only accounted for 5 minutes of the difference in sleep time (Agras et al., 2004).

There are several limitations based on the above review of the literature surrounding sleep and obesity risk in children. First, there is a lack of objectively measured sleep. Most studies use parent or self-reported methods of collecting information about participant’s sleep. Therefore, in most studies, sleep duration is the only sleep parameter assessed. Next, there are few studies that include participants younger than 5 years old. Therefore less is known about the sleep-obesity relationship in this age group. Additionally, the majority of studies exploring the sleep-obesity relationship use BMI and BMIz as the only measures of obesity risk. This limitation is significant because there is some evidence to support an association between inadequate sleep duration and/or quality and other markers of obesity, such as waist circumference and percentage body fat (McNeil et al., 2015). Furthermore, there are few studies
that have examined Canadian children therefore the extent to which results from other countries
may be relevant to Canadian populations is unknown. Finally, the current available research
exploring the sleep-obesity relationship is unable to confirm causation due to the lack of
experimental and longitudinal research. In other words, much of the current research is
observational in nature and focuses on the cross-sectional relationships between sleep and
obesity. Therefore, the temporal relationship between sleep and obesity is less understood.
Additionally, there has been very little experimental or intervention research exploring how the
manipulation of sleep variables could influence obesity over time.

2.6 Blood Pressure and Sleep in Children

There is limited literature supporting a relationship between sleep and blood pressure in
children and there have been no studies observing this relationship specifically in preschool
children. A cross-sectional study by Sung and colleagues (2008) observed the association
between parent-reported sleep duration and blood pressure among a sample of 14842 children
and adolescents in Hong Kong (ages 6-18). Results indicated that higher systolic and diastolic
blood pressure was associated with lower sleep durations in this sample. Similarly, a cross-
sectional study by Wells and colleagues (2008) observed this relationship among 4452 children
(ages 10-12 years) in Brazil and found a significant association between shorter sleep duration
and higher systolic blood pressure. Interestingly, Sampei and colleagues (2006) also identified a
significant association between higher systolic blood pressure and shorter sleep durations in 117
children 5-6 years old. These two studies suggest that sleep duration may affect systolic blood
pressure more significantly than diastolic blood pressure. In contrast, the cross-sectional study by
Martikainen did not find any significant associations between ambulatory-measured blood
pressure and sleep duration in their sample of 231 8-year old children. Therefore, to strengthen
the understanding of the relationship between sleep and blood pressure among preschool children, further studies observing the longitudinal nature of this relationship are necessary.

2.7 Proposed Mechanisms for Effect of Sleep on Obesity Risk Measures

Although there has been limited experimental research conducted with children regarding the relationship between sleep and obesity, numerous studies involving adult participants have been conducted to identify the mechanisms responsible for the sleep-obesity relationship. Chaput and Tremblay (2012) proposed three main pathways for how insufficient sleep can lead to weight gain and potential risk of obesity. These pathways include changes in homeostatic feeding behaviour, non-homeostatic (hedonic) feeding behaviour and physical activity. In addition to these hypothesized pathways, there is also evidence suggesting a role of cytokines (Santos, Tufik, & De Mello, 2012) and circadian rhythms in the sleep-obesity relationship (Bray & Young, 2007).

Homeostatic feeding behaviour and non-homeostatic feeding behaviours can result in weight gain by increasing energy intake. Homeostatic feeding behaviour refers to the up-regulation of hormones which are active in stimulating hunger and satiety. Changes in levels of hormones relevant to hunger and satiety may result in increased energy intake and subsequent weight gain. Specifically, leptin, ghrelin, cortisol and the orexin system have been studied with regards to sleep duration. Spiegel and colleagues (2004) examined the effects of two days of sleep restriction (4 hours of sleep per night) and two days of sleep extension on non-fasted plasma levels (blood samples obtained every 20 minutes from 8:00am to 9:00pm) of leptin and ghrelin in healthy men. Results showed that sleep restriction was associated with reductions in leptin and increases in ghrelin. These hormonal changes were also associated with increases in hunger and appetite ratings. Furthermore, in a similar study by Spiegel, Leproult and Van Cauter
(1999), the effect of 6 nights of sleep restriction (4 hours per night) versus sleep recovery (12 hours in bed), on metabolic and endocrine functions were examined in healthy men. Results showed that the sleep restricted condition had lower glucose tolerance, lower thyrotropin concentrations, higher evening cortisol concentrations, and higher sympathetic nervous system activity. These results are significant and relevant to the sleep-obesity relationship because decreased carbohydrate tolerance and increased sympathetic tone are risk factors for obesity. Furthermore, raised cortisol levels can be reflective of age-related insulin resistance. In contrast, several studies have been performed which have been unable to reproduce findings supporting a relationship between decreased sleep duration and changes in neuroendocrine hormones. For example, Magee, Huang, Iverson and Caputi (2009) investigated how two days of sleep restriction (5 hours of sleep per night) affected neuroendocrine hormone levels in healthy adult males. Results showed that compared to extended sleep (8-10 hours), sleep restriction was not significantly associated with changes in adiponectin, ghrelin, glucagon-like peptide 1, or leptin. Peptide YY (PYY) levels were significantly lower after sleep restriction, suggesting a possible role for PYY in the sleep-obesity pathway, however no other studies in humans have examined the effects of sleep on this hormone. Nedeltcheva et al. (2009) also found no effect of sleep restriction on leptin and ghrelin levels in healthy adults.

Contrary to homeostatic feeding is non-homeostatic or hedonic feeding which refers to the subjective desire to consume food, without energy deficit. This type of feeding is another pathway through which sleep is proposed to influence weight gain. This tendency to eat can be influenced environmentally and is not in response to physiological mechanisms controlling hunger and appetite (Lowe & Butryn, 2007). Nedeltcheva et al. (2009) propose hedonic hunger as a potential mechanism for the sleep-obesity relationship. Regardless of insignificant changes
in leptin and ghrelin, Nedeltcheva et al. (2009) showed that sleep restriction was associated with increased consumption of calories from snacks with higher carbohydrate content. This increase in energy intake is proposed to be due to increased exposure to the obesogenic environment because of the increased number of waking hours. The hedonic pathway was further supported in a study by Markwald and colleagues (2013), which examined the changes in energy and food intake associated with insufficient sleep in healthy adults. Results from this study show that insufficient sleep increased energy needs (by increasing energy expenditure), however food intake increased beyond what is necessary to maintain energy balance, therefore resulting in weight gain. Food intake increased despite appropriate increases in leptin and PYY and decreases in ghrelin. Spaeth, Dinges and Goel (2013) examined subsequent weight gain in addition to caloric intake and meal timing associated with sleep restriction and found that adults experiencing sleep restriction in a laboratory setting for five days gained significantly more weight than control participants. The resulting weight gain was attributed to an increase in caloric intake in the evening hours due to a later bedtime; supporting the proposition that decreased sleep duration may increase an individual’s exposure to the obesogenic environment.

The idea of greater exposure leading to increased caloric intake has also been observed in children ages 9-16 in a cross-sectional study by Golley et al. (2013), which identified that children who went to bed at a later time had a higher intake of energy-dense foods, compared to those who went to bed earlier. The resulting increases in energy intake associated with sleep restriction have also been related to changes in neuronal activity in response to food stimuli. For example, both St. Onge et al. (2012) and Benedict (2012) conclude that shorter sleep duration was associated with higher neuronal activity in response to food stimuli in adult samples.
The third pathway through which sleep is proposed to influence weight gain is through a decrease in physical activity and therefore a decrease in energy expenditure. This decrease in physical activity is proposed to be due to fatigue resulting from insufficient sleep, however evidence supporting this mechanistic route is weak (Chaput & Tremblay, 2012). In a study involving adolescents by Gupta and colleagues (2002), sleep quantity, sleep quality and physical activity were measured using actigraphy and results showed that physical activity during the day decreased by 3% for each one hour increase in sleep disturbance. Nedeltcheva et al. (2009), found no significant differences in energy expenditure (including activity energy expenditure, thermic effect of food, and resting metabolic rate), using the doubly labeled water technique, between overweight healthy adults sleeping 5.5 hours per night and 8.5 hours per night. Similarly, St. Onge et al. (2011) found no significant differences in total energy expenditure between short (4 hours per night) and habitual (9 hours per night) sleeping conditions for five nights. In contrast, as previously mentioned, Markwald et al. (2013), showed that sleep restriction compared to normal sleep was significantly associated with an increase in total energy expenditure by approximately 5%, measured in a whole room calorimeter. In sum, there is insufficient evidence to support a strong role of changes in energy expenditure in the sleep-obesity relationship.

In addition to the three pathways proposed by Chaput and Tremblay (2012) described above, there is also evidence of changes in cytokine levels and circadian rhythms which may also have mechanistic roles in the development of obesity or weight gain resulting from insufficient sleep. Vgtontzas et al. (2004) investigated the effects of sleep restriction from eight hours to six hours for one week on plasma levels of proinflammatory cytokines IL-6, TNF-alpha and cortisol. Results showed that after sleep restriction peak cortisol secretion was lower in the morning and
associated with an increase in 24-hour IL-6 secretion and an increase in 24-hour TNF-alpha secretion. It is notable that the increase in IL-6 secretion is similar to an increase observed after one night of complete sleep loss. IL-6 and TNF-alpha are biomarkers of systemic inflammation and increases in these cytokines may lead to insulin resistance, cardiovascular disease, obesity risk and osteoporosis. Finally, with regards to circadian timing, Markwald et al. (2013) found that those that wake earlier have a lower caloric breakfast than those that wake later. This could be due to the internal circadian clock among early risers promoting sleep, due to melatonin levels being high. Similarly, energy intake may have been higher at night when bedtime was later, due to a delay in melatonin onset. Higher melatonin levels are indicative of the biological night and therefore promote sleep.

Although the most well studied benefit of adequate sleep is to restore and maintain central nervous system function (Broussard, Ehrmann, Van Cauter, Tasali, & Brady, 2012), the above research suggests that sleep is also important in peripheral energy metabolism. However, there are several limitations to the mechanistic research surrounding sleep and obesity. First, much of the present research has examined sleep quantity, not quality, therefore the mechanistic relationship between sleep quality and obesity is less understood. Next, there is limited research in children and adolescent population, and most of the literature is cross-sectional in nature. Finally, the experimental studies examining effects of sleep measured acute physiological changes related to obesity, thus less is understood about the chronic effects of insufficient sleep.

2.8 Interventions to improve sleep habits in preschool children

Consistent with research focusing on associations between sleep measures and obesity risk, there have been few studies that have observed the effect of an intervention on improving sleep habits and the subsequent effect on obesity risk outcomes in children younger than five
years old. From the existing research, intervention studies which have targeted sleep and measured obesity risk outcomes in this younger population typically include sleep as part of a more comprehensive intervention program including diet and physical activity. Additionally, in most cases intervention studies that target sleep exclusively only measure change in sleep and do not measure change in obesity risk. Finally, much of the literature surrounding sleep interventions in children focuses on intervening once children have developed a sleep disorder or start experiencing sleep problems and few studies target sleep using a preventative approach.

In a systematic review by Kuhl, Clifford and Stark (2012), behavioural correlates of obesity were examined in preschoolers. Inadequate sleep was identified as a risk factor for obesity and therefore suggested to be included in obesity prevention interventions. Kuhl and colleagues (2012) explain how sleep hygiene improvement can be smoothly implemented into obesity prevention interventions through parent training in behavioural management. Suggested sleep hygiene behavioural management strategies include maintaining a regular sleep and wake schedule, having a bedtime routine, and removing televisions from the sleep environment. Additionally, establishing more general behavioural management strategies, for example positive reinforcement is recommended to support positive changes in sleep hygiene (Kuhl et al., 2012).

The acceptability and efficacy of an intervention study by Dawson-McClure et al. (2014) using a parenting and child behavioural intervention approach to prevent obesity was tested in children (average age 4.3). Children and their parents were recruited through six public elementary schools in low-income urban communities in New York City. A one-group pre-post test design was used to implement the program called “ParentCorps”. Previously the ParentCorps program was used more generally to improve parenting and help child behaviour regulation. Therefore this program was enhanced to focus on factors related to obesity risk, including physical activity,
diet and sleep. The program involved 14 weekly two-hour sessions over a 5 month period for parents with concurrent childcare available. The content of the program focused on health promotion including physical, social, emotional and behavioural regulation and each week featured a main topic. Results showed that post-intervention parent-reported sleep problems decreased from pre-intervention in the boys enrolled in the study. Several other health-related outcomes were improved at post-intervention including child nutrition knowledge, preference for physical versus sedentary activity, increased time spent walking and engaged in outdoor activities, and decreased television viewing. However, there were no significant changes in BMI or percent overweight from pre to post intervention (Dawson-McClure et al., 2014).

Another intervention study by Puder et al (2011) tested the effect of a school-based multidimensional lifestyle intervention on aerobic fitness and adiposity in 652 preschool children (72% migrants of multicultural origins) with an average age of 5.2 years. The design of the study was a cluster randomized single blinded trial called the Balabeina study which occurred over one school year in 40 preschool classes in Switzerland. The intervention program involved four components: physical activity, nutrition, media use and sleep. The curriculum changes in the intervention group involved workshops, lessons, home activities, extracurricular activities and environmental changes. As part of the intervention, students, teachers and parents were each targeted. Changes in child sleep duration were measured by parental report pre and post-intervention, however there were no significant changes in either the intervention or control group. Puder and colleagues (2011) speculate that the lack of change in sleep duration could be because the children were already experiencing sufficient sleep at baseline (only 5% slept less than 10 hours per night). Although there were no significant changes in sleep duration, there were positive changes seen in primary outcome measures in the intervention group including
increased aerobic fitness, increased motor agility, decreased percentage body fat, decreased waist circumference, increased physical activity, decreased media use, and improved eating habits (Puder et al. 2011).

In a home-based intervention study in Boston called “Health Habits, Happy Homes” Haines et al. (2013) explored the effect of a home-based intervention to improve household routines on the prevention of overweight/obesity in children 2-5 years old. The study included 121 children randomized to either the intervention (n=62) or control condition (n=59). The intervention group received an intervention comprising of motivational coaching, mailed educational materials and weekly text messages promoting eating meals as a family, obtaining adequate sleep, and limiting screen time. The control group received general child development education materials in the mail. Outcomes measured included: family meals, sleep quantity and screen time. A parent-reported survey was used to measure these outcomes. Results showed that compared to the control participants, children who received the intervention program had increased sleep duration, decreased TV time on weekends and decreased BMI.

In sum, the literature shows that few intervention studies targeting obesity risk include sleep as a targeted risk factor, even though there is evidence to support a relationship between sleep measures and obesity and overweight status in preschool children. Further research is needed to investigate the effectiveness of interventions to improve sleep habits in the preschool population.
Table 2.1: Summary of sleep-obesity research in children younger than 5 years old

<table>
<thead>
<tr>
<th>Author(s)</th>
<th>Location</th>
<th>Sample size (n)</th>
<th>Age</th>
<th>Study Design</th>
<th>Measures of obesity risk</th>
<th>Measures of sleep duration/quality</th>
<th>Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Taveras et al., 2014</td>
<td>Massachusett s, USA</td>
<td>1046</td>
<td>Recruited during pregnancy</td>
<td>Longitudinal</td>
<td>BMI z-score, dual X-ray absorptiometry total, trunk fat mass index, waist and hip circumference</td>
<td>Sleep scores calculated from mother-reported sleep duration</td>
<td>Children between 6 months old and 7 years old who had lower sleep scores (mother-reported) had higher BMI, trunk fat mass, waist circumference and hip circumference.</td>
</tr>
<tr>
<td>Bell &amp; Zimmerman 2010</td>
<td>USA national</td>
<td>1930</td>
<td>Baseline (1997): 0-59 months (n=822) &amp; 60-154 months (n=1108)</td>
<td>Longitudinal</td>
<td>BMI z-scores</td>
<td>Sleep scores calculated from parent-reported sleep duration</td>
<td>Younger children (0-59 months at baseline) – low nighttime sleep at baseline was associated with increased odds of overweight and increased odds of obesity at follow-up. Older children (60-154 months at baseline) – Contemporaneous sleep associated with increased odds of a shift from normal weight to overweight or overweight to obesity at follow-up.</td>
</tr>
<tr>
<td>Sekine et al., 2002</td>
<td>Japan</td>
<td>8941</td>
<td>2-4y</td>
<td>Cross-sectional</td>
<td>BMI z-scores</td>
<td>Parent-reported sleep duration, bedtime and wake time</td>
<td>Dose-response relationship between sleep duration and obesity: compared to children sleeping 11 hours or more, sleep duration of 10-11, 9-10 and less than 9 hours were at an increased odds of obesity with odds ratio of 1.20, 1.34, and 1.57 respectively.</td>
</tr>
<tr>
<td>Reilly et al. 2005</td>
<td>United Kingdom</td>
<td>909</td>
<td>4mo-5yr at baseline, 7yr at follow-up</td>
<td>Longitudinal</td>
<td>BMI z-scores</td>
<td>Parent-reported sleep duration</td>
<td>Children were more likely to be obese at age 7 if they were sleeping less than 10.9 hours compared to those sleeping greater than 12 hours at 30 months old.</td>
</tr>
<tr>
<td>Study</td>
<td>Location</td>
<td>Sample Size</td>
<td>Study Design</td>
<td>Variables</td>
<td>Findings</td>
<td></td>
<td></td>
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<tr>
<td>Snell, Adam, &amp; Duncan, 2007</td>
<td>USA national</td>
<td>2281</td>
<td>Longitudinal</td>
<td>BMI z-scores</td>
<td>Sleep diaries (parent-reported for younger children, child-reported with assistance for older children) – sleep duration, bedtime and wake time. Children who slept less, went to bed later or got up earlier at baseline had higher BMIs and were more likely to be overweight at follow-up.</td>
<td></td>
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</tr>
<tr>
<td>Klingenberg et al. 2012</td>
<td>Denmark</td>
<td>311</td>
<td>Cross-sectional and longitudinal</td>
<td>Body fat (DEXA), BMI z-score, triceps skin-fold and subscapular skin-fold</td>
<td>Parent-reported sleep duration at 9mo, 18mo and 3yr. Actigraphy measured sleep duration at 3yr. No significant associations found.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carter, Taylor, Williams, &amp; Taylor 2011</td>
<td>New Zealand</td>
<td>244</td>
<td>Longitudinal</td>
<td>BMI z-score (every year), bioelectrical impedance analysis (every year), dual energy x-ray absorptiometry (ages 5-7)</td>
<td>Actigraphy measured sleep duration (only measured at ages 3-5). Reductions in BMI and fat mass at age 7 were associated with longer sleep durations at age 3.</td>
<td></td>
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</tr>
<tr>
<td>Anderson &amp; Whitaker, 2010</td>
<td>USA national</td>
<td>8550</td>
<td>Cross-sectional</td>
<td>BMI</td>
<td>Mother-reported sleep duration. Odds of obesity were lower among those who experienced greater than 10.5 hours of sleep.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>von Kries et al., 2002</td>
<td>Bavaria, Germany</td>
<td>6862</td>
<td>Cross-sectional</td>
<td>BMI and fat mass</td>
<td>Parent-reported sleep duration. Children who slept longer than 10.5 hours had less than half the risk of being obese or having high body fat.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mamun et al., 2007</td>
<td>Brisbane, Australia</td>
<td>2494</td>
<td>Longitudinal</td>
<td>BMI</td>
<td>Parent-reported sleeping problems. Children with sleeping problems at 2-4 years were more likely to be obese and have a higher BMI.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 1.2: Summary of sleep-obesity research reviews that include children younger than 5 years old

<table>
<thead>
<tr>
<th>Author(s)</th>
<th>Number of Studies Included</th>
<th>Age</th>
<th>Study Design</th>
<th>Findings (In children)</th>
<th>Number of studies including children between 1-5yr</th>
</tr>
</thead>
</table>
| Fatima, Doi, & Mamun 2014 | Review: 11 | 0.5-18yr | Systematic review and meta-analysis of prospective associations between short sleep and overweight/obesity | - Children and adolescents who sleep for a shorter duration have approximately twice the odds of ow/ob compared with those who sleep for longer duration.  
- Adolescents are at higher risk compared to children. Younger children are at higher risk compared to older children.                                                                 | 13                                      |
| Cappuccio et al., 2008 | 30             | 2-102yr | Systematic review and meta-analysis of cross-sectional studies assessing relationships between short sleep duration and obesity | 7/11 studies (including children) reported a significant association between short sleep duration and obesity (pooled OR=1.89).                                                                                       | 1                                      |
| Liu, Zhang, & Li 2012 | 25             | 0-19yr  | Review of 25 cross-sectional evidence (between 2006-2011) of the relationship between sleep duration and overweight/obesity | All indicated significant associations between short sleep duration and childhood overweight/obesity.                                                                                                                     | 3                                      |
| Chen et al., 2008        | 17             | 0-19yr  | Systematic review and meta-analysis of 17 cross sectional cohort and case control studies looking at the relationship between sleep duration and obesity | Children with shorter sleep duration had a 58% (pooled OR=1.58 (1.26,1.98)) higher risk for overweight/obesity compared to children having longer sleep duration.  
Children with shortest sleep                                                                                                                  | 4                                      |
duration had a 92% higher risk compared to children having longer sleep duration.

Risk of overweight/obesity decreased by 9% for each hour increase in sleep.

<table>
<thead>
<tr>
<th>Study</th>
<th>Age Range</th>
<th>Study Design</th>
<th>Findings</th>
<th>Study Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hart &amp; Cairns, 2011</td>
<td>0-18yr</td>
<td>Systematic review of cross-sectional and longitudinal associations between sleep and obesity in children and adolescents</td>
<td>All studies identified a negative association between sleep duration and obesity risk, however results were not always significant across all categories of sleep, or for all genders.</td>
<td>11</td>
</tr>
</tbody>
</table>
| Marshall, Glozier, & Grunstein, 2008       | 3-102yr   | Review of cross-sectional and longitudinal associations between sleep duration and obesity | Cross-sectional: Negative association between short sleep duration and obesity or weight gain.  
Longitudinal: Shorter sleep duration at baseline is subsequently associated with obesity at follow-up. | 4          |
3.0 Rationale for the Current Study

Understanding the risk factors for childhood obesity is important because it can help guide interventions and policy changes targeting the obesity problem. Decreased sleep duration has been associated with increased obesity risk in children (See reviews Fatima et al., 2014; Liu et al., 2012, Chen et al., 2008). Sleep quality, bed timing and sleep variability have also been associated with obesity risk in children (McNeil et al., 2015; Snell et al., 2007; Spruyt et al., 2011). However, less is known about children under 5 years old, sleep quality, and Canadian children. Additionally, there is a lack of studies that use objectively measured sleep and a narrow scope of how obesity risk is measured, typically just BMI. Furthermore, even though sleep has been associated with adverse weight outcomes, sleep is not traditionally targeted in interventions aiming to improve child or family health.

The present thesis will address the above literature gaps by exploring the relationship between objectively measured sleep in children 18 months old to 5 years old and markers of obesity risk including BMI, BMIz, waist circumference, body composition and blood pressure. In addition, this study will examine the impact of the Guelph Family Health Study intervention on various sleep parameters. Results of this study will provide insight on how sleep is related to obesity risk in young Canadian children. Additionally, the results from this study will help guide interventions aiming to improve sleep habits in young children by providing an understanding as to what sleep parameters have more of an association with obesity markers and how sleep habits can change as a result of a family based intervention.

4.0 Research Objectives

Primary objective: To examine the cross-sectional and longitudinal associations between sleep measures (duration, quality, and variability) with markers of obesity risk (BMI, BMIz, waist circumference, body composition and blood pressure).
circumference, body composition and blood pressure) among child participants in the Guelph Family Health Study.

Secondary Objective: To examine the extent to which children participants who receive the Guelph Family Health Study intervention improve their sleep quantity, quality and variability, compared to a control group.

5.0 Methodology

5.1 Guelph Family Health Study Design

To examine the aforementioned objectives, data analysis of the pilot phase of the Guelph Family Health Study (GFHS) will be performed. The design of the GFHS pilot is a randomized controlled trial of 44 families, including 55 children between 18 months and 5 years old. There were 13 Families (17 children) randomized to the control group, which received monthly emails with general health information. There were 14 families (17 children) randomized to the email+2 intervention group (2-HV group), which received tailored weekly emails and two home visits with a health educator. There were 17 families (21 children) randomized to the email+4 intervention group (4-HV group), which received tailored weekly emails and four home visits with a health educator. Figure 1 displays a schematic representation of the study flow for the GFHS pilot. To achieve the objectives for this study, sleep data from the Actigraphs collected at baseline and at the 6-month follow-up as well as data from the health assessments (BMI, BMIz, body composition, waist circumference and blood pressure) at baseline and 6-month were used for analysis.

A total of 65 families were recruited for the pilot phase of the Guelph Family Health Study through flyers, social media, a local Family Health Team, the Guelph Community Health Centre, and word-of-mouth in Wellington County, Ontario, Canada. Exclusion criteria for the
Sabrina Douglas

study were relocation within the first year of the study and the age of the children in the families—must be 1.5-6 years of age at the time of recruitment. Due to reasons such passive decline (16), active decline (2), ineligibility (2), and family illness (1), 44 families completed the baseline health assessment. For this study, 37 and 23 families were included in the primary and secondary analyses respectfully, due to sleep data availability. Families were reimbursed for their time. All study procedures were administered at the University of Guelph after the parents of the participants gave written, informed consent. The study was approved by the University of Guelph Research Ethics Board (RCT 02223234).
Figure 1: Guelph Family Health Study Work Flow

Recruitment through flyers, social media, local Family Health Team, the Guelph Community Health Centre, and word-of-mouth

Online registration and consent

Completion of online questionnaires

Home visit by Study Coordinator
- Family receives 3-day food record and accelerometer for children

Health Assessment
- Measurement of: Height, weight, waist circumference, blood pressure, body composition, saliva collection

Blood collection at LifeLabs (Optional)

Randomization

Treatment 1
- 1 tailored e-mail/week for 6 months + 2 home visits with a Health Educator

Treatment 2
- 1 tailored e-mail/week for 6 months + 2 home visits with a Health Educator

Treatment 3
- 1 tailored e-mail/week for 6 months + 4 home visits with a Health Educator


5.2 Sleep Measures

In the current study, the following sleep outcomes were examined at baseline and at 6 months: Sleep quantity (total nighttime sleep duration), sleep quality (sleep efficiency), and sleep duration variability. All sleep variables were measured using Actigraphy. Children in the GFHS wore an activity monitor by Actigraph and Actilife 6 Data Analysis Software (Actigraph, 2015) was used to extract the data from the monitor. Parents were instructed to keep the activity monitors on their children for 3-7 days, only removing it if the child would be in water for a long period of time (e.g. swimming lessons). For the baseline assessment participants wore the activity monitor on their non-dominant wrist. For the 6-month assessment, participants wore the activity monitor on their non-dominant wrist and a selected number of participants also wore an activity monitor on their waist in conjunction. The purpose of two activity monitors was to compare results from the two methods, however for the purpose of this project only wrist Actigraphy data was be evaluated. To determine sleep/wake status, the Sadeh algorithm was applied to the raw sleep data in one-minute epochs.

5.2.1 Sleep Quantity

Sleep quantity was calculated based on Actigraphy results from the activity monitor worn by each participant. The Actilife software provided a “total sleep time” variable for each night and these values were averaged for each participant to provide an average nighttime sleep duration for each participant. This value represents the total time the participant spent sleeping (in minutes), excluding the time they spent awake in bed.

5.2.2 Sleep Quality

As mentioned in section 1.4, there is no agreed upon definition for sleep quality which is used variably across the literature. For the purposes of the current study, sleep efficiency was
considered a sleep quality variable. Along with sleep duration, sleep quality was also captured by the activity monitor worn by participants. Sleep efficiency is a percentage of total time spent in bed to total time spent sleeping.

5.2.3 Sleep Quantity Variability

Sleep variability was also measured using the activity monitor. The coefficient of variation was used to calculate the sleep quantity variability for each participant from the total sleep time variable provided by the Actilife software.

5.3 Obesity Risk Measures

The following obesity risk biomarkers were examined: BMI, BMIz, body composition, waist circumference, and blood pressure. These measures were taken at the Health Assessment visit at baseline and at 6-months. The Health Assessment visit occurred at the University of Guelph Body Composition and Metabolism Lab and involved the family meeting with the GFHS coordinator and a research assistant.

5.3.1 Body Mass Index (BMI) and BMI Z-scores (BMIZ)

BMI was calculated from baseline and 6-month height and weight measurements taken at the Health Assessment visit. Height was measured using a standard protocol adapted for use in children between 18 months and 5 years old (Frisancho, 2004). In cases where the participant was able to stand a pediatric length board was used to measure in a standing position. In cases where the participant could not stand, the length board was laid on a bed and the participant was measured while lying down (1 occurrence at baseline and 6-months). Height measurements were taken in centimeters and when possible the measures were duplicated and the mean of the two measures was calculated. Weight was measured in kilograms using a scale by Tanita Corporation (Model BWB-627-A), modified by Life Measurement. Weight was the only measurement taken
only once due to the precision and accuracy of the scale. BMI Z-scores were computed using the WHO Anthro 3.2.2 software (2011).

5.3.2 Waist Circumference

Waist circumference was measured at baseline and 6-months at the family’s Health Assessment visit. A standard protocol was used based on the Canadian Society for Exercise Physiology’s guidelines (the Canadian Society for Exercise Physiology, 2008). These measurements were taken in centimeters with a standard measuring tape and when possible the measurements were duplicated and the average of the two was calculated.

5.3.3 Body Composition

To access fat mass, Bioelectrical Impedance Analysis (BIA) was performed using Quantum IV – Body Composition Analyzer™ (RJL Systems, Clinton Township, MI). Prior to being tested children were required to fast and avoid vigorous physical activity for two hours, and to void their bladder at least half an hour before. Children were also required to remove any clothing with metal so as to avoid interference with the BIA current. Children were required to lie still for the duration of the test, which takes approximately one minute to perform. Raw data output of reactance, impedance, resistance, and phase angle were provided after the test. Raw data was entered into an equation by Kushner and colleagues (1992) to determine fat mass.

5.3.4 Blood Pressure

Blood pressure was measured using an oscillometric blood pressure monitor on the right upper arm (OMRON Healthcare, n.d.). Both systolic and diastolic blood pressure were considered. Measurements were taken twice at the baseline Health Assessment and three times at the 6-month Health Assessment. The purpose of increasing from two to three measurements was to have more accurate means for each measure for each participant, because the children were
young and were not able to sit completely still while the blood pressure cuff was on their arm.

Averages of the two or three measurements were calculated for analysis.

### 5.4 Confounding Variables

A variable is considered confounding when it is not the predictor variable and it could possibly be associated with the outcome variable. These confounding variables are extraneous and are not being examined as part of the current study and therefore may interfere with the internal validity of the results. Without controlling for potential confounding variables in the present study, the magnitude of change in sleep quantity/quality/variability and the relationship between sleep quantity/quality/variability and obesity risk may be misinterpreted. Although randomization of families in the GFHS should control for confounding, these variables will still be controlled for to reinforce the validity of the results.

To examine the primary objective which was to determine the cross-sectional and longitudinal associations between sleep measures (quantity, quality, and variability) with biomarkers of obesity in children 18 months old to 5 years old in the GFHS, separate models were run for each sleep measure (sleep quantity, sleep quality, and sleep variability) and obesity risk marker (BMI, BMIz, waist circumference, body composition and blood pressure). In the cross-sectional models the following confounders were controlled for: Age, sex and income (Age and sex were not included in the BMIz models). In the longitudinal models the following confounders were controlled for: Baseline sleep and obesity risk measures, age, sex, income and intervention status (Age and sex were not included in the BMIz models).

To examine the secondary objective which was to determine the extent to which children participants who receive the GFHS intervention improved their sleep duration, quality and variability, compared to a control group, separate models were run for each sleep measure (sleep
quantity, sleep quality, and sleep variability). In each of these models the following confounding variables were controlled for: Sex, age, income and baseline BMI.

Sex, age and income were collected by questionnaires completed by each parent enrolled in the study at baseline.

5.5 Data Analysis

Data analysis for this study was performed using SAS 9.4 for Windows. A p-value of \( \leq 0.05 \) was considered statistically significant. The participant demographic data was analyzed by calculating means (±SD) and frequencies. Below outlines the data analysis protocol for both objectives.

5.5.1 Data Analysis Protocol for Primary Objective

The primary objective of the present study was to examine the cross-sectional and longitudinal associations between sleep measures (duration, quality, and variability) with markers of obesity risk (BMI, BMIz, waist circumference, body composition and blood pressure) in children participants in the Guelph Family Health Study. To examine potential cross-sectional and longitudinal associations between sleep parameters and obesity markers, separate generalized estimating equation (GEE) models were used for each sleep variable: sleep quantity, sleep quality (sleep efficiency) and sleep variability. To examine the cross-sectional associations, first the models were run with sleep measures as the independent variables and obesity risk measures as the dependent variables. Second, the models were run again to adjust for the confounders mentioned above (section 4.4). To examine the longitudinal associations, first the models were run with change in sleep measures as the independent variables and obesity risk measures and the dependent variables. Second, the models were run again to adjust for the confounders mentioned above (section 4.4).
5.5.2 Data Analysis Protocol for Secondary Objective

The secondary objective of the present study was to examine the extent to which children participants who received the Guelph Family Health Study intervention (either email+2 or email+4) improved their sleep quantity, quality and variability, compared to a control group, over a 6-month intervention period. To examine the effect of the intervention on the various sleep variables, separate GEE models were used for each sleep variable. First, the models were run with only intervention status as the independent variable and sleep variables (sleep quantity, sleep quality, and sleep variability) as the dependent variables. Second, the models were run again to adjust for the confounders mentioned above (section 4.4).

6.0 Results

6.1 Primary Research Objective

The primary research objective was to examine the cross-sectional and longitudinal associations between sleep measures (duration, quality, and variability) with markers of obesity weight status (BMI, BMIz, waist circumference, body composition and blood pressure) among child participants in the Guelph Family Health Study. It was hypothesized that in the cross-sectional analysis lower total sleep time, lower sleep efficiency and higher sleep variability will be associated with higher BMI, BMIz, waist circumference, blood pressure and fat mass. Furthermore, it was hypothesized that in the longitudinal analysis increases in total sleep time, increases in sleep efficiency and decreases in sleep variability from baseline to 6-months would be associated with lower BMI, BMIz, waist circumference, blood pressure and fat mass at 6-months.


6.1.0 Study Sample

Demographics and baseline characteristics of participants are shown in Table 1. Of the 55 children participants in the Guelph Family Health Study at baseline, 46 had valid sleep data and were included in the cross-sectional analyses of this objective. Reasons for excluded or missing data include participant refusal (5), problems downloading data (2), outlier data (1) and only 1 night of sleep available (1). There were nine families with two children (siblings) included. T-tests were performed to determine that there were no statistically significant differences in demographic and weight status variables between participants included versus excluded. Not all participants completed all obesity risk measures, therefore there were different sample sizes for BMI (N=43), waist circumference (N=44), blood pressure (N=26) and fat mass (N=34) in the cross-sectional models. Of the 46 participants with valid baseline sleep measures, 22 (47.8%) were male and 24 (52.2%) were female. The majority of participants were white (76.1%), with the remainder of participants being either a mix of white and other (10.9%) or other (13.0%). The average age of participants at baseline was 42.3 months (3.5 years). The average baseline BMI and BMIz scores were 15.90 Kg/m$^2$ and 0.34 respectively. Using BMI-for-age cutoffs by the WHO, participants were classified as wasted (2.1%), normal weight (67.4%), risk of overweight (15.2%), or overweight (8.7%; Dietitians of Canada, 2014). Baseline sleep measures are also summarized in table 1. Overall, the mean total sleep time was 472.41 minutes, sleep efficiency was 83.89% and sleep variability was 0.28. Additionally, there was a strong correlation between sleep total sleep time and sleep efficiency ($r = 0.71$, $p < 0.0001$)

Of the 55 children participants in the Guelph Family Health Study at baseline, 32 had valid sleep data and were included in the longitudinal analyses of this objective. Reasons for excluded or missing data include: Firmware issues (8), participant refusal (7), missing baseline
measures (4), loss to follow-up (2), problems downloading data (1), and only 1 night of sleep available (1).

Table 6.1: Demographics/Baseline Characteristics of Participants in Primary Objective

<table>
<thead>
<tr>
<th>Demographic/Baseline Characteristic</th>
<th>Overall (n=46)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Families</td>
<td>37</td>
</tr>
<tr>
<td>Sex</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>22 (47.8)</td>
</tr>
<tr>
<td>Female</td>
<td>24 (52.2)</td>
</tr>
<tr>
<td>Ethnicity</td>
<td></td>
</tr>
<tr>
<td>White or Caucasian</td>
<td>35 (76.1)</td>
</tr>
<tr>
<td>White and other</td>
<td>5 (10.9)</td>
</tr>
<tr>
<td>Other</td>
<td>6 (13.0)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mean (SD) or Count (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BMI (Kg/m²)</td>
</tr>
<tr>
<td>BMIZ</td>
</tr>
<tr>
<td>Wasted</td>
</tr>
<tr>
<td>Normal</td>
</tr>
<tr>
<td>Risk of overweight</td>
</tr>
<tr>
<td>Overweight</td>
</tr>
<tr>
<td>Obese</td>
</tr>
<tr>
<td>Age (months)</td>
</tr>
<tr>
<td>Total sleep time (mins)</td>
</tr>
<tr>
<td>Sleep efficiency (%)</td>
</tr>
<tr>
<td>Sleep variability</td>
</tr>
</tbody>
</table>

6.1.1 Generalized Estimating Equation Results – Cross Sectional Analyses

Results from the cross-sectional analyses are shown in Table 3. There were no significant associations found in the cross-sectional analyses.

6.1.2 Generalized Estimating Equation Results – Longitudinal Analyses

Results from the longitudinal analysis are shown in Table 4. In general, there were significant relationships found with regard to BMI, BMIZ and waist circumference, but not with regard to the rest of the weight status and obesity markers. When looking at BMI, a significant relationship was found with sleep variability in the expected direction. In the adjusted model,
results also indicated that increases in sleep variability were associated with higher BMI at 6-months ($\beta$ = 1.83, 95% CI 0.43, 3.24). Similarly, a significant relationship was observed between BMIz and sleep variability in the expected direction. In the adjusted model, results indicated that increases in sleep variability were associated with higher BMIz at 6-months ($\beta$ = -0.93, 95% CI 0.40, 1.45). Additionally, with BMIz, there was a significant relationship with sleep efficiency. In the adjusted model, results indicated that increases in sleep efficiency were associated with lower BMIz at 6-months ($\beta$ = -0.03, 95% CI -0.04, 0.01). When looking at waist circumference there was a significant relationship with sleep variability in the expected direction, indicating that an increase in sleep variability was associated with higher waist circumference at 6-months ($\beta$ = 5.51, 95% CI 0.98, 10.04). This relationship did not remain significant in the adjusted model ($\beta$ = 2.476, 95% CI -0.98, 5.93).

When considering the change in sleep from baseline to 6-months and its relationship with BMI, it is important to consider what is driving the changes in sleep behaviours. Some of the participants (75% of the total 32 participants) included in the longitudinal analyses were exposed to the Guelph Family Health Study Intervention. Sleep was one of the behaviours targeted in this intervention, however intervention status was included as a covariate in these models. Another factor which could affect sleep is age – as children age they require less sleep (Hirshkowitz et al., 2015). However, age was also included as a covariate in these models. Therefore, by including intervention status and age in the longitudinal models as covariate, it allows for a better observation of how sleep organically changed from baseline to 6-months. Changes in sleep could be occurring due to chance, changes in family routines unrelated to the GFHS intervention, seasonality changes or other unknown factors.
Table 6.2: Results of Cross-Sectional Generalized Estimating Equations Analyses of Sleep Measures with Obesity Risk Measures

<table>
<thead>
<tr>
<th>Obesity Risk Variable</th>
<th>Sleep Variable</th>
<th>Unadjusted Estimate (95% CI)</th>
<th>P-value</th>
<th>Adjusted Estimate (95% CI)*</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>BMI (n=43)</td>
<td>TST</td>
<td>-0.00 (-0.01, 0.00)</td>
<td>0.80</td>
<td>-0.00 (-0.01, 0.00)</td>
<td>0.71</td>
</tr>
<tr>
<td></td>
<td>Efficiency</td>
<td>-0.06 (-0.14, 0.03)</td>
<td>0.17</td>
<td>-0.05 (-0.14, 0.04)</td>
<td>0.25</td>
</tr>
<tr>
<td></td>
<td>Sleep Variability</td>
<td>-0.97 (-2.99, 1.04)</td>
<td>0.34</td>
<td>-1.30 (-3.34, 0.74)</td>
<td>0.21</td>
</tr>
<tr>
<td>BMIz (n=43)</td>
<td>TST</td>
<td>-0.00 (-0.00, 0.00)</td>
<td>0.87</td>
<td>-0.00 (-0.00, 0.00)</td>
<td>0.58</td>
</tr>
<tr>
<td></td>
<td>Efficiency</td>
<td>-0.02 (-0.09, 0.06)</td>
<td>0.63</td>
<td>-0.02 (-0.10, 0.05)</td>
<td>0.51</td>
</tr>
<tr>
<td></td>
<td>Sleep Variability</td>
<td>-0.81 (-2.52, 0.90)</td>
<td>0.35</td>
<td>-1.08 (-2.87, 0.71)</td>
<td>0.24</td>
</tr>
<tr>
<td>Systolic BP (n=26)</td>
<td>TST</td>
<td>-0.05 (-0.11, 0.02)</td>
<td>0.17</td>
<td>-0.04 (-0.12, 0.02)</td>
<td>0.16</td>
</tr>
<tr>
<td></td>
<td>Efficiency</td>
<td>-1.66 (-3.39, 0.08)</td>
<td>0.06</td>
<td>-1.72 (-3.50, 0.05)</td>
<td>0.06</td>
</tr>
<tr>
<td></td>
<td>Sleep Variability</td>
<td>10.63 (-8.38, 29.65)</td>
<td>0.27</td>
<td>13.78 (-8.39, 35.96)</td>
<td>0.22</td>
</tr>
<tr>
<td>Diastolic BP (n=26)</td>
<td>TST</td>
<td>-0.045 (-0.12, 0.03)</td>
<td>0.24</td>
<td>-0.05 (-0.12, 0.03)</td>
<td>0.24</td>
</tr>
<tr>
<td></td>
<td>Efficiency</td>
<td>-1.713 (-3.94, 0.51)</td>
<td>0.13</td>
<td>-1.86 (-4.05, 0.34)</td>
<td>0.10</td>
</tr>
<tr>
<td></td>
<td>Sleep Variability</td>
<td>0.593 (-26.37, 27.56)</td>
<td>0.97</td>
<td>1.79 (-34.42, 37.98)</td>
<td>0.92</td>
</tr>
<tr>
<td>Waist circumference (n=44)</td>
<td>TST</td>
<td>-0.00 (-0.01, 0.01)</td>
<td>0.48</td>
<td>-0.00 (-0.01, 0.01)</td>
<td>0.45</td>
</tr>
<tr>
<td></td>
<td>Efficiency</td>
<td>0.04 (-0.16, 0.23)</td>
<td>0.71</td>
<td>-0.01 (-0.25, 0.23)</td>
<td>0.95</td>
</tr>
<tr>
<td></td>
<td>Sleep Variability</td>
<td>-3.73 (-8.70, 1.23)</td>
<td>0.14</td>
<td>-3.19 (-7.32, 0.94)</td>
<td>0.13</td>
</tr>
<tr>
<td>Fat Mass (n=34)</td>
<td>TST</td>
<td>0.00 (-0.00, 0.00)</td>
<td>0.87</td>
<td>0.00 (-0.00, 0.00)</td>
<td>0.77</td>
</tr>
<tr>
<td></td>
<td>Efficiency</td>
<td>0.00 (-0.08, 0.08)</td>
<td>0.96</td>
<td>0.00 (-0.08, 0.08)</td>
<td>0.99</td>
</tr>
<tr>
<td></td>
<td>Sleep Variability</td>
<td>-0.60 (-2.12, 0.93)</td>
<td>0.44</td>
<td>-0.42 (-1.83, 0.99)</td>
<td>0.56</td>
</tr>
</tbody>
</table>

*aAdjusted for baseline age, sex (except BMIz), and income
### Table 6.3: Results of Longitudinal Generalized Estimating Equations Analyses of Sleep Measures with Obesity Risk Measures

<table>
<thead>
<tr>
<th>Obesity Risk Variable</th>
<th>Sleep Variable</th>
<th>Unadjusted Estimate (95% CI)</th>
<th>P-value</th>
<th>Adjusted Estimate (95% CI)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>a</td>
<td></td>
</tr>
<tr>
<td>BMI</td>
<td>Change in TST</td>
<td>-0.00 (-0.01,0.01)</td>
<td>0.82</td>
<td>0.00 (-0.00,0.00)</td>
<td>0.61</td>
</tr>
<tr>
<td>(N=30)</td>
<td>Change in Efficiency</td>
<td>-0.04 (-0.13,-0.05)</td>
<td>0.39</td>
<td>-0.02 (-0.05,0.01)</td>
<td>0.23</td>
</tr>
<tr>
<td></td>
<td>Change in Sleep Variability</td>
<td>1.79 (-0.16,3.75)</td>
<td>0.07</td>
<td>1.21 (0.40,0.98)</td>
<td>0.00</td>
</tr>
<tr>
<td>BMIZ</td>
<td>Change in TST</td>
<td>-0.00 (-0.00,0.00)</td>
<td>0.89</td>
<td>-0.00 (-0.00,0.00)</td>
<td>0.71</td>
</tr>
<tr>
<td>(N=30)</td>
<td>Change in Efficiency</td>
<td>-0.04 (-0.01,0.02)</td>
<td>0.18</td>
<td>-0.03 (-0.04,-0.01)</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td>Change in Sleep Variability</td>
<td>1.27 (-0.12,2.66)</td>
<td>0.07</td>
<td>-0.93 (0.41, 1.46)</td>
<td>0.00</td>
</tr>
<tr>
<td>Waist Circumference</td>
<td>Change in TST</td>
<td>-0.01 (-0.01,0.02)</td>
<td>0.46</td>
<td>0.00 (-0.01,0.01)</td>
<td>0.76</td>
</tr>
<tr>
<td>(N=29)</td>
<td>Change in Efficiency</td>
<td>-0.05 (-0.33,0.23)</td>
<td>0.72</td>
<td>-0.04 (-0.14,0.06)</td>
<td>0.44</td>
</tr>
<tr>
<td></td>
<td>Change in Sleep Variability</td>
<td>5.51 (0.98,10.04)</td>
<td>0.02</td>
<td>2.47 (-0.93, 5.88)</td>
<td>0.15</td>
</tr>
<tr>
<td>Systolic BP</td>
<td>Change in TST</td>
<td>0.01 (-0.03,0.05)</td>
<td>0.62</td>
<td>0.03 (-0.01,0.06)</td>
<td>0.15</td>
</tr>
<tr>
<td>(N=14)</td>
<td>Change in Efficiency</td>
<td>-0.01 (-0.97,0.99)</td>
<td>0.98</td>
<td>-0.06 (-0.90,1.02)</td>
<td>0.90</td>
</tr>
<tr>
<td></td>
<td>Change in Sleep Variability</td>
<td>2.21 (-9.39,13.81)</td>
<td>0.71</td>
<td>10.70 (-1.72,23.12)</td>
<td>0.09</td>
</tr>
<tr>
<td>Diastolic BP</td>
<td>Change in TST</td>
<td>-0.00 (-0.04,0.03)</td>
<td>0.84</td>
<td>0.00 (-0.05,0.05)</td>
<td>0.97</td>
</tr>
<tr>
<td>(N=14)</td>
<td>Change in Efficiency</td>
<td>-0.30 (-0.96,0.36)</td>
<td>0.37</td>
<td>-0.21 (-1.07,0.64)</td>
<td>0.63</td>
</tr>
<tr>
<td></td>
<td>Change in Sleep Variability</td>
<td>6.17 (-13.63,25.98)</td>
<td>0.54</td>
<td>7.95 (-9.34,25.23)</td>
<td>0.37</td>
</tr>
<tr>
<td>Fat Mass</td>
<td>Change in TST</td>
<td>-0.00 (-0.01,0.01)</td>
<td>0.43</td>
<td>0.00 (-0.00,0.00)</td>
<td>0.49</td>
</tr>
<tr>
<td>(N=22)</td>
<td>Change in Efficiency</td>
<td>0.05 (-0.10,0.20)</td>
<td>0.48</td>
<td>0.03 (-0.03,0.08)</td>
<td>0.31</td>
</tr>
<tr>
<td></td>
<td>Change in Sleep Variability</td>
<td>1.43 (-0.64,3.49)</td>
<td>0.18</td>
<td>0.87 (-0.19,1.93)</td>
<td>0.11</td>
</tr>
</tbody>
</table>

*aAdjusted for age, sex, income, intervention status and baseline obesity risk measure (except BMIZ)
6.2 Secondary Research Objective

The secondary research objective was to examine the extent to which children participants who receive the Guelph Family Health Study intervention improve their sleep quantity, quality and variability, compared to a control group. It was hypothesized that greater improvements in sleep quantity, quality and variability would be seen in participants receiving the Guelph Family Health study intervention, compared to participants in the control group.

6.2.1 Study Sample

Demographics and baseline characteristics of participants are shown in Table 5. Of the 55 children participants in the Guelph Family Health Study at baseline, 30 had valid sleep data and were included in this objective. Reasons for excluded or missing data include firmware issues (8), participant refusal (7), missing baseline measures (4 sleep and 2 BMI), loss to follow-up (2), problems downloading data (1), and 1 night of sleep available (1). There were no statistically significant differences in demographic and weight status variables between participants included versus excluded. There were seven families with 2 children (siblings) included. In the sample there were 12 participants in the 4-home visit group, 10 participants in the 2-home visit intervention group and 8 participants in the control group. There were 16 (53.3%) males and 14 (46.7%) females. The majority of participants were white (80.0%), with the remainder of participants being either a mix of white and other (10.0%) or other (10.0%). The average age of participants at baseline was 42.7 months (3.6 years). The average baseline BMI and BMIZ scores were 15.9 Kg/m² and 0.25 respectively. Using BMI-for-age cutoffs by the WHO, participants were classified as wasted (3.3%), normal weight (66.7%), risk of overweight (23.3%), or overweight (6.7%; Dietitians of Canada, 2014). Baseline sleep measures are also
summarized in table 5. Overall, the mean total sleep time was 476.30 minutes, sleep efficiency was 84.2% and sleep variability was 0.28.

### 6.2.2 Generalized Estimating Equation Results

Results from the generalized estimating equation models are shown in Table 6. There were no significant differences in sleep variables between the 2-home visit group and the control group or between the 4-home visit group and the control group in either the unadjusted or adjusted model. Considering each group’s absolute change and trend in sleep variables, there are some noteworthy findings.

First looking at the 4-HV group it can be determined that this group had the least favourable changes from baseline to follow-up, because each of these changes were in the opposite of the hypothesized direction. Starting with total sleep time, it can be determined that the 4-HV group had a relatively high total sleep time score at baseline (489.84 minutes) and the highest score at 6-months (483.91 minutes), with a decrease of 5.93 minutes. For sleep efficiency, the 4HV group decreased from 84.32% to 83.51% from baseline to 6-months. Finally, for sleep variability there was an increase of 0.08 from baseline (0.24) to 6-months (0.32).

Next, looking at the 2-HV group it can be determined that each sleep measure change was in the hypothesized direction. First, this group had an improvement in total sleep time from baseline (473.07 minutes) to 6-months (483.63 minutes) with an increase of 10.56 minutes. For sleep efficiency, the 2-HV group started with a baseline score of 84.15%, and had an improvement of 0.41% which brought this group to 84.56% at 6-months. Finally, for sleep variability, the 2-HV group started with a score of 0.27 at baseline and had the largest improvement (-0.14) which brought this group to the lowest score of 0.13 at 6-months.
Next, looking at the control group it can be determined that the total sleep time scores were the lowest in this group at baseline (460.04 minutes) and at 6-months (474.01 minutes) with the greatest increase of 13.97 minutes. For sleep efficiency, the scores increased from baseline with the lowest score (84.11%) to 6-month with the highest score (85.21%). For sleep variability, this group started with the highest score of 0.33 at baseline but then decreased (-0.11) to 0.22 at 6-months.

Therefore, it is noteworthy that the most favourable changes in sleep scores were found in the 2-HV and control group while the least favourable scores were in the 4-HV group. It should be noted that the changes in sleep efficiency and sleep variability were not very substantial in any of the groups, with only one of the changes (sleep efficiency in the control group) being greater than 1 unit.
<table>
<thead>
<tr>
<th>Demographic/Baseline Characteristic</th>
<th>Overall (n=30)</th>
<th>4-Home Visit Group (n=12)</th>
<th>2-Home Visit Group (n=10)</th>
<th>Control (n=8)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Families</td>
<td>23</td>
<td>9</td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td>Sex</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>16 (53.3)</td>
<td>5 (41.7)</td>
<td>6 (60.0)</td>
<td>5 (62.5)</td>
</tr>
<tr>
<td>Female</td>
<td>14 (46.7)</td>
<td>7 (58.3)</td>
<td>4 (40.0)</td>
<td>3 (37.5)</td>
</tr>
<tr>
<td>Ethnicity</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>White or Caucasian</td>
<td>24 (80.0)</td>
<td>11 (91.7)</td>
<td>8 (80.0)</td>
<td>5 (62.5)</td>
</tr>
<tr>
<td>White and other</td>
<td>3 (10.0)</td>
<td>1 (8.3)</td>
<td>1 (10.0)</td>
<td>1 (12.5)</td>
</tr>
<tr>
<td>Other</td>
<td>3 (10.0)</td>
<td>0 (0.0)</td>
<td>1 (10.0)</td>
<td>2 (25.0)</td>
</tr>
<tr>
<td><strong>Mean (SD) or Count (%)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BMI (Kg/m²)</td>
<td>15.9 (1.2)</td>
<td>15.59 (1.03)</td>
<td>15.6 (1.1)</td>
<td>16.70 (1.29)</td>
</tr>
<tr>
<td>BMIz</td>
<td>0.25 (1.05)</td>
<td>-0.08 (1.15)</td>
<td>0.11 (0.90)</td>
<td>0.92 (0.85)</td>
</tr>
<tr>
<td>Wasted</td>
<td>1 (3.3)</td>
<td>1 (8.3)</td>
<td>0 (0.0)</td>
<td>0 (0.0)</td>
</tr>
<tr>
<td>Normal</td>
<td>20 (66.7)</td>
<td>9 (75.0)</td>
<td>7 (70.0)</td>
<td>4 (50.0)</td>
</tr>
<tr>
<td>Risk of overweight</td>
<td>7 (23.3)</td>
<td>2 (16.7)</td>
<td>3 (30.0)</td>
<td>2 (25.0)</td>
</tr>
<tr>
<td>Overweight</td>
<td>2 (6.7)</td>
<td>0 (0.0)</td>
<td>0 (0.0)</td>
<td>2 (25.0)</td>
</tr>
<tr>
<td>Obese</td>
<td>0 (0.0)</td>
<td>0 (0.0)</td>
<td>0 (0.0)</td>
<td>0 (0.0)</td>
</tr>
<tr>
<td>Age (months)</td>
<td>42.7 (12.7)</td>
<td>40.1 (12.7)</td>
<td>43.10 (12.7)</td>
<td>46.13 (13.22)</td>
</tr>
<tr>
<td>Total sleep time (mins)</td>
<td>476.30 (88.54)</td>
<td>489.84 (54.42)</td>
<td>473.07 (95.42)</td>
<td>460.04 (124.43)</td>
</tr>
<tr>
<td>Sleep efficiency (%)</td>
<td>84.21 (2.95)</td>
<td>84.32 (2.31)</td>
<td>84.15 (3.89)</td>
<td>84.11 (2.84)</td>
</tr>
<tr>
<td>Sleep variability</td>
<td>0.28 (0.21)</td>
<td>0.24 (0.19)</td>
<td>0.27 (0.24)</td>
<td>0.33 (0.21)</td>
</tr>
</tbody>
</table>
### Table 6.5: Results of Generalized Estimating Equations Analyses of Differences in Sleep Variables at 6 Months, Comparing Both Intervention Groups to the Control Group

<table>
<thead>
<tr>
<th>Sleep Variable</th>
<th>Baseline</th>
<th>6 Months</th>
<th>Change</th>
<th>Unadjusted Estimate (95% CI)</th>
<th>P-value</th>
<th>Adjusted Estimate (95% CI)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (SD)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>TST</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 HV (N=12)</td>
<td>489.84 (54.42)</td>
<td>483.91 (84.65)</td>
<td>-5.93 (113.85)</td>
<td>9.89 (-53.91,73.69)</td>
<td>0.76</td>
<td>-18.42 (-97.75,60.91)</td>
<td>0.65</td>
</tr>
<tr>
<td>2 HV (N=10)</td>
<td>473.07 (95.42)</td>
<td>483.63 (121.64)</td>
<td>10.56 (89.19)</td>
<td>9.62 (-76.11,95.34)</td>
<td>0.83</td>
<td>-17.20 (-106.60,72.21)</td>
<td>0.71</td>
</tr>
<tr>
<td>Control (N=8)</td>
<td>460.04 (124.43)</td>
<td>474.01 (72.97)</td>
<td>13.97 (134.21)</td>
<td>-0.80 (7.57)</td>
<td>-1.70 (-6.29,2.90)</td>
<td>0.47</td>
<td>-3.40 (-8.47,1.57)</td>
</tr>
<tr>
<td><strong>Sleep Efficiency</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 HV (N=12)</td>
<td>84.32 (2.31)</td>
<td>83.51 (6.41)</td>
<td>-0.80 (7.57)</td>
<td>-1.70 (-6.29,2.90)</td>
<td>0.47</td>
<td>-3.40 (-8.47,1.57)</td>
<td>0.19</td>
</tr>
<tr>
<td>2 HV (N=10)</td>
<td>84.15 (3.89)</td>
<td>84.56 (7.91)</td>
<td>0.41 (5.36)</td>
<td>-0.66 (-6.04,4.73)</td>
<td>0.81</td>
<td>-2.47 (-8.18,3.24)</td>
<td>0.40</td>
</tr>
<tr>
<td>Control (N=8)</td>
<td>84.11 (2.84)</td>
<td>85.21 (5.35)</td>
<td>1.10 (4.59)</td>
<td>-0.11 (0.27)</td>
<td>-0.09 (-0.19,0.01)</td>
<td>0.09</td>
<td>-0.07 (-0.20,0.06)</td>
</tr>
<tr>
<td><strong>Sleep Variability</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 HV (N=12)</td>
<td>0.24 (0.19)</td>
<td>0.32 (0.14)</td>
<td>0.08 (0.27)</td>
<td>0.10 (-0.07,0.22)</td>
<td>0.09</td>
<td>0.11 (-0.05,0.27)</td>
<td>0.16</td>
</tr>
<tr>
<td>2 HV (N=10)</td>
<td>0.27 (0.24)</td>
<td>0.13 (0.07)</td>
<td>-0.14 (0.28)</td>
<td>-0.09 (-0.19,0.01)</td>
<td>0.09</td>
<td>-0.07 (-0.20,0.06)</td>
<td>0.29</td>
</tr>
<tr>
<td>Control (N=8)</td>
<td>0.33 (0.21)</td>
<td>0.22 (0.13)</td>
<td>-0.11 (0.27)</td>
<td>-0.09 (-0.19,0.01)</td>
<td>0.09</td>
<td>-0.07 (-0.20,0.06)</td>
<td>0.29</td>
</tr>
</tbody>
</table>

*aAdjusted for: Age, sex, income, baseline sleep variable, and baseline BMI*
7.0 Discussion

Research has shown a decreasing trend in sleep duration in recent decades in the general public (Matricciani et al., 2012; Jean-Louis et al., 2014). This trend has been more highly researched in older children, teenagers and adults but has also been observed in preschool children. Furthermore, impairments in sleep have been associated with negative health outcomes such as obesity, diabetes and cardiovascular disease (Meier-Ewert et al., 2004). Currently, the literature lacks thorough investigation of objectively measured sleep, measurement of sleep quality and variability, and measures of obesity other than BMI. Furthermore, there is limited literature available about sleep and obesity in samples of Canadian children. To address these gaps, the primary purpose of this project was to identify cross-sectional and longitudinal associations between sleep (quantity, quality and variability) and obesity (BMI, BMIz, fat mass, blood pressure and waist circumference) in preschool children. Additionally, there is a lack of intervention studies targeting sleep in the preschool population as a means of reducing or preventing obesity. Therefore, the secondary purpose of this project was to examine the extent to which preschool children who receive home visits with a health educator improve their sleep quantity, quality and variability, compared to a control group.

Contrary to our hypotheses, the main findings from the cross-sectional analyses of the primary objective indicated that there were no significant associations between sleep measures and weight status and obesity markers. A possible reason why these unexpected results were found could be due to the small sample size in our study. Because we had a small sample size, we had more variability in our results, therefore the uncertainty in the precision of our estimate is less. The main findings from the longitudinal analysis of the primary objective was that that children who increased their ratio of time sleeping in bed rather than awake in bed, had lower
BMIz at the 6-month follow-up. Also, those that increased the variability in the total time they spent sleeping, had higher BMI and BMIz at 6-months. These results were in the hypothesized direction and were significant after adjusting for covariates (age, sex, income, intervention status and baseline obesity variable). Finally, an increase in the variability in the total time they spent sleeping was associated with a higher waist circumference at 6-months, however the significance did not remain after adjusting for covariates. The main finding from the secondary objective was that there were no significant differences in the sleep outcomes between groups post-intervention.

7.1 Comparison of Primary Objective Findings to Literature

Recent research has demonstrated that sleep quantity, quality and variability are associated with adverse obesity outcomes in children, adolescents and adults (For reviews see Patel & Hu, 2008; Cappuccio et al., 2008; Hart & Cairnes, 2011). Currently the majority of the literature explores the cross-sectional relationship between sleep quantity and BMI exclusively, usually through parent-reported sleep. Therefore less is known about the relationship between sleep quality and variability with regards to preschool obesity. Additionally, markers of obesity risk other than BMI are rarely measured. There have been no Canadian studies performed measuring the relationship between sleep and obesity in preschool aged children. Therefore our study provides insight into this relationship in the Canadian context. To address these gaps in the literature, this study measured sleep quantity, quality and variability using wrist actigraphy data and observed the cross-sectional and longitudinal relationships between these variables and five measures of obesity risk: BMI, BMIz, blood pressure, body composition and waist circumference.
7.1.1 Sleep Quantity

Sleep quantity was assessed using actigraphy and was considered to be the total time spent sleeping from the time participants fell asleep at night to the time they woke up the next morning. Therefore, daytime naps were excluded from the sleep quantity variable. Main findings from the cross-sectional and longitudinal generalized estimating equation results indicated no significant associations in the expected direction between sleep quantity and obesity measures. Currently the literature is somewhat mixed in their findings with regards to sleep quantity and obesity, and different measures of sleep and obesity used in each studies complicates comparisons between them. Our findings were consistent with results from the SKOT cohort by Klingenberg and colleagues (2012), where the cross-sectional (at 3-years old) and longitudinal (measurements at 9 months, 18 months and 3 years old) between actigraphy-measured and parent-reported sleep quantity and several adiposity indicators (BMIz, sum of skin-folds, percent body fat, and fat mass) were explored in 311 Danish children. This cross-sectional and longitudinal analysis found no significant associations between sleep quantity and adiposity. Arguably, a possible reason why there were no significant associations found between sleep quantity and obesity markers in our study is due the overall inadequate sleep experienced by participants. Children in the SKOT cohort participants experienced approximately 3 more hours of sleep than our participants. Another difference between the SKOT cohort and our study is the method used to measure sleep duration. Klingenberg and colleagues (2012) used actigraphy for the cross-sectional analysis and parent-reported sleep for the longitudinal analysis.

In contrast to the above findings, there have also been studies which have demonstrated a relationship between shorter sleep quantity and obesity in preschool children. Notably, Sekine and colleagues (2002) conducted a large cross-sectional study with 8941 children (ages 2-4
years) and found a dose-response relationship between parent-reported sleep duration and obesity (determined by BMI): Compared to children sleeping 11 hours or more, sleep durations of less than 11 hours were at an increased odds of obesity. A similar dose-dependent relationship was demonstrated in a cross-sectional study by von Kries et al. (2002) which showed that 5-6 year old children (N=6862) in Germany were at a lower risk of obesity (BMI) and have excess fat mass (Bioelectrical Impedance Analysis) if they were sleeping (parent-reported) for more than 11.5 hours daily. Additionally, Anderson and Whitaker (2010) demonstrated that 4-year old children in the USA had a decreased risk of obesity (BMI) when experiencing greater than 10.5 hours of mother-reported sleep per week night. Comparing our studies effect size to that of the studies mentioned above is difficult due to the different methods used to assess sleep quantity and obesity. Most studies use only parent-report to measure sleep quantity and BMI to assess obesity risk.

There have also been several longitudinal studies which have demonstrated a relationship between sleep quantity and obesity. The most common findings have been that shorter sleep durations early in life are associated with higher BMI several years later (Bell & Zimmerman 2010; Reilly et al. 2005; Snell, Adam, & Duncan, 2007). Taveras et al. (2014) has expanded beyond BMI to measure other markers of obesity such as fat mass and waist circumference. Their findings indicate that children in Massachusetts (N=1046) with shorter sleep duration at 6-months old had higher BMI and waist circumference at 7 years of age. Consequently, these significant findings indicate a longitudinal relationship between sleep quantity and obesity, however this was not supported by our findings. Of importance is the time between measurements in these studies compared to our study. These studies ranged from 4-6.5 years between baseline and follow-up, whereas our study was 6-months between baseline and follow-
up measures. Therefore, it can be argued that there was not enough time to observe an association between change in sleep quantity and obesity markers in our study. Furthermore, children’s sleep duration was measured by parent report in these previous studies and it has been demonstrated that parents tend to over-estimate the length of time their children spend sleeping at night (Kushnir & Sadeh, 2013; Lam et al, 2011). Consequently, comparing the findings from the parent-reported sleep studies to our more objective actigraphy findings requires caution. However, the longitudinal study in New Zealand by Carter and colleagues (2011) used actigraphy to measure sleep quantity and demonstrated a relationship between longer sleep duration at age 3 years and lower BMI and fat mass at age 7 years (N=244). Once again, studies have shown a longitudinal relationship between sleep and obesity however the shorter time between baseline and follow-up may have prevented us from accurately capturing this relationship.

7.1.2 Sleep Quality

Actigraphy-measured sleep efficiency was used to assess sleep quality in this study and is defined as the ratio of time spend sleeping to time spent in bed. Therefore a higher sleep efficiency percentage is indicative of a higher sleep quality. Main findings from the cross-sectional results indicated that there were no significant associations between sleep efficiency and any of the weight status or obesity markers. While there have been no studies to date, which have objectively measured sleep quality in preschool children, sleep quality has been measured in older children with mixed findings. Notably, McNeil et al. (2015) measured sleep quantity and efficiency by actigraphy and demonstrated that in a cross-sectional analysis only sleep efficiency was inversely associated with weight, waist circumference, percentage body fat, BMIz and waist to height ratio. This study was similar to ours in that their sample was Canadian (Ottawa), they
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used an objective sleep measure and they measured several different weight status and obesity markers. Differences include their older sample (age 9-11 years) and larger sample size (N=567). Having an older sample may affect results because older children have different sleep requirements. For example, older children typically do not nap during the day, whereas preschool children do. We did not include nap times in our analyses, therefore our total sleep times may be slightly less than the actual total sleep times. Furthermore, because we had a small sample size, there was more variability in our results which may have resulted in less precise estimates. In another cross-sectional study by Martikainen and colleagues (2011), there were no significant associations found between actigraphy-measured sleep quantity and efficiency and cardiovascular function in 8-year old children from Finland. Cardiovascular function was measured by ambulatory blood pressure (N=231) and cardiovascular reactivity (N=265, assessed using a psychosocial stress test). They found no significant associations between sleep measures and cardiovascular function. Our study also measured blood pressure however instead of ambulatory blood pressure it was a measurement taken twice at the baseline health assessment and 3 times at the 6-month follow-up health assessment. Differences between these two methods of blood pressure measurement are important because ambulatory blood pressure has been shown to more accurately measure blood pressure compared to clinic measurements (Hodgkinson et al., 2011).

There have not been any longitudinal studies conducted in preschool children using actigraphy to measure sleep. One study measures sleep quantity longitudinally through parent report and includes actigraphy-measured sleep (including sleep quality) at one time point (Klingenberg et al. 2012), however this does not allow for a longitudinal observation of sleep quality. Another study measures sleep by actigraphy at ages 3, 4 and 5, but not at age seven.
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when obesity and weight status markers are measured (Carter et al., 2011). Therefore, our study provides an interesting insight into the longitudinal relationship between sleep quality and weight status and obesity markers. The main findings from the longitudinal results were that increases in sleep efficiency from baseline to 6-months were associated with lower BMIz at 6-months after adjusting for covariates. While there haven’t been any longitudinal studies using actigraphy to measure sleep quality in children, a unique study by Al Mamum and colleagues (2007) found that Australian children with parent-reported sleep problems at age 2-4 years were more likely to be obese and have a higher BMI at 21 years (N=2494). Sleep problems were assessed by a parent answering the question “As you remember your child’s behavior between 2 and 4 years of age, did he/she have irregular sleeping habits?” when the child was 5 years old. Therefore our longitudinal results support these findings, however there were several methodological differences. First, our study used a more objective measure of sleep quality, whereas Mamum et al. (2007) used one parent-reported question to measure sleep quality. Second, our study’s follow-up measures were taken 6-months after baseline, whereas Mamun et al. (2007) measured BMI at age 21. Third, our study measured the change in sleep quality from baseline to follow-up, whereas Mamum et al. (2007) only measured sleep at age 6 months and 2-4 years.

Furthermore, when comparing sleep quantity and quality among children in this study to other studies, it should be noted that means of these variables are lower than was is typically presented in the literature for this age range. This difference could be explained by a few factors. First, there are few existing studies which have objectively measured sleep quantity and quality in preschool children. Most studies use parent-report to assess sleep in young children which has been shown to result in over-estimates of sleep quantity (Kushnir & Sadeh, 2013; Lam et al, 2011). Second, our study did not include daytime naps in the total sleep time variable. Therefore,
it is difficult to compare our total sleep time results to other studies which included total nighttime sleep and daytime sleep together. Finally, not all Actigraphy studies use the same methodology, software and hardware to assess sleep. For example, in a study by McNeil and colleagues, a similar device was used to assess sleep, however this device was worn on the hip rather than the wrist. Comparing total sleep time and sleep efficiency from wrist-worn monitors and waist-worn monitors should be done with caution because waist-worn monitors have been shown to overestimate both variables compared to wrist-worn monitors (Hjorth et al., 2012).

7.1.3 Sleep Variability

Sleep duration variability was the final sleep variable considered in this study and the coefficient of variation was used to measure the variability for each participant. Main findings from the longitudinal analyses were that increases in sleep variability from baseline to follow-up were associated with higher BMI and BMIz at follow-up, therefore agreeing with the hypothesis. Also, agreeing with our hypothesis was the finding that increases in sleep variability from baseline to follow-up were associated with higher waist circumference at follow-up, however this finding did not remain after adjusting for covariates. Comparisons to literature were done with caution because methods differ with regards to how sleep variability measured. There are fewer studies measuring sleep variability compared to sleep duration because day to day variability needs to be measured over several days and is more accurately measured through actigraphy rather than parent-report. Prior to this study, there have been no studies observing the relationship between sleep duration variability and weight status and obesity markers in preschool aged children. In an American cross-sectional study by Spruyt and colleagues (2011), obese children between ages 4 and 10 years showed more variability in actigraphy-measured sleep duration on weekends compared to school days. Additionally, higher sleep duration
variability was associated with altered insulin, and low-density lipoprotein (LDL) and CRP in overweight children (N=308). This study provides a physiological explanation for the relationship between sleep variability and obesity. In another cross-sectional study by Rodriguez-Colon et al. (2015), it was demonstrated that increased actigraphy-measured sleep duration variability and sleep efficiency variability were associated with lower heart rate variability and higher heart rate in adolescents. While Spruyt et al. (2011) and Rodriguez-Colon et al. (2015) have identified a cross-sectional relationship between sleep variability and biomarkers of cardiovascular risk, a longitudinal relationship has not been explored. Therefore our study provides a novel approach to the study of actigraphy-measured sleep variability and several weight status and obesity markers through both cross-sectional and longitudinal observations of sleep variability in preschool children.

7.2 Comparison of Secondary Objective Findings to Literature

The secondary objective was to examine the extent to which preschool children who received home visits with a health educator improved their sleep quantity, quality and variability, compared to a control group. Findings indicated that there were no significant differences in the sleep outcomes between groups post-intervention. As a reminder, the changes from baseline to follow-up for the 4HV, 2 HV and control were -13.48, 13.44, and 5.34 minutes respectively for total sleep time. For sleep efficiency the mean change from baseline to follow-up for the 4HV, 2HV and control group were -0.99%, 0.35%, and 0.28% respectively. Finally for sleep variability, the mean change from baseline to follow-up for the 4HV, 2HV and control group were 0.08, -0.15, and -0.14 respectively.

Although these models were adjusted for baseline sleep measures, the small sample size created groups with differences in sleep variables at baseline. For example, the 4HV group
demonstrated a decrease in total sleep time from baseline to follow-up, however with the exception of the 2-HV group at 6-months, the 4-HV group had total sleep time means that are relatively higher than the other two groups. In contrast, the 2HV group started with lower means for total sleep time and sleep efficiency compared to the 4HV group, therefore the 2HV group had more room to improve and could explain why this group experienced greater improvements in these sleep variables.

There are few existing lifestyle interventions in the literature which have targeted sleep in preschool children in the context of weight status and/or obesity. More common are intervention studies targeting diet, physical activity and sedentary behaviour. In 2012, Kuhl and colleagues conducted a review of studies which examined the relationship between behavioural correlates of obesity in the context of prevention and intervention programs in preschool children. In this review, the authors identified that none of the studies observing sleep (versus diet, physical activity or sedentary activity) were intervention or prevention studies, however the authors made suggestions on how to change sleep behaviours in future intervention studies. For example, Kuhl and colleagues explain training parents in how to improve sleep hygiene strategies may be effective for improving obesity outcomes. For example, maintaining a regular sleep and wake schedule, having a bedtime routine, and removing televisions from the sleep environment. These suggestions are consistent with the intervention methods applied in our study.

More recently there have been three intervention studies which have targeted sleep as part of their lifestyle intervention to improve or prevent obesity in preschoolers. First, Haines and colleagues (2013) found that a home-based intervention was effective at increasing parent-reported sleep duration. This Boston-based intervention aimed to improve household routines with the goal of preventing overweight and obesity in 121 children 2-5 years old. With regard to
sleep duration, results showed that the intervention group increased by 0.75 hours per night compared to the control group from baseline to follow-up. This change is large compared to our study where the 4HV group and 2 HV group had a -0.32 minute and 0.22 minute change in sleep duration, respectively, compared to the control group from baseline to follow-up. The current study builds on this study and uses similar 6-month intervention delivery period, age of children, and content/methods of the intervention. Differences are that our study had a smaller sample size, which may reduce our ability to identify a significant intervention effect, and measured sleep through actigraphy, therefore measuring sleep efficiency and variability as well. In another intervention study called “ParentCorps” by Dawson-McClure and colleagues (2014), coaching in foundational parenting and child behaviour regulation were used to improve several health related outcomes. Included in these changes from pre- to post-test were decreases sleep problems in the boys in the study. Sleep problems were reported from the parents by answering six questions about bedtime resistance, for example “Your child struggled at bedtime, cried or refused to stay in bed”. Compared to our pilot study, the ParentCorps study had a larger sample size (n=91), used parent-reported sleep behaviours, and included participants from a low-income community. As mentioned previously, a larger sample size allows for a more precise estimate. Also, parent-reported sleep behaviours are less accurate compared to more objective methods of sleep assessment (Kushnir & Sadeh, 2013; Lam et al, 2011). Furthermore, participants in the ParentCorps study were from a low-income community and were ethnic minorities, while the participants in our study were from families with diverse incomes and was not minority specific. This difference is important to note because the ParentCorps sample may have started their intervention with worse sleep compared to our sample. While the overall aim of their intervention study was similar to ours (to prevent obesity), the intervention methods differed.
The ParentCorps intervention used 14 two-hour group sessions over 5 months to teach parents healthy parenting strategies. In contrast, the intervention called the Ballabeina Study by Puder et al. did not show any improvements in parent-reported sleep duration from pre to post intervention. This was a school-based intervention which targeting preschool children, parents, teachers and the school environment. The intervention involved physical activity, nutrition, media use and sleep components. Students participated in physical activity sessions and nutrition/media use/sleep sessions. Teachers participated in two workshops prior to the intervention and one meeting during the intervention. They received all the intervention materials in advance and were supported by Health Promoters for the physical activity sessions. Parents participated in three evening meetings where healthy behaviour with regards to physical activity, diet, sleep and screen time were discussed. Finally, the environmental changes included curricular changes and structural changes to promote physical activity. The intervention had a much larger sample size compared to ours (n=652) and occurred over one school year.

In sum, while there have been interventions which have targeted sleep in preschool children in the context of obesity prevention, both methods and findings have been inconsistent. A possible reason why our study did not find differences between intervention groups and the control group with regard to changes in sleep variables could be due to the small sample. For these analyses only 13, 7 and 7 participants were randomized to the 4HV, 2HV and control group respectively. Also, six months may not be a long enough time to see changes in sleep in preschool children. Therefore when the Guelph Family Health Study expands to recruits more families, and collects measures every six months for many years, changes in sleep may become more significant.
Contribution to the Literature

To date there have been no Canadian studies observing the relationship between sleep and obesity in preschool children. Previous research highlights that there is a need to further understand the relationship between sleep and obesity in preschool children because there seems to be a negative relationship between the two in older children, adolescents and adults (Meier-Ewert et al., 2004). Furthermore, existing research is limited in parent-reported sleep measurement, where parents tend to over-estimate the total sleep their children spend sleeping (Kushnir & Sadeh, 2013; Lam et al, 2011). Through use of actigraphy in our study we measure sleep more objectively, while also being able to measure sleep quality and sleep variability. Also, most studies use only BMI as a marker of weight status, therefore other measures of adiposity are required to further understand the relationship between sleep and obesity. By measuring BMI, BMIz, blood pressure, fat mass and waist circumference we provide a more comprehensive assessment of weight status and obesity risk in our sample.

Another contribution of our study is the long-term nature of the Guelph Family Health Study and the ability to measure relationships cross-sectionally and longitudinally, and observe the effect of an intervention. Most previous studies with preschoolers have observed only the cross-sectional relationships and studies that have observed the longitudinal relationship have used only parent-reported sleep duration. Therefore, our study contributes to the literature through cross-sectional and longitudinal analysis of the relationship between sleep and obesity, and the effect of a family-based intervention on sleep in the Canadian context.

Limitations

While our study provides evidence of a possible relationship between sleep duration, quality and variability and markers of weight status and obesity in preschool children, the results
of the study should be interpreted with consideration to study limitations. First, the sample size was not optimal as each of the analyses included a sample size of less than 50 participants. Therefore there was more variability in our results which may have resulted in less precise estimates. This is especially important to consider in the secondary objective results because the sample size was divided into three groups (4HV, 2HV and control group), to compare the effect of the intervention. This was the pilot version of the Guelph Family Health Study, therefore when the study expands to include more families, a larger sample size will be available. In addition to being a pilot study, another reason why the sample was less than ideal was due to missing accelerometer data. Several participant accelerometer data files were corrupt after trying to download them. Also, several participants only wore the activity monitor for one or two nights, therefore their data was excluded from the analyses.

The second limitation was the difficulty in measuring waist circumference in the preschool children. It is difficult measuring waist circumference in young children because they tend to move around quite a bit and stick out their stomachs while being measured. Therefore, the research assistants reported difficulty in obtaining the most accurate measurements of waist circumference. Through the pilot, these techniques have improved and moving forward with the Guelph Family Health Study more accurate measures of waist circumference can be obtained.

A third limitation is the use of actigraphy to measure sleep duration, quality and variability in this study. While actigraphy is a more valid measure of sleep than parent-report (Kushnir & Sadeh, 2013; Lam et al, 2011), the gold-standard of sleep assessment is polysomnography, and involves overnight monitoring of the brain and body by an electroencephalogram test (National Sleep Foundation, 2014). Because this test monitors brain activity directly, it is currently the most accurate measure of sleep behaviour. However, this
method is not practical for use in large-scale study such as the Guelph Family Health Study. The test must be performed in a lab and would measure sleep that wouldn’t be representative of a child’s typical sleep experience at home (Bedtime routines, room lighting, etc.).

The fourth limitation is that the analyses performed in this study did not take into consideration the goals families made with their health educator at their first home visit. The 2HV and 4HV group received two and four home visits, respectively, from a Health Educator over the 6-month intervention period. At the first home visit the Health Educator helped the parent(s) involved in the study choose one or more goals to work on over the course of the study. The options were physical activity, diet, sleep, and screen time, and not all families chose sleep as one of their goals. Therefore, it is possible that families who chose not to work on sleep as a goal may have not been interested in improving their sleep behaviours or they were already confident that their current behaviours didn’t need improvement. Additionally, families which chose to work on sleep as a goal may have been experiencing poorer sleep and therefore had more room to improve from baseline to 6-months.

The fifth limitation is the potential mediating effects of diet and physical activity which were not included as confounders in the analyses of this study. These variables have been shown to mediate the relationship between sleep and adiposity in children, adolescents and adults (Golley et al., 2013; Patel 2009). Therefore, the extent to which these variables may have played a role in the underlying mechanism of the sleep-adiposity association in the present study is unknown and should be considered in future research.

The sixth limitation is the process by which participants were recruited for participation in the Guelph Family Health Study Pilot. Participants were recruited through flyers, social media, a local Family Health Team, the Guelph Community Health Centre, and word-of-mouth
in Wellington County, Ontario, Canada. Therefore this self-selection process may have created a sample which could be different than those who chose not to participate in the study. For example, parents who chose to participate may have a more keen interest in improving their children's health compared to parents who opted not to participate. Additionally, parents who chose to participate may have already been practicing many of the healthy behaviours emphasized in the Guelph family health study. Therefore, our sample may have better sleep than the average Canadian preschool population.

The next limitation is the 6-month time period from baseline to follow-up. Most longitudinal studies have followed participants for at least one year, which may be more adequate in terms of observing changes in adiposity. While 6 months has allowed for some associations to be found in the longitudinal results, further time points would allow for a greater understand of the temporal relationship between sleep and weight and obesity status.

The final limitation is the differences in sleep variables between groups (2HV, 4HV and control) at baseline. Due to the small sample size, the groups were not equal after randomization, therefore this is important to consider when interpreting the results of the secondary objective. For example, as previously mentioned (See section 7.2) the 4HV group had a much higher total sleep time mean at baseline therefore showed the smallest improvement from baseline to follow-up.

7.5 Strengths

Despite the several limitations in our study, there are many strengths as well which make this study a novel approach to sleep and obesity research and an interesting addition to the literature. First, the age of participants included strengthened the study because few studies have observed the relationship between sleep and obesity in preschool children. With regards to
Canadian studies specifically there have been no studies in preschoolers. Similarly, there have been no longitudinal studies using actigraphy with preschoolers. Therefore our study provides insight into how sleep is associated with obesity and weight status in this younger age group.

The second strength of our study is the use of actigraphy-measured sleep duration, quality and variability. To date there have been few studies using actigraphy to measure sleep with regards to obesity and none of these studies have been conducted in the Canadian context (Klingenberg et al., 2012; Carter et al., 2011). As previously mentioned, validity studies have shown that parents tend to over-estimate the amount of time their child sleeps during the night (Kushnir & Sadeh, 2013; Lam et al, 2011). Furthermore, actigraphy allowed us to measure sleep quality and variability in addition to sleep duration. Therefore, we were able to capture a more comprehensive picture of participant sleep behaviours. The inclusion of these variables was important because previous research indicates that sleep variability and quality might be associated with obesity related markers and behaviours, independent of nighttime sleep duration (McNeil et al., 2015; He et al., 2015).

Third, using four measures of obesity and weight status strengthened our study. As measures obesity and weight status we measured BMI, BMIz, blood pressure, fat mass and waist circumference. Similar to how we measured several sleep variables, this diversity has allowed a more comprehensive assessment of obesity and weight status. Using several markers was important because a few studies have observed a relationship between sleep and markers of obesity risk, other than BMI (Chaput et al., 2011; Taveras et al., 2014). Therefore, studies measuring only BMI may not be able to capture this relationship.

The fourth strength of the study was the use of Generalized Estimating Equations (GEE) for the analysis. The GEE model was used instead of Linear Regression Models because there
were several pairs of siblings included in each of the analyses. The GEE model can correct for the possible correlation of outcomes among siblings while estimating a model (Liang & Zeger 1986). The next strength of the study was that while observing the relationship between sleep and obesity, several confounders were accounted for. For the cross-sectional analyses, age and sex were included in the models. For the longitudinal analyses, age (except BMIz), sex (except BMIz), intervention status and baseline obesity variable were included in the model. The inclusion of intervention status as a covariate in the model was important to be able to include participants across all three groups in the longitudinal analysis. Due to the small sample size, simply using the control group in this model was not feasible. For comparison between groups with regards to the effect of the intervention, age, sex, baseline BMI and baseline sleep variable were included in the analysis. Therefore, the inclusion of these variables as covariates allowed for us to control for the potential confounding between these variables and our outcome variables. Due to the small sample size, we included only the most significant covariates to maximize the power and precision of the estimate.

The fifth strength of the study is the longitudinal design used to observe the temporal relationship between changes in sleep variables and subsequent obesity and weight status. A limitation to previous studies including preschool children was that they only measured sleep and obesity/weight status at one time point. In other words, for their longitudinal analyses sleep was measured at one time point, then an obesity related variable was measured at a later date and associations were made between the two (Taveras et al., 2014; Bell & Zimmerman 2010; Reilly et al. 2005; Snell, Adam, & Duncan, 2007; Klingenberg et al. 2012; Carter, Taylor, Williams, & Taylor 2011; Mamun et al., 2007). The strength of our study was the using the change in sleep
variables from baseline to follow-up, which better captures the sleep patterns of participants over time.

7.6 Next Steps

While this study addresses many of the gaps in the literature, there are several ways in which future studies may expand and improve based on the principles presented here. First, while this study follows participants longitudinally for 6-months, further follow-up time-points may be beneficial. This longer time frame will allow a greater understanding of the temporal relationship between sleep though early childhood through adulthood. Second, this study measured BMI, BMIz, blood pressure, fat mass and waist circumference as markers of obesity and weight status. To deepen the understanding of the physiological mechanisms responsible for the relationship between sleep and obesity, measuring blood biomarkers such as blood triglycerides, blood glucose, and cholesterol is recommended. Additionally, several studies have investigated the mechanism responsible in adult samples and have found results suggesting that there may be a hormonal response at play. Notably, leptin ghrelin, cortisol and the orexin system have been studied, therefore measuring these hormones may provide further insight into the mechanisms responsible for this relationship. Third, bed times and wake times have also been associated with BMI in older children (Golley et al., 2013). Therefore including these variables in future analyses with preschool children would be beneficial. Finally, increasing the number of nights that participants wear activity monitors is recommended for future studies. For the purposes of this study, participants with at least two nights of valid sleep data were included in the analyses to allow for the largest sample size possible. However, to ensure that the mean sleep variables are as representative of each participant’s average sleep behaviour as possible, at least three nights of sleep data is what is seen in previous literature.
8.0 Conclusions

In summary, this thesis explored the cross-sectional and longitudinal associations between sleep and obesity in preschool children as well as the effect of the Guelph Family Health Study intervention on sleep in preschoolers. The sleep variables included in this study were sleep quantity, sleep quality and sleep quantity variability and the obesity and weight status markers were BMI, BMIz, blood pressure, fat mass and waist circumference. There were 46 preschool children included in this study, however each analyses had a different sample size due to missing data for some of the variables. These participants were children participating in the Guelph Family Health Study. In the cross-sectional analyses, none of the hypothesized associations were found to be significant. In the longitudinal analyses, significant associations were found between increases in sleep efficiency (from baseline to 6-months) and lower BMIz (at 6-months), and increases in sleep variability and higher BMI and BMIz. Also, a significant association was found between an increase sleep efficiency from baseline to 6-months and lower waist circumference at 6-months, however this significance did not remain after adjustment for covariates. The results from the secondary objective indicate that there were no significant differences between the intervention groups and the control group in terms of changes in sleep variables from baseline to 6-months. However, at baseline groups started at different levels of sleep variables due to the small sample size, therefore this may explain the lack of significant results for this objective. This study provides insight into how sleep may play a role in obesity outcomes in preschool aged children. The results of this study can inform future obesity prevention interventions and help guide future studies exploring the relationship between sleep and obesity in preschool children.
9.0 References


