Bi-directional Association between Sleep and

Outdoor Active Play among 10- to 13-year-olds

By

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Abstract

**Purpose:** The purpose of this study was to investigate whether there is a bi-directional relationship between sleep characteristics (time in bed, sleep duration, sleep efficiency) and outdoor active play (OAP) within children.

**Methods:** Participants consisted of 433 children aged 10-13 years. Time in bed, sleep duration, and sleep efficiency were measured for 8 consecutive nights using data from a sleep log and Actical accelerometer. OAP was measured for the 7 days that fell in between these 8 nights using a combination of data from accelerometers, global positioning system (GPS) loggers, and geographic information system (GIS). Generalized estimating equation (GEE) models with first-order autoregressive matrix [AR(1)] were used to assess the relationships of interest. These models accounted for the repeated measures nested within participants and adjusted for several confounders.

**Results:** Time in bed, sleep duration, and sleep efficiency were not significantly associated with the following day’s OAP. There was a small but significant ($p = 0.017$) association between OAP and the following night’s time in bed, which suggested that each hour increase in OAP was associated with a 5.1 minute (95% CI: 0.9 - 9.4) increase in time in bed. OAP was not significantly associated with sleep duration or sleep efficiency.

**Conclusions:** None of the sleep characteristics predicted the following day’s OAP. Higher levels of OAP predicted a longer time in bed, but not sleep duration or sleep efficiency.
Co-Authorship

This thesis is the work of Yingyi Lin under the supervision of Dr. Ian Janssen. The research question was a collaborative effort between the two authors. Yingyi Lin performed data entry, cleaning and reduction of the Active Play Study databases, developed the SAS program to derive the objective sleep and OAP variables from the accelerometer, GPS and GIS data, performed all statistical analyses, interpreted the results, and wrote all thesis chapters. Dr. Janssen provided guidance on the statistical analysis, interpretation of results and revised the entire thesis and its associated work extensively.
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<tr>
<td>AR(1)</td>
<td>First order autoregressive matrix</td>
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<td>BMI</td>
<td>Body mass index</td>
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<td>GEE</td>
<td>Generalized estimating equation</td>
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<td>GIS</td>
<td>Geographic information system</td>
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<tr>
<td>GPS</td>
<td>Global positioning system</td>
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<tr>
<td>ICC</td>
<td>Intra-class correlation coefficient</td>
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<td>LPA</td>
<td>Light intensity physical activity</td>
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<td>MVPA</td>
<td>Moderate-to-vigorous intensity physical activity</td>
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<td>OAP</td>
<td>Outdoor active play</td>
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Chapter 1

General Introduction

1.1 Introduction

Sleep is important for child and adolescent health because it allows the diurnal rhythm of hormones needed for growth, maturation and energy homeostasis to act properly. Insufficient sleep duration and quality during childhood and adolescence is associated with an array of psychosocial and physical health deficits such as poor cognitive development, impaired academic performance, accidental injuries and an increased risk of overweight and obesity. Over the past century, there has been consistent and rapid decline in sleep duration such that young people sleep about 100 minutes/day less now than they did 100 years ago. In addition to a shortened sleep duration, concerns have been raised about a poor sleep quality. The reported prevalence of poor sleep quality among children and adolescents varies from 11% to 47%. Physical activity, like sleep, is a modifiable behaviour that is associated with numerous physical and mental health outcomes in children and adolescents. For instance, one systematic review concluded that there are dose-response relations between physical activity and blood cholesterol, blood pressure, metabolic syndrome, obesity, bone mineral density and depression. Despite its health benefits, a lack of physical activity remains a significant public health problem worldwide. More than 80% of 13-15 year olds do not accumulate the recommended 60 minutes of moderate-to-vigorous physical activity (MVPA) on a daily basis.
In recent years, some studies have suggested there is a connection between sleep and physical activity. In adults, experimental studies have consistently shown that sleep promotes physical activity and that being physically active is beneficial for sleep.\textsuperscript{14–26} However, large-scale observational studies examining the bi-directional association between sleep and physical activity in pediatric populations have produced conflicting and inconsistent results.\textsuperscript{27–32} Thus, it is unclear if this bi-directional relationship exists in children and adolescents, who accumulate their physical activity in a different manner from adults. Specifically, while adults tend to accumulate their physical activity through bouts of continuous and structured exercise, children accumulate a lot of their physical activity through outdoor active play (OAP), a highly sporadic and unstructured form of physical activity.\textsuperscript{33,34} The research in this thesis aims to address some of the gaps that currently exist in sleep and physical activity literature among the pediatric population.

\section*{1.2 Overview of Thesis}

This thesis examines whether there is a bi-directional relationship between children’s sleep characteristics (including time in bed, sleep duration and sleep efficiency) and OAP. The conceptual framework that guides this thesis is shown in Figure 1.1. This figure illustrates that several mechanisms might explain why sleep quantity and quality could promote OAP. These mechanisms include increasing energy and growth hormone and decreasing fatigue and insulin resistance. In turn, a number of biological mechanisms could explain why OAP could benefit sleep characteristics including body temperature elevation, increased secretion of growth
hormone and melatonin, and decreased glucose concentrations. The conceptual framework also recognizes that the bi-directional relationship between sleep characteristics and OAP could be confounded by several factors that are not in the causal pathways. Age is associated with shortened sleep duration\(^35\) and a decreased level of OAP.\(^36\) Sex difference exists such that girls sleep slightly longer than boys,\(^37\) while boys tend to play outdoors more than girls.\(^36\) Lower level of OAP and shorter sleep duration have also been observed among children and adolescents with a lower family socioeconomic status\(^38-41\) and ethnic minorities.\(^39,40,42\) Decreases in obesity measures, such as the body mass index (BMI), are associated with higher level of OAP\(^43\) and longer sleep duration.\(^44\) Children’s maturity status influences both sleep\(^45\) and physical activity.\(^46\) Healthy eating behaviours are associated with both sleep\(^47\) and OAP.\(^48\) Young people with chronic medical condition(s) reported limited OAP\(^49\) and a shorter sleep duration and poorer sleep quality.\(^50\) Additionally, children play outdoors more often and sleep longer on non-school days than school days,\(^37,51,52\) and on days with more daylight hours.\(^53,54\) Some physical environmental characteristics of the home neighbourhood, such as green spaces\(^55-59\) and automobile traffic noise,\(^60\) are also factors associated with both OAP and sleep. OAP could also be related to other types of physical activity such as organized sport and active transportation. Lastly, since time in a day is finite (i.e., fixed at 24 hours), both sleep and OAP may be associated with the wear time of the measurement devices during waking hours.
Figure 1.1. Conceptual framework of thesis

This thesis examines whether there is a bi-directional relationship between children’s sleep characteristics (i.e. time in bed, sleep duration and sleep efficiency) and OAP while controlling for selected confounders, i.e. whether (1) children’s nighttime sleep characteristics is associated with their OAP in the following day; (2) children’s OAP during the day is associated with their sleep characteristics in the subsequent night.

1.3 Objectives and Hypotheses

The objectives and hypotheses of this thesis research are:

1) To determine whether children’s sleep characteristics (including time in bed, sleep duration and sleep efficiency) at night are associated with the amount of OAP they accumulate the following day. It is hypothesized that sleep characteristics are positively associated with OAP.
2) To determine whether children’s OAP during the day is associated with their sleep characteristics in the subsequent night. It is hypothesized that daytime OAP is positively associated with sleep characteristics.

1.4 Scientific and Public Health Importance

Sleep and physical activity may be co-dependent health behaviours that influence each other. To date, the bi-directional association between sleep and physical activity has not been well investigated, and the studies that do exist have produced conflicting and inconsistent results, and suffer from measurement bias. Additionally, observational research examining the bi-directional relationship between sleep and OAP among children and adolescents is of significant public health importance. First, it could provide evidence-based information for future experimental studies to help clarifying possible causal effects between daily lifestyle behaviours. Second, it could shed light on developing effective population interventions to promote healthy child development. For example, an intervention that aims to increase physical activity could not only increase children’s activity level, but might also improve the quantity and quality of sleep.61

1.5 Thesis Layout

This thesis conforms to the guidelines for a manuscript-based thesis as recommended by the Queen’s School of Graduate Studies and Research.62 The first chapter is a general
introduction to the main subject area of this thesis. The second chapter critically reviews the literature surrounding sleep characteristic, OAP, and their possible interrelationships. The third chapter is the manuscript. The fourth chapter summarizes the findings and provides an overall discussion. Finally, several appendices are included at the end of the document. Many of these appendixes provide comprehensive details of the research methods that could only be summarized in the manuscript chapter.
1.6 References


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Chapter 2

Literature Review

2.1 Overview

This literature review aims to (1) review the biological mechanisms linking sleep characteristics (i.e. time in bed, sleep duration and sleep efficiency) with physical activity; (2) summarize and critically evaluate the literature that has examined the bi-directional relationships between sleep and physical activity among pediatric populations; (3) provide an overview on the measurements of sleep characteristics and physical activity; and (4) provide a rationale for this thesis in terms of its potential implications for public health.

2.2 Definition and Conceptualization of Key Terms

In Canada, a child usually refers to a person aged less than 12 years, and an adolescent a person aged 12 to 17 years. The research project in this thesis focused on pre and early adolescents (i.e., 10 to 13 years). Because the number of studies in this specific age range is limited, the literature review covers the entire school-aged period (i.e., ages 5-17). When studies of children and adolescents were unavailable, adult literature was referred to.

Sleep can be defined as an active, repetitive and reversible state of perceptual disengagement from and unresponsiveness to the environment.\(^1\) It is an essential component of children’s development required for their physical and mental health, learning, memory processes and school performance.\(^2\text{-}^5\) Time in bed reflects the total amount of time during which
the individual is in bed, which is of clinical significance and supports a diagnosis of insufficient sleep.\textsuperscript{6} \textit{Sleep duration} quantifies the actual time during which the individual is asleep.\textsuperscript{7} \textit{Sleep quality} indicates to how well an individual experiences sleep.\textsuperscript{7} A commonly used measure of sleep quality is \textit{sleep efficiency}, which refers to the percentage of total time in bed spent sleeping.\textsuperscript{6,7} In 2016, the first Canadian sleep recommendations were published. They recommend that children aged 5-13 years should sleep 9 to 11 hours per night with consistent bed and wake-up times.\textsuperscript{8}

\textit{Physical activity} is bodily movement that increases energy expenditure.\textsuperscript{9} It can be of a light (energy expenditure 1.5 - 2.9 times above rest), moderate (3.0 - 5.9 times above rest), or vigorous (\geq 6 times above rest) intensity.\textsuperscript{10} It is recommended that school-aged children and adolescents accumulate at least 60 minutes per day of moderate-to-vigorous intensity physical activity (MVPA) and several hours per day of light intensity physical activity (LPA).\textsuperscript{8} Behaviours that contribute to a child’s total daily MVPA and LPA are: (1) organized sports and programs (e.g. hockey practice, soccer game, dancing class), (2) physical education class and other activities that occur as part of the school curriculum, (3) active transportation (e.g., walking to the corner store, biking to school), (4) \textit{active play} (e.g. playground activities, ball games played in the street, tag), and (5) incidental activities of daily living (e.g. walking around the home, shopping).\textsuperscript{11} Physical activity includes but is not limited to “exercise”, which is defined as planned, structured, and repetitive physical activities.\textsuperscript{12} Many of the physical activities that children engage in do not qualify as exercise. For instance, active play is sporadic, highly unscheduled, and unorganized.\textsuperscript{11,13,14} Although active play can be performed both indoors (e.g., active video games, hide-and-seek) and outdoors (e.g., road hockey, running and jumping around), the proposed thesis will focus on \textit{outdoor active play} (OAP) since it is a more vigorous
form of play, and that active video games are not recommended as a strategy to increase children’s daily physical activity.\textsuperscript{15,16}

In the proposed thesis, \textit{acute effects} refer to the effects of sleep on physical activity, or the effects of physical activity on sleep, that occur within short time exposure window, i.e. less than one week. \textit{Chronic effects} refer to effects that occur over a longer time exposure window, i.e. equal to or greater than one week.\textsuperscript{17}

\section*{2.3 Importance of Sleep and Physical Activity}

\subsection*{2.3.1 Health Benefits of Sleep and Prevalence of Insufficient/Poor Sleep}

Sleep allows the diurnal rhythm of hormones needed for children’s growth, maturation and energy homeostasis to act properly.\textsuperscript{5} Among children and adolescents, sufficient sleep quantity is associated with lower adiposity indicators, fewer accidental injuries, better emotional regulation, better cognitive development, better academic achievement, and a better quality of life and well-being.\textsuperscript{3,7,18–23} Sleep quality (and efficiency) also has numerous physical and mental health benefits for young people. For example, children’s behaviour, emotional state and cognitive function are associated with sleep quality.\textsuperscript{2,24–27}

The consensus finding across epidemiologic studies worldwide is that a large proportion of school-aged children are not getting enough sleep.\textsuperscript{28–33} In Canada, recent data suggest that a third of 10-13 year olds do not meet the sleep duration recommendations,\textsuperscript{33} and report trouble falling or staying asleep.\textsuperscript{34} Self-reports of sleep duration and quality used in most of these large-scale epidemiologic studies often overestimate actual sleep duration when compared with
objectively measured sleep amounts, signifying that the problem of insufficient and poor sleep in children may be even greater than currently available statistics suggest.\textsuperscript{35}

2.3.2 Health Benefits of Physical Activity and Prevalence of Physical Inactivity

Within children and adolescents, dose-response relations exist between physical activity and several physical and mental health indicators such as, blood cholesterol, blood pressure, metabolic syndrome, obesity, bone mineral density, immune system function and depression.\textsuperscript{36,37} The active play domain of physical activity not only has positive impacts on children’s physical health through energy expenditure, but also reduces stress and aggressiveness, and leads to an increased sense of well-being at the emotional level.\textsuperscript{13,38,39} Moreover, since OAP often takes place in the absence of parents, it provides children with opportunities to 'make it on their own' and develop a sense of independence, which at the social skill level increases children’s cooperation, interaction and building a social network, and at the cognitive development level that improves creativity, problem-solving, attention and self-discipline.\textsuperscript{38,40–43}

Physical inactivity remains a significant public health concern among children and adolescents. Worldwide, more than 80\% of adolescents do not meet the physical activity guidelines.\textsuperscript{44} In Canada, only 9\% of the school-aged children and adolescents accumulate at least 60 minutes of MVPA on a daily basis.\textsuperscript{14} Canadian physical activity experts have suggested that OAP is a domain of physical activity that is particularly deficient.\textsuperscript{13,14} These experts have also highlighted that active play is greatly understudied by comparison to the other domains of physical activity such as organized sport, physical education and active transportation.
2.4 Sleep as a Predictor of Physical Activity

2.4.1 Possible Mechanisms

There are several potential mechanisms by which a shortened sleep quantity could influence physical activity (Figure 2.1). The most direct effect of inadequate sleep on physical activity could be through feelings of sleepiness and tiredness, as discussed in studies of adults\(^45-47\). Sleepiness and tiredness could be mediated by increased ratings of perceived exertion (e.g., it feels harder to do physical activities after sleep deprivation) and a lack of motivation to engage in physical activity\(^{48,49}\). In adolescents, Carskadon et al. found that this sleepiness recovers to regular levels after one night of sufficient sleep\(^50\). Second, Bromley et al. hypothesized that the observed decrease in physical activity after sleep restriction may be a compensatory mechanism to offset the metabolic cost of extended wakefulness during the shortened sleep duration\(^51\). Finally, a lack of sleep could influence physical activity by contributing to hormonal changes including an increase in insulin resistance and corresponding decrease in glucose tolerance, resulting in a reduced time to exhaustion when exercising, and a reduced secretion of growth hormone, which has been found to impair maximum oxygen uptake in exercise performance and capacity among adults\(^{48,52,53}\). All the aforementioned biological mechanisms linking sleep quantity to physical activity are acute or short-term effects that would primarily influence physical activity on the day after the sleep deprivation occurred. Therefore, studies looking at whether a shortened sleep quantity influences physical activity should be conducted over short periods of time.
2.4.2 Acute Effects of Sleep on Physical Activity

2.4.2.1 Experimental Studies

To date, only one experimental study has assessed the acute effects of sleep quantity (i.e. time in bed) on physical activity among a pediatric population. Using a within-subject counterbalanced design, Hart et al. examined whether experimental changes in time in bed lead to changes in sedentary behaviour and physical activity within a group of 37 children aged 8-11 years. Compared with when the children increased their sleep, when they decreased their sleep by a mean of 2 h 21 min, they reported watching an additional hour of television each day ($p < 0.001$). Overall, children were less active on average (i.e. with less mean activity counts per
epoch) if time in bed was shortened. However, children’s total activity counts accrued throughout the entire day were higher after the shortened sleep condition.\textsuperscript{54}

Observation from Hart et al.’s research is consistent with the findings in the adult literature. In general, studies that focused on mean daytime activity level observed that adult participants were less active following sleep restriction.\textsuperscript{51,55–57} However, studies that assessed total energy expenditure throughout the 24 hour period and/or during all waking hours generally found that total physical activity either did not differ\textsuperscript{58–60} or was greater following sleep restriction.\textsuperscript{61–63} These findings suggest that decreased sleep is associated with lower average activity levels, yet increased overall energy expenditure. Additional time awake may help compensated for these lower mean activity levels, such that the participants were able to accumulate more physical activity throughout the waking hours given the longer period of time they spent awake during these experimental conditions. It is possible that the increased movement in the short sleep condition was a result of an increased effort to stay awake.

\textit{2.4.2.2 Observational Studies}

To my knowledge, a total of six observational studies have investigated the acute effects of sleep on the following day’s physical activity, with one conducted in adults and the others in children. Although all of these studies used objective measures of both sleep and physical activity, their findings were inconsistent and conflicting.

Among healthy older women, Lambiase et al. found a positive association between sleep quality and physical activity, i.e. a 1\% increase in sleep efficiency was associated with a 0.32\% increase in total daily physical activity and 0.54\% increase in MVPA the following day.
However, no association was found between sleep quantity and physical activity/MVPA in the same study.\(^64\) Three studies conducted in children also found no temporal association between sleep quantity/quality and physical activity/MVPA level in the subsequent day.\(^65\)–\(^67\) Even more unexpectedly, in a group of healthy school-aged children, Pesonen et al. observed negative associations between sleep and physical activity. Specifically, for each one standard deviation unit increase in sleep duration and sleep efficiency the preceding night, physical activity the following day decreased by 0.09 and 0.16 standard deviation units, respectively.\(^68\)

### 2.4.3 Chronic Effects of Sleep on Physical Activity

Although the biological mechanisms that link sleep characteristics and physical activity are acute, several studies have also examined whether sleep is associated with physical activity after a follow-up period of several years. For example, in a group of 40-60 year-old adults, Haario et al. found that frequent insomnia symptoms at baseline was associated with physical inactivity 5-7 years later.\(^69\) Another prospective study of older adults reported that better initial sleep quality predicted higher levels of physical activity two years later.\(^49\) However, the authors of these studies provided unconvincing explanations for these associations. In particular, they suggested that “sleepiness” or “physical energy” explain the observed associations between sleep and physical activity 2 or more years later.\(^49,69\) In my opinion, these are acute (short-term) effects that would not persist for such an extended period of time.
2.5 Physical Activity as a Predictor of Sleep

2.5.1 Possible Mechanisms

Physical activity could influence sleep through several pathways, some of which are acute and some of which are chronic (Figure 2.2). Some researchers have hypothesized that the increase in body temperature that follows a bout of exercise could promote better sleep over the short term.\textsuperscript{70–72} Second, the decreased glucose level and increased growth hormone release that occur after physical activity have been found to benefit sleep through homeostatic sleep regulation.\textsuperscript{73,74} In spite of these beneficial effects, physical activity late at night is reported to significantly decrease melatonin levels during sleep, which contributes to disturbed sleep.\textsuperscript{75} This, to some extent, implies that only physical activity in proper contexts could benefit sleep. For example, physical activity performed outdoors with bright light exposure was found to have sleep-promoting effects, i.e. prolong sleep duration and improve sleep quality, by positively affecting sleep-related hormonal responses, such as increasing melatonin level.\textsuperscript{76,77} In addition to these acute effects, physical activity could have chronic effects on sleep.\textsuperscript{73} It is well-established that chronic exercise results in reductions in trait anxiety and has anti-depressive effects.\textsuperscript{78–80} Habitual exercise also enhances vagal modulation, with a resulting decrease in heart rate,\textsuperscript{81} which could hence improve sleep.\textsuperscript{17,73}
2.5.2 Acute Effects of Physical Activity on Sleep

2.5.2.1 Experimental Studies

To my knowledge, only one experimental study has assessed the acute effects of physical exercise on sleep among a pediatric population. In that study a group of healthy school-aged children aged 11-13 years performed three bouts of ten minutes of intense cycling exercise at 85-90% maximal heart rate. While sleep efficiency increased significantly by 4.4% after the exercise condition, exercise did not benefit sleep duration.\textsuperscript{74} This evidence, albeit limited, is consistent with results from the extensive laboratory studies conducted among healthy adult populations. As summarized in a recent meta-analysis, the adult literature indicates that exercise has small but beneficial and acute effects on sleep duration and sleep efficiency.\textsuperscript{17}
2.5.2.2 Observational Studies

I am aware of four observational studies that have investigated the acute effects of daytime physical activity on sleep using objective measurements within a pediatric sample.\textsuperscript{65,66,68,82} As summarized in the following paragraph, the results of these four studies are inconsistent.

In a cohort of 1,231 children aged 6-10 years, Ekstedt et al. found positive association between daytime total activity/MVPA and sleep efficiency in the following night. Specifically, for each one standard deviation unit increase in both total activity and MVPA during the day, sleep efficiency increased by 0.024 standard deviation units. However, sleep duration was not associated with MVPA.\textsuperscript{65} Other researchers have found null or negative association between daily sleep and physical activity in the subsequent night. For example, in a group of 65 children aged 8-11 years, Vincent et al. found that there was not a significant temporal association between daytime sleep and physical activity duration/efficiency.\textsuperscript{66} Among 7-year-old children, Nixon et al. also reported no significant association as measured for 24 hours.\textsuperscript{82} However, in a cohort of 275 children aged 8 years, Pesonen et al. found a negative association, which suggested that higher level of children’s physical activity during the day was related to shorter sleep duration and lower sleep efficiency in the following night. Specifically, for each one standard deviation unit increase in physical activity during the day, sleep duration and efficiency decreased by 0.30 and 0.16 standard deviation units, respectively. Further, it was found that gender moderated the associations between sleep and physical activity duration, with stronger effects among girls than boys.\textsuperscript{68}
2.5.3 Chronic Effects of Physical Activity on Sleep

A recent meta-analysis that summarizes the evidence from experimental studies among adult populations showed that regular exercise interventions lasting from 2 to 52 weeks have small beneficial effects on sleep duration and sleep efficiency.\textsuperscript{17} These experimental findings differ from the results of observational studies. For example, Haario et al. found no significant association between physical inactivity at baseline and insomnia symptoms after a 5-7 year follow-up.\textsuperscript{69} Similarly, another 2-year follow-up study showed that initial physical activity level did not significantly predict later sleep quality.\textsuperscript{49} These “null” associations observed between sleep and physical activity do not support the aforementioned possible pathways by which chronic regular physical activity improves sleep, and suggest that the associations between sleep and physical activity should be studied acutely.

2.6 Bi-directional Associations between Sleep and Physical Activity

Based on the evidences from experimental studies discussed above, it could be hypothesized that there is a bi-directional relationship between sleep and physical activity in both adults and children. That is, insufficient and (or) poor sleep would decrease physical activity the following day, and lower levels of physical activity during the day would in turn hinder sleep in the subsequent night. Conversely, sufficient/good sleep and higher level of physical activity could be mutually beneficial, and trigger a virtuous circle that improves health outcomes.

Observational studies examining the bi-directional relationship between sleep and physical activity, however, have produced conflicting results. Two studies found positive relationship between sleep and physical activity,\textsuperscript{64,65} five studies found non-significant
associations, and two studies found negative association, i.e. longer sleep duration and (or) higher sleep efficiency was followed by decreased physical activity and (or) MVPA, and that increased physical activity and (or) MVPA was followed by shortened sleep duration and (or) lower sleep efficiency. Results are even inconsistent within different subsamples examined within the same study.

In terms of the unexpected findings, a few researchers have presented possible explanations. For the negative association found between sleep and physical activity, Pesonen et al. hypothesized that the child’s “inherent/trait activity level” might manifest itself in a higher physical activity level during both daytime and night, which may not only explain children’s physical activity during the day, but may also define the level of activity during their sleep at night. This by definition decreases sleep duration and (or) efficiency if the child has high level of physical activity/MVPA during the day. This explanation is in line with the findings from other research that shortened sleep duration, and (or) poor sleep quality, caused hyperactivity, and impulsiveness in children. Mcneil et al. and Hart et al. also proposed that children who do not sleep well may consciously move more the next day as a means of fighting off fatigue and staying awake. In addition, Vincent et al. suggested that difference in study results may be caused by discrepancies between average sleep and physical activity duration levels between samples. Thus, the observed null association between sleep and physical activity might be explained by the ceiling effects in sleep research. That is, even substantial increase in daytime physical activity might not improve sleep duration in children who already have sufficient sleep.
2.7 Study Design and Measurement Issues to Consider when Studying Associations between Sleep and Physical Activity

There are a number of study design issues that need to be considered when studying the relationships between sleep and physical activity. These include issues around the limited utility of experimental designs in this topic area, the appropriate follow-up length to use in observational studies, the appropriate methods used to measure sleep and physical activity behaviours, and the importance of considering different domains of physical activity.

Although experimental studies provide the strongest form of causal evidence, they have limited utility for studying the bi-directional relationships between sleep and physical activity among children. First, it is difficult for participants to maintain their habitual sleep and physical activity behaviours in the laboratory where they are under experimenters’ observation, instruction and supervision.\textsuperscript{60,88} Even experimental studies conducted outside of laboratory setting are problematic because of the extensive control of behaviors, which become unnatural and no longer resemble real life.\textsuperscript{74,54} Second, most experimental studies have examined the effects of physical activity on sleep, or the effects of sleep on physical activity, for only one or two days. Since both sleep and physical activity are influenced by multiple factors, several days, such as one week, including both weekdays and weekend may be necessary to delineate the beneficial effects of physical activity on sleep, and vice versa. Third, results from experimental studies are limited by very small sample sizes which are underpowered to detect small effects and lack generalizability. Fourth, the physical activity interventions used in experimental studies are “exercise” based (i.e., “prolonged bouts of planned and structured activity), and this type of physical activity has limited relevance for children, who accumulate the vast majority of their
activity in a highly unstructured, unplanned, and sporadic manner, such as through active play.\textsuperscript{9,89}

Observational studies conducted in “natural” free-living conditions, if properly designed and conducted, allow investigators to observe whether spontaneous (i.e. not investigator-induced) changes in children’s physical activity are followed by changes in sleep, and whether natural changes in sleep are followed by changes in physical activity. A typical cross-sectional study,\textsuperscript{90,91} where participants report their regular sleep duration/quality and physical activity level, cannot answer the question of how sleep and physical activity affect each other, neither sort out the directionality of the association in a within-subject level. There are also issues with most prospective cohort studies as the follow-up length used is not appropriate. For example, if a researcher evaluates the association between sleep and physical activity over a long study period (such as 10 years), participants may change their sleep habit considerably throughout the study period, making their baseline sleep variable a less ideal predictor. Thus, typical longitudinal study does not necessarily reflect cause-effect relationship between sleep and physical activity, because it is unknown if the exposure observed at baseline induces a process that eventually show up in the effect of the outcome several years later.\textsuperscript{49,69,92}

In my opinion, the most appropriate approach to investigate the bi-directional relationships between children’s sleep and physical activity is using longitudinal data (repeated measurements of both behaviours nested within subjects) collected over a short time period. First, it is clearly a prerequisite for a causal relationship that a temporal sequence can be convincingly demonstrated. Second, both sleep and physical activity are behaviours that operate with daily fluctuation and they could instantly influence each other through the aforementioned acute biological mechanisms.\textsuperscript{50,92,93}
In addition to considering the aforementioned study design issues, studies examining the relationship between sleep and physical activity need to carefully consider measurements issues. Self- or parent-reported measures of sleep and physical activity among children have often come under scrutiny as they depend on the children’s or parents’ ability to accurately remember and retrospectively report these two behaviours. Self-reported and objective measures were found to be poorly correlated with a tendency for self-reports to overestimate both sleep duration and physical activity level. If the overestimation level differs, the real association between sleep and physical activity would be diluted/exaggerated. However, few datasets exist that objectively measured both sleep and physical activity over 24-hour periods, all of which conducted in children lacked the suggested sleep log/diary to help identify the sleep onset/offset together, thus to generate more accurate sleep quantity and quality variables.

Accelerometers are a promising method of objectively measuring sleep and physical activity in epidemiological research. Accelerometers provide researchers with accurate and reliable information about the total amount, frequency, intensity, duration of physical activity in the free-living environment. Recently, it has been proposed that that important indicators of sleep, such as sleep duration and sleep efficiency, can also be assessed using the same Actical accelerometer over the same measurement period (e.g. 7 days), which is proved as theoretically feasible and cost-effective in reducing participants’ compliance burdens (Figure 2.3). However, accelerometer cannot measure children’s OAP on its own, because it provides no contextual information about the physical activity, i.e. what children were doing and where they were active. For this reason, portable global positioning system (GPS) was introduced as a useful and sufficiently precise device to complement accelerometer-based physical activity monitors with spatial data derived from geographic information system (GIS). The combination of
activity, time and place data collected from accelerometer, GPS logger and GIS can determine where physical activity occurs, and thus assess children’s OAP.\textsuperscript{100–102}

\begin{center}
Figure 2.3. Accelerometer (Actical) data
\end{center}

This illustration of accelerometer data portrays a child’s movement intensities over a 24 hour period. The x-axis represents time throughout the day. The y-axis represents a count value obtained by the accelerometer for each 15-second long measurement period (or epoch); higher count values reflect a higher intensity of movement.

In addition to considering the measurement of physical activity, the domain of physical activity should be considered when studying the relationship between sleep and physical activity. Typically, children accumulate their daily physical activity by engaging in active play, active transportation, and organized activities such as physical education class and organized sport.\textsuperscript{14}

The organized and structured nature of some of these activities, particularly sport, could impact how that behaviour influences sleep. For example, in Canada, school-aged children often participate in organized sports late in the evening (e.g. hockey game from 8:30 to 10:00 p.m.) and early in the morning (e.g., 6:00 - 7:00 a.m. swimming practice). Since late-night physical
activities were found to cause sleep disorders through blunting the nocturnal increase of plasma melatonin levels, the scheduled and structured nature of organized activities may disrupt children’s normal nocturnal sleep.\textsuperscript{75,103} Conversely, as explained in the following paragraph, active play, particularly when performed outdoors, may have a more positive benefit for sleep, and (or) reap a more positive benefit from sleep.

Sunlight exposure obtained during OAP may help regulate nighttime sleep by decreasing cycling adenosine monophosphate, which leads to the peaceful and settled conditions required for a good night’s sleep.\textsuperscript{76,77,104} Because OAP is an unscheduled activity that occurs in a child’s free time, it could be easily sacrificed when children have insufficient and (or) poor sleep in the preceding night due to feelings of sleepiness and tiredness. This is supported by Hart et al.’s finding that experimental shortened sleep predisposed school-aged children to watch more television in their free time,\textsuperscript{54} Williams et al.’s postulation that children’s sleep duration was related more to sedentary time,\textsuperscript{105} as well as Janssen’s finding that children’s free-time, which in generations past was mostly spent engaging in OAP, has in recent decades been largely replaced with sedentary screen time pursuits.\textsuperscript{13}

\section*{2.8 Correlates of Sleep and Physical Activity}

Confounding is an important issue to consider in observational studies. There are several correlates of sleep and physical activity that need to be considered in studies looking at the relationship between these two behaviours. These correlates could represent intrapersonal, interpersonal, and environmental factors.\textsuperscript{106}
2.8.1 Correlates of Sleep

Intrapersonal factors, including age, sex, race and body mass index (BMI) status are associated with sleep duration. It is generally perceived that sleep duration declines with age, which could be ascribed to biological process like the development/pubertal onset during early adolescents. Shorter sleep duration has also been observed among ethnic minorities, such as black children. In terms of gender differences, Olds et al. reported that Australian girls sleep slightly longer than Australian boys. While in Canada, recent estimates suggest that there is no gender difference in sleep duration and quality. Sleep duration is inversely associated with children’s BMI and other obesity measures.

At the interpersonal level, stressful social ties disrupt children’s sleep, as when family composition changes because of parental divorce or remarriage, or families live closer to poverty, while parental monitoring of children behavior (especially in setting a time for them to go to bed) strongly predicts healthy sleep habits among children. Sufficient sleep quantity and adequate sleep quality were protected by the presence of household rules and regular sleep-wake routines, which highlights parents' perception of the importance of sleep for their own and their children's health and well-being. Also, family socioeconomic status is inversely correlated with sleep, such that sleep duration is lower among those from low socioeconomic backgrounds, which may in part reflect specific households or neighborhood variables, such as overcrowding and noise levels. In comparison with family factors, peer-sleep relationship has drawn much less attention from researchers. Buxton et al. first investigated the association between peer group ties and children’s sleep and found that positive peer associations (having friends who strive to do right and succeed in school) are associated with less sleep disruption, and prolonged sleep duration on school nights.
At the environmental level, green space and time spent around park spaces were found to positively impact average sleep duration.\textsuperscript{117} Moreover, among a representative sample of Canadian children and adolescents, longer sleep duration was observed on weekends than on weekdays, which is in line with the finding among Australian children that non-school day sleep is longer than school day sleep.\textsuperscript{33,107}

### 2.8.2 Correlates of OAP

At the intrapersonal level, age, sex and race, are associated with children’s OAP. Among Canadian children and adolescents, the proportion participating in OAP is greater in boys than girls and generally decreases with age.\textsuperscript{14} This gender difference is also supported by studies demonstrating that boys have a greater independent mobility than girls.\textsuperscript{41,118} Additionally, lower levels of OAP have been observed among children from ethnic minorities.\textsuperscript{119,120}

In terms of interpersonal factors, both family and peers play an important role in affecting children’s OAP. For example, children with lower family socioeconomic position are more likely to display low levels of OAP when compared with high socioeconomic position children.\textsuperscript{119,120} Parents with lower education are less willing to let children play outdoors independently further away from home.\textsuperscript{120,121} Children are more likely to play outdoors often when they have more siblings in the household.\textsuperscript{122} In addition to family factors, the presence of friends in children’s neighborhood was also reported to be positively associated with their active free-play in outdoor locations, while peer support and encouragement were found to increase children’s leisure-time activity, both during school time recess and after-school time periods.\textsuperscript{121–124}
At the environmental level, presence of greenspaces (developed and undeveloped) and other play spaces in the neighbourhood such as cul-de-sacs, may promote OAP.\textsuperscript{121,124–126} Some natural features are also proposed as the correlates of children’s OAP, such as hours of daylight per day, which is potentially a promoting factor.\textsuperscript{100}

2.9 Thesis Rationale

As in many areas of child health, habits like sleep and physical activity that are established in the early years may persist into adulthood and influence chronic conditions that happen in the adult years.\textsuperscript{20,22,43,127} While sleep and physical activity are often thought of as independent behaviours, they in fact may be co-dependent behaviours as more/better sleep may promote a higher level of physical activity and vice versa. However, evidences from observational studies on the bi-directional association between sleep and physical activity among children is inconsistent. One possible explanation is that sleep may have differential effects on different domains of physical activity, and that different types of physical activity may have different impacts on sleep. With all that being said, more research on the bi-directional relationships between children’s sleep and physical activity is warranted given recent population trends of insufficient (poor) sleep and physical inactivity among children.
2.10 References


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Chapter 3

Bi-directional Association between Sleep and

Outdoor Active Play among 10- to 13-year-olds
3.1 Abstract

**Purpose**: The purpose of this study was to investigate whether there is a bi-directional relationship between sleep characteristics (time in bed, sleep duration, sleep efficiency) and outdoor active play (OAP) within children.

**Methods**: Participants consisted of 433 children aged 10-13 years. Time in bed, sleep duration, and sleep efficiency were measured for 8 consecutive nights using data from a sleep log and Actical accelerometer. OAP was measured for the 7 days that fell in between these 8 nights using a combination of data from accelerometers, global positioning system (GPS) loggers, and geographic information system (GIS). Generalized estimating equation (GEE) models with first-order autoregressive matrix [AR(1)] were used to assess the relationships of interest. These models accounted for the repeated measures nested within participants and adjusted for several confounders.

**Results**: Time in bed, sleep duration, and sleep efficiency were not significantly associated with the following day’s OAP. There was a modest but significant (p = 0.017) association between OAP and the following night’s time in bed, which suggested that each hour increase in OAP was associated with a 5.1 minute (95% CI: 0.9 - 9.4) increase in time in bed. OAP was not significantly associated with sleep duration or sleep efficiency.

**Conclusions**: None of the sleep characteristics predicted the following day’s OAP. Higher levels of OAP predicted a longer time in bed, but not sleep duration or sleep efficiency.
3.2 Introduction

Insufficient sleep quantity and quality are associated with an array of negative health outcomes among children and adolescents, such as poor cognitive development, anxiety, depression and obesity.\textsuperscript{1–3} Insufficient physical activity, particularly of a moderate-to-vigorous intensity, is also associated with a poor mental and physical health.\textsuperscript{4,5} Unfortunately, a large proportion of children and adolescents do not get enough sleep or physical activity. In Canada, for instance, 20\% of children and adolescents do not meet sleep recommendations,\textsuperscript{6} and only 9\% meet physical activity recommendations on a daily basis.\textsuperscript{7} Outdoor active play (OAP) is a type of physical activity that is particularly low among young Canadians.\textsuperscript{8,7}

Sleep and physical activity have historically been thought of as independent behaviours; however, there is a growing interest in determining whether they are connected. Research examining the possible connection between sleep and physical activity within the pediatric population has produced inconsistent findings. Studies have reported that nighttime sleep quantity and quality positively,\textsuperscript{9} negatively,\textsuperscript{10,11} or do not\textsuperscript{10,12,13} predict the next day’s physical activity. Similarly, studies have reported that physical activity during the day positively,\textsuperscript{11,12,14–16} negatively,\textsuperscript{11} or does not\textsuperscript{12,13,15,16} predict the subsequent night’s sleep duration and quality. These inconsistencies may in part reflect the lack of specificity of the physical activity measures. That is, observational studies looking at the relationship between sleep and physical activity have captured the total time spent in all types of physical activity. Consideration should be given to specific types of physical activity because different types of physical activity may have different relationships with sleep, and these relationships could become obscured when total physical activity is considered.\textsuperscript{17} For instance, because organized sports are often scheduled for the early
morning and late evening, they might negatively impact sleep by disrupting when children can go to bed at night and when they need to wake up in the morning.\textsuperscript{18,19} However, if children do not have sufficient sleep the preceding night, their OAP the following day might be easily sacrificed. Conversely, OAP, an unscheduled activity, may benefit sleep because it is associated with increased sunlight exposure which in turn contributes to the peaceful and settled conditions required for a good night’s sleep.\textsuperscript{20–22}

The purpose of this study was to investigate whether there is a bi-directional relationship between sleep quantity and quality and OAP among 10- to 13-year-olds. Specifically, this study examined whether sleep characteristics (i.e. time in bed, sleep duration and sleep efficiency) at night was associated with the amount of OAP accumulated the following day, and whether OAP accumulated during the day was associated with sleep characteristics the following night.

3.3 Methods

3.3.1 Study Participants

The study sample was from the Active Play Study. Data were collected between January 2015 and December 2016. To be included, participants must have been aged 10 to 13 years and lived and attended school in Kingston, Ontario. Non-English or French speakers and non-ambulatory individuals were excluded. Participants were recruited to ensure proportional representation of the city’s 10- to 13-year-old population by age, sex, and residence within its 12 electoral districts. An equal number of participants were studied in each of the four seasons. Recruitment strategies included word of mouth, social media, and advertisements posted and
distributed in schools, stores, and community centres. An example advertisement is in Appendix A (p. 89). Participants and a parent/guardian provided written informed consent prior to participation (Appendix B, p. 91). The study was approved by the General Research Ethics Board at Queen’s University, with additional ethics clearance obtained by the Queen’s University Health Sciences Research Ethics Board to perform the analyses included in this thesis (Appendix C, p. 97).

Twenty five (5.5%) of the 458 participants who participated in the Active Play Study were excluded from the present analyses because they did not have valid sleep and OAP measures for any of the 8 nights and 7 days (as explained below). Thus, the final sample consisted of 433 participants. Participants who were excluded from the analyses were similar in age (11.5 vs. 11.8 years) and ethnicity (90.5% vs. 88.0% white) to those who were included; however, there was a difference in gender distribution (68.0% male vs. 49.2% male). Within these 433 participants, there were several days and nights with insufficient (invalid) data to determine sleep and/or OAP, and these nights and days were removed. The final number of observations were 2253 for the analyses where nighttime sleep characteristics predicted the following day’s OAP, and 2263 for the analyses where daytime OAP predicted the following night’s sleep characteristics.

### 3.3.2 Data Sources

Data sources included the following: 1) Participants wore an Actical accelerometer (Philips Respironics, Murrysville, PA) on their right hip for 7 days and 8 nights to continuously
assess their movement in 15-second epochs; 2) During the same week, participants wore a Garmin Forerunner 220 Global Positioning System (GPS) watch (Garmin Ltd, Canton, Switzerland) which continuously recorded their longitude and latitude position; 3) During the same week, participants maintained a log wherein they recorded the times they went to bed at night and got up in the morning, the times they participated in organized sports and programs, the times they worked or did chores outdoors, and the times they removed their accelerometer or GPS watch (Appendix D, p. 100); 4) Participants and one of their parents/guardians each completed a ~20-minute long questionnaire on a tablet computer (Appendix E, p. 103; Appendix F, p. 105); 5) A series of physical measures (e.g., height, weight) were obtained; 6) Geographic information system (GIS) data for the city of Kingston were obtained from several sources; 7) Information on school calendars and schedules (e.g., start/end times, recess times) were obtained from school websites and by asking participants; 8) Sunrise/sunset times for the city of Kingston during each day of data collection were obtained from online resources.²³

### 3.3.3 Measurement of Sleep

Three sleep characteristics were assessed to capture sleep quantity and quality: time in bed, sleep duration, and sleep efficiency. They were measured over 8 consecutive nights. Time in bed (hours/day) was calculated as the difference between when participants turned off the lights to go to bed at night and when they got out of bed in morning, which they recorded on the log. These recorded times were verified, and corrected when necessary, by having a member of the research team visually inspecting the recorded log times against the Actical accelerometer data. A protocol and few examples of this verification and correction process are provided in
Appendix G (p. 108). In our laboratory, this process is highly reliable as 90% of the verified and corrected sleep times are within 10 minutes of each other based on repeated attempts completed by different researchers.

Sleep duration (hours/day) was calculated as the total time spent sleeping during time in bed. To determine time spent sleeping, each of the 15-second long epochs (measurement intervals) from the Actical accelerometer was defined as either ‘sleeping’ or ‘awake’ based on a sleep likelihood score, and the time of the ‘sleeping’ epochs were summed. The sleep likelihood score was based on a weighted rolling average of count value for the epoch in question and the 8 epochs that proceed and follow it. Sleep efficiency (%) was calculated as the ratio of sleep duration to time in bed.24,25 The method of estimating sleep/awake status using a waist-worn Actical accelerometer was developed and cross-validated in a sub-study of 50 children from the present study. Results from the sub-study showed that there is no significant difference in sleep efficiency estimates between the waist-word Actical accelerometer and a wrist worn accelerometer developed specifically to assess sleep characteristics [89.0 (3.9)% vs 88.7 (3.1%), p = 0.66].26

3.3.4 Measurement of OAP

The method for assessing OAP was developed by our laboratory and was one of the main objectives of the Active Play Study. This method used data from several sources and involved a combination of automated steps, manual checks and corrections.
First, times recorded in the log (start and end times for sleep, organized sports, outdoor chores, and accelerometer non-wear periods) were checked by visually inspecting these times within the accelerometer data using Actical 3.10 software (Philips Respironics, Murrysville, PA). If necessary, corrections were made to the recorded times.

Second, Personal Activity and Location Measurement (PALMS) software (Center for Wireless and Population Health Systems, University of California, San Diego, CA) was used to merge the accelerometer and GPS data based on each 15-second accelerometer epoch. PALMS identified periods of time with missing GPS latitude and longitude coordinates, which occurred if the satellite signal was lost (e.g. when a participant entered a large building). When possible, missing geospatial coordinates were imputed by the research team by using Google Maps (Google, Mountain View, CA) and street view images to determine where the participant was immediately before the signal was lost and immediately after the signal returned. For instance, if the signal was lost for 30 minutes when a participant was in a building, the latitude and longitude coordinates for the centre of that building were imputed for all 15-second epochs that occurred during that 30 minutes.

Third, PALMS software used a validated algorithm to identify all vehicle and non-vehicle (e.g., walking, bicycling) trips, and all 15-second epochs that occurred during trips were flagged. Trip detection was based on distance traveled over time (i.e., travel ≥ 100 meters over ≥ 180 seconds at a speed of ≥ 1 km/hour). Trip modality was determined by the 90th percentile of travel speed (walking = 1 to 9.99 km/hour, cycling = 10 to 24.99 km/hour, vehicle = ≥ 25km/hour). Each of these trips identified by PALMS were checked by visually inspecting all of the GPS coordinates for that trip in Google Maps. During these visual inspections we
identified and then deleted a number of false positive trips. An example of a false positive trip is a trip identified by PALMS that, upon visual inspection, was found to occur on school grounds during the recess period. This example reflected OAP and not active transportation.

The data from each participant was then exported from PALMS into a CSV file that was subsequently opened in ArcMap version 10.4 software (Esri, Redlands, CA). The longitude and latitude coordinates for each 15-second epoch were geocoded into a map layer. A second map layer that contained the footprints for all buildings within the city of Kingston was opened. The two map layers were spatially joined, and the latitude and longitude coordinates of each 15-second epoch where identified as being in a building (indoors) or not in a building (outdoors), and the jointed data was exported as an Excel file. The Excel files were merged together using SAS version 9.4 statistical software (SAS Inc., Carry, NC), wherein falsely identified indoor times were corrected by an algorithm that had a sensitivity of 95%.

The merged file contained over 19 million rows, with > 40,000 rows per participant (i.e., one row of data for each 15-second long epoch that occurred over the 7 day/8 night measurement period). Additional “time” information were merged into the master file, including 1) the sleep, organized sport, and chore/work times in the logs; 2) the start and end times of the school day and school recess times; and 3) whether each day represented a school day or a non-school day (weekend or holiday).

A SAS program was then developed to determine the number of minute spent in OAP on each measurement day. The SAS program started by identifying and deleting all 15-second epochs for the days in which there was insufficient (< 10 hours) accelerometer and GPS watch
wear time during waking hours. We then flagged all 15-second epochs that could not have occurred during OAP because it occurred during one or more of the following conditions: 1) time in bed, 2) indoors, 3) school curriculum time (but not recess time) on a school day, 4) a vehicle trip or non-vehicle trip, 5) while participating in an organized sport or program, or 6) while performing work or chores. All of the 15-second epochs that were not flagged in the proceeding step were then classified as either occurring during OAP or as sedentary time spent outdoors using a specifically designed algorithm that has a specificity of 85%, sensitivity of 85% and positive predictive value of 99% for identifying OAP. These daily OAP values were exported into a dataset with multiple observations for each participant (e.g., one row per day). Each row represented a separate day.

3.3.5 Confounders

Several factors that are associated with both sleep and physical activity and which may confound the bi-directional relationship between these behaviours were considered, including characteristics of the participant, their family, their neighbourhood environment, and characteristics that reflected the calendar day when the sleep and physical activity measures were obtained. Participant factors consisted of biological sex (male or female), age (continuous), ethnicity (white or non-white, including mixed race), the presence of a chronic medical condition (yes or no), body mass index (BMI) z-score based on the World Health Organization growth reference (continuous), biological maturity using the maturity offset method (continuous), unhealthy eating patterns [frequency of fast food consumption (rarely, 2 - 3 times/month, or ≥ 1 time/week) and frequency of snacking while engaging in screen
Family factors consisted of annual family income (≤ $50,000, $50,001 - 100,000, > $100,000, or not reported), and the number of parents in the household (single or dual parent). Neighbourhood environment factors included the proportion of land area within a 1 km distance of the home devoted to green space (continuous) and a traffic volume index, which was calculated as: [(km of arterial roads * average daily vehicle counts on arterial roads in Kingston) + (km of collector roads * average daily vehicle counts on collector roads in Kingston) + (km of local roads * average daily vehicle counts on local roads in Kingston)] / total road distance in buffer in km (continuous). Finally, characteristics of the day the sleep and physical activity measures were obtained including the type of day (school day, a non-school day in which the participant was enrolled in an organized day camp program, or other non-school days such as weekends and holidays), minutes/day of daylight hours, minutes/day spent participating in the other domains of physical activity (i.e., organized sports and programs, active transportation, physical activity during school curriculum; and minutes/day of accelerometer and GPS watch wear time during waking hours.

3.3.6 Preparation ofDatasets

Two data sets were formed for the statistical analyses. Each dataset had up to 7 repeated sleep - OAP or OAP - sleep pairings for each participant; each pairing represented a unique row (or observation) in the dataset. The first dataset was used to explore the relationship between nighttime sleep characteristics (exposure) and OAP the following day (outcome). The first row of data for each participant contained the sleep characteristics on day 1 (e.g., 10:00 p.m. on Monday to 7:00 a.m. on Tuesday) and OAP on day 2 (e.g., 07:00 a.m. to 10:00 p.m. on
Tuesday). This sleep - OAP pairing continued for the remaining 6 rows for each participant. The second dataset was used to explore the relationship between daytime OAP (exposure) and sleep characteristics in the subsequent night (outcome). The first row of data for each participant contained OAP on day 2 (e.g., 07:00 a.m. to 10:00 p.m. on Tuesday) and sleep characteristics on day 2 (e.g., 10:00 p.m. on Tuesday to 7:00 a.m. on Wednesday). This OAP - sleep pairing was repeated for the remaining 6 rows. The covariate data were repeated for all 7 rows for each participant within each dataset, with the exception of the daylight hours, type of day, and other physical activity domain variables, which varied for each row.

3.4 Statistical Analysis

All data were analyzed using SAS version 9.4 software. A p-value of < 0.05 was used to denote statistical significance. There was sufficient power to detect a meaningful effect in this study and the power calculations are provided in Appendix H. Standard descriptive statistics were used to describe the sample. Generalized estimating equation (GEE) models with a first order autoregressive matrix [AR(1)] were performed to assess the relationship of interest, which accounted for the repeated measures nested within participants and were adjusted for confounders. In analyses testing whether nighttime sleep was associated with OAP the following day, sleep characteristics represented the within-person independent variables and OAP the within-person dependent variable. Since ~20% of the days had zero values for OAP, a negative binomial distribution and a logit link were specified to adjust for the over-dispersion of non-zero values, and non-zero values were rounded to integer values to mimic count data. In analyses testing whether OAP during the day was associated with sleep characteristics the following
night, OAP represented the within-person independent variable and sleep characteristics the within-person dependent variables. To adjust for potential confounders, the backward elimination method was used, wherein the predictor with the largest p-value over 0.10 was removed at each stage.

3.5 Results

Demographic information of the 433 participants included in the data analysis are in Table 3.1 (p.74). The average (standard deviation) age was 11.5 (1.1) years. Approximately 49.2% were male and 90.5% were white. The average time in bed and sleep duration were 9:28 (1:08) and 8:26 (1:28) hours: minutes, respectively. The average sleep efficiency was 89.1% (5.6%). The average OAP was 38.5 (44.5) minutes per day and 20% of the days had 0 values for OAP. However, ~20% of the study sample were below the sleep recommendations, while ~20% of the measurement days had 0 values of OAP (data not shown).

The associations between nighttime sleep and the following day’s OAP are shown in Table 3.2 (p.75). The β coefficients in the table represent the change of OAP in minutes for every one hour increase in time in bed and sleep duration and every 1% increase in sleep efficiency. After adjusting for relevant covariates, none of the three nighttime sleep characteristics (time bed, sleep duration, sleep efficiency) were significantly associated with the following day’s OAP.
The associations between daytime OAP and the following night’s sleep are shown in Table 3.3 (p.76). The β coefficients in the table represent the change of sleep characteristics (hours for time in bed and sleep duration, % for sleep efficiency) for every 1 minute increase in OAP. After adjusting for relevant covariates, OAP during the day was significantly (p = 0.017) associated with time in bed on the following night. Extrapolation of the β coefficients indicated that each 60 minute/day increase in OAP was associated with an additional 5 minute/night increase in time in bed. The associations between OAP and sleep duration approached but did not reach statistical significance, and OAP was not associated with sleep efficiency.

To determine if the 0 values for OAP influenced the relationships, we performed a sensitivity analysis wherein all of the observations with 0 OAP values were removed prior to conducting the regression analyses. The patterns and significance of findings for the sensitivity analysis were comparable to those shown in Tables 3.2 and 3.3 (data not shown).

3.6 Discussion

To our knowledge, this is the first study to examine the associations between sleep and OAP in children. We used objective tools and detailed logs to measure these behaviours. The statistical analyses allowed us to examine the temporal and bi-directional associations between sleep and OAP. Our results indicate that the sleep characteristics did not predict OAP. OAP was a modest predictor of time in bed but it was not associated with sleep duration or sleep efficiency.
Our finding that time in bed, sleep duration, and sleep efficiency were not positively associated with the following day’s OAP is consistent with other observational studies that measured total physical activity or physical activity of a moderate-to-vigorous intensity.\textsuperscript{10–13} Conversely, a randomized crossover trial reported that children were about 4\% more active in the days following a 1.5 hour increase in time in bed versus the days following a 1.5 hour decrease in time in bed.\textsuperscript{9} A possible explanation as to why the experimental study design found associations that were not observed in observational studies is that, the 3 hour difference in time in bed is a drastic change that does not reflect the normal night-to-night variability in sleep. As evidence of this, in our study the night-to-night difference in time in bed only reached 3 hours for 3\% of the observations (data not shown). It is also worth noting that in the experimental study the 1.5 hour difference in time in bed between the baseline and sleep increased (or decreased) conditions did not lead to a change in physical activity.\textsuperscript{9}

The association between daytime OAP and time in bed was statistically significant; however, the strength of the association was very weak. In fact, an hour/day increase in OAP, a volume of OAP that was almost double the average of our sample, was associated with only a 5 minute/night increase in time in bed without a corresponding change in sleep duration or efficiency. Thus, our findings suggest that it is unlikely that OAP interventions would also have a clinically meaningful impact on sleep, unless these interventions were able to change OAP by several hours/day, which is doubtful. Six other studies have investigated the acute effects of daytime physical activity on sleep characteristics in children using objective measurements.\textsuperscript{11–16} The only one of these studies that found a meaningful association was Dworak et al.’s experimental study of 11-13 year olds.\textsuperscript{14} The physical activity in that experimental study consisted of performing 30 minutes of continuous vigorous intensity exercise on a cycle
ergometer in a laboratory. While effective at improving sleep, that pattern (continuous) and intensity (vigorous only) of exercise is not typically observed in children, and it does not approximate the sporadic movement pattern and intensity of OAP. In fact, evidence suggests that only 27% of the time children participate in OAP is spent at a moderate-to-vigorous intensity.

Some of the findings from this manuscript have important public health implications. First, we observed that ~20% of the participants did not meet the sleep guidelines and that they accumulated no OAP on ~20% of the measurement days. Therefore, both of these behaviours require public health attention. Second, since OAP was positively associated with time in bed, a positive (albeit small) side effect of interventions aimed at increasing OAP might also be an improvement in time in bed.

Our study was not void of limitations. First, the generalizability of the results may be limited to 10- to 13-year-olds without a diagnosed sleep disorder. Second, although accelerometers provide valid estimates of sleep duration and efficiency, our study’s internal validity may be somewhat compromised because sleep variables were not assessed via polysomnography, the gold standard. With that being said, accelerometers can be used in free-living conditions, while polysomnography measures need to be obtained in laboratory or clinical settings and these setting and the equipment could disrupt normal sleep behaviours. Also, it is possible that OAP was misclassified due to the limitations of accelerometer and GPS device. For example, if participant removed their accelerometer while engaging in water-based OAP, their OAP would have been underestimated. Since the measurement bias of both sleep and OAP were likely non-differential, the associations of interest might have gone towards the null. Finally, although we investigated the relationships temporally using the appropriate exposure time
window, temporality on its own does not equate to causality. More intervention research is needed to learn more about the causal nature of the relationships between sleep and physical activity in children.

3.7 Conclusion

This study assessed the temporal and bi-directional relationships between sleep characteristics and OAP in a sample of 10- to 13-year-olds. Daytime OAP was weakly associated with time in bed on the following night. None of the other associations were statistically or clinically significant.
3.8 References


44. Marco C a., Wolfson AR, Sparling M, Azuaje A. Family socioeconomic status and sleep patterns


49. Mcintosh LB. Examining the influence of environmental opportunities and exposures on children’s sleep duration. 2014;(August).


Table 3.1. Demographic characteristics of study participants (n = 433)

<table>
<thead>
<tr>
<th>Variable</th>
<th>N/Mean</th>
<th>%/SD</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age (years)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>112</td>
<td>25.9</td>
</tr>
<tr>
<td>11</td>
<td>108</td>
<td>24.9</td>
</tr>
<tr>
<td>12</td>
<td>110</td>
<td>25.4</td>
</tr>
<tr>
<td>13</td>
<td>103</td>
<td>23.8</td>
</tr>
<tr>
<td><strong>Sex</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>213</td>
<td>49.2</td>
</tr>
<tr>
<td>Female</td>
<td>220</td>
<td>50.8</td>
</tr>
<tr>
<td><strong>Race</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>392</td>
<td>90.5</td>
</tr>
<tr>
<td>Non-white</td>
<td>41</td>
<td>9.5</td>
</tr>
<tr>
<td><strong>Body mass index status</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Underweight</td>
<td>8</td>
<td>1.9</td>
</tr>
<tr>
<td>Normal</td>
<td>307</td>
<td>70.9</td>
</tr>
<tr>
<td>Overweight</td>
<td>73</td>
<td>16.9</td>
</tr>
<tr>
<td>Obese</td>
<td>45</td>
<td>10.4</td>
</tr>
<tr>
<td><strong>Chronic condition</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>263</td>
<td>60.7</td>
</tr>
<tr>
<td>Yes</td>
<td>170</td>
<td>39.3</td>
</tr>
<tr>
<td><strong>Family structure</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Single parent</td>
<td>59</td>
<td>13.6</td>
</tr>
<tr>
<td>Dual parent</td>
<td>371</td>
<td>85.7</td>
</tr>
<tr>
<td>Not reported</td>
<td>3</td>
<td>0.7</td>
</tr>
<tr>
<td><strong>Family income ($ CDN per year)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(\leq 50,000)</td>
<td>67</td>
<td>15.5</td>
</tr>
<tr>
<td>50,001 - 100,000</td>
<td>118</td>
<td>27.3</td>
</tr>
<tr>
<td>&gt; 100,000</td>
<td>196</td>
<td>45.3</td>
</tr>
<tr>
<td>Not reported</td>
<td>52</td>
<td>12.0</td>
</tr>
<tr>
<td><strong>Sleep</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time in bed (hours;minutes)</td>
<td>9:28</td>
<td>1:08</td>
</tr>
<tr>
<td>Sleep duration (hours;minutes)</td>
<td>8:26</td>
<td>1:28</td>
</tr>
<tr>
<td>Sleep efficiency (%)</td>
<td>89.1</td>
<td>5.6</td>
</tr>
<tr>
<td><strong>Physical activity (minuets/day)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OAP</td>
<td>38.5</td>
<td>44.5</td>
</tr>
<tr>
<td>Organized sports and programs</td>
<td>33.6</td>
<td>69.4</td>
</tr>
<tr>
<td>Curriculum-based activity</td>
<td>11.0</td>
<td>16.7</td>
</tr>
<tr>
<td>Active transportation</td>
<td>15.9</td>
<td>22.0</td>
</tr>
</tbody>
</table>
Table 3.2. Associations between nighttime sleep characteristics and OAP the following day (n = 432 participants and 2253 sleep - OAP pairings).

<table>
<thead>
<tr>
<th>Sleep Characteristic</th>
<th>β (95% confidence interval)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time in bed</td>
<td>0.008 (-0.047, 0.063)</td>
<td>0.777</td>
</tr>
<tr>
<td>Sleep duration</td>
<td>0.010 (-0.068, 0.045)</td>
<td>0.722</td>
</tr>
<tr>
<td>Sleep efficiency</td>
<td>-0.008 (-0.017, 0.002)</td>
<td>0.103</td>
</tr>
</tbody>
</table>

All models controlled for sex, age, BMI, frequency of snacking and eating fast food, family income, number of parents in household, organized sports, active transportation, wear time of accelerometer and GPS watch during waking hours, daylight hours, and neighbourhood traffic volume.
Table 3.3. Associations between OAP during the day and the following night’s sleep characteristics (n = 433 participants and 2263 OAP - sleep pairings).

<table>
<thead>
<tr>
<th>Sleep Characteristic</th>
<th>B (95% confidence interval)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time in bed *</td>
<td>0.001 (0.000, 0.003)</td>
<td>0.017</td>
</tr>
<tr>
<td>Sleep duration *</td>
<td>0.001 (-0.000, 0.002)</td>
<td>0.075</td>
</tr>
<tr>
<td>Sleep efficiency †</td>
<td>-0.000 (-0.005, 0.005)</td>
<td>0.985</td>
</tr>
</tbody>
</table>

* Controlled for sex, age, BMI, frequency of snacking and wear time of accelerometer and GPS watch during waking hours.

† Controlled for sex, maturity offset, chronic conditions, and wear time of accelerometer and GPS during waking hours.
Chapter 4

General Discussion

4.1 Summary

The objectives of this thesis were to determine if: (1) nighttime sleep quantity and quality were associated with the amount of outdoor active play (OAP) accumulated the following day, and (2) OAP accumulated during the day was associated with sleep quantity and quality the following night. This thesis made use of repeated sleep and OAP measures obtained on a diverse sample of Kingston children aged 10 to 13 years. Sleep characteristics and OAP were measured over 8 consecutive nights and 7 consecutive days, respectively, using a combination of data from logs, accelerometers, global positioning system (GPS) loggers, and geographic information system (GIS). Generalized estimating equation models were used to assess the relationships of interest. These models accounted for the repeated measures nested within participants and adjusted for several confounders. The results indicated that time bed, sleep duration, and sleep efficiency were not associated with OAP the following day. A higher level of OAP during the day was significantly associated with a longer time in bed, but not with sleep duration or sleep efficiency.

4.2 Strength

The present study used logs, accelerometer, GPS and GIS data to estimate sleep and OAP variables,¹ rather than self-report methods alone, which have typically been used in other
epidemiological studies examining the associations between sleep and physical activity. Previous studies have found poor to moderate correlations between self-reported and objectively-measured physical activity\textsuperscript{2} and sleep variables,\textsuperscript{3} which suggests that self-reported measures of these behaviours are biased. Thus, the use of objective data in my research to supplement the self-reported logs was a methodological strength.

Another strength of the study is the study design. First, the short time exposure window (i.e. \(< 24\) hours) used in the study is consistent with the biological mechanisms that could link sleep and physical activity. Second, instead of investigating the relationships from the perspective of children’s overall physical activity level, this study measured OAP, which is a good manifestation of the inherent nature of children’s activity and possible to act upon in public health intervention.\textsuperscript{4,5} Also, the week-long measurement period allowed us to capture both school and non-school days and to assess natural changes in sleep and OAP behaviours that occur over the week in the participants’ normal living environments. Experimental studies are typically conducted for a much shorter period of time (2 or 3 days) in a laboratory or clinic, which create artificial sleep and physical activity conditions that alter normal behaviours.

4.3 Limitations

4.3.1 Internal Validity

Internal validity refers to the degree to which the information collected accurately answers the research question, i.e. the extent to which the results are accurate within the study sample.\textsuperscript{6} There are several ways in which the internal validity of a study can be compromised due to systematic errors such as selection bias, information bias, or uncontrolled confounding.
Selection bias is a sampling error that is introduced when there is a systematic difference between participants and non-participants that results in a sample that would generate different results than the population of interest. One form of selection bias is a volunteer bias. Although the number of participants included in the study was stratified to ensure proportional representation by age, sex, season of study, and electoral districts in the city of Kingston, participation was voluntary and therefore children who elected to participate may have differed from those who did not. For example, prior to volunteering, participants knew that they would be required to wear an accelerometer throughout the entire week-long measurement period, in addition to maintaining a detailed sleep and activity log. This could have resulted in a situation where more active children were more likely to participate in the study than less active children. In an effort to combat this selection bias, participants were compensated $40 for completing the study, and the experience of our research team suggests that this compensation was a major driver of the desire to participate in the study. It is also noteworthy that the total physical activity levels in our sample are very similar to what has been observed in the nationally representative Canadian Health Measures Survey, which suggests there was not a volunteer bias. Furthermore, since this was an etiologic study and not a descriptive one, a volunteer bias is more likely to have influenced the prevalence of the exposures, outcome, and covariates. It is less likely to have influenced the relationship between sleep and OAP, which if present, would likely be explained by biological factors that would be the same in participants and non-participants.

Random errors in the measurement of an exposure, outcome, or covariate of interest are defined as information error. When these error are made systematically, it is defined as information bias. The information bias may have also been present in this study, particularly for many of the confounders which were self-reported by the participants and their parents. This
may have led to misclassification, and subsequently over- or under-estimating the true associations due to residual confounding. This information bias may be due to a recall bias and/or a social desirability response bias. For example, children tend to under-report negative behaviours such as fast food consumption.\(^8\) Also, it is possible that both sleep and OAP were misclassified due to the limitations of accelerometer and (or) GPS device. Compared with the “gold standard”, i.e. polysomnography, sleep characteristics assessed via accelerometer might lead to a significant risk of either overestimation or underestimation.\(^9\) With that being said, accelerometers can be used in free-living conditions, while polysomnography measures need to be obtained in laboratory or clinical settings using equipment that could disrupt normal sleep behaviours. Also, it is possible that OAP was misclassified due to the limitations of accelerometer and GPS device. For example, if participant removed their accelerometer while engaging in water-based OAP, their OAP would have been underestimated. Since the information bias of both sleep and OAP was likely non-differential, the observed associations might have been underestimated.

4.3.2 External Validity

External validity refers to the degree which the results of a study are generalizable to populations outside of the sample that was studied.\(^6\) This study attempted to recruit a representative sample of children aged 10-13 in Kingston, Ontario, Canada. Although the observed associations might not differ between participants and non-participants with regard to internal validity, the results may not be generalizable outside of municipalities that are dissimilar to Kingston. One possible reason is the significant cross-cultural differences in both sleep\(^10-12\) and OAP/physical activity\(^12\) among children, which limits the study generalizability to
population in other regions. Also, because both OAP and sleep habits change with age,\textsuperscript{13–15} these results may not be applicable to younger children and older adolescents.

### 4.4 Causality

A central and essential theme that surrounds all etiological epidemiologic studies is causation. A commonly used method of assessing causation is Hill’s criteria of causation,\textsuperscript{16} which is discussed in this section. Because only one of the relationships (i.e. OAP→time in bed) that were examined in my thesis research was statistically significant, the discussions of causality focus on that relationship.

Temporality is a necessary component of causation.\textsuperscript{16} The data structure used in the analysis are longitudinal by nature, since daytime OAP (e.g. Tuesday) was linked with the following night’s time in bed (e.g. Tuesday night). This was done repeatedly across the week-long measurement period for all participants. As such, there was temporality between the exposure and outcome. Furthermore, the timeframe between exposure and outcomes assessments was within 24 hours, which is consistent with the biological mechanisms discussed in Chapter 2 suggesting that physical activity would have acute but not long-term effects on sleep.

Strength of association is a criteria that states that stronger associations are more likely to be causal as they are less likely to be due to an unmeasured extraneous variable.\textsuperscript{16} The only statistically significant relationship in my research was the relationship between OAP and time in bed. The strength of this was very weak. In fact, 1 hour/day increase in OAP, a volume of OAP that was almost double the average of the sample, was associated with only a 5 minute/night increase in time in bed.
If a dose-response relationship is seen between the exposure and outcome of interest, this is further evidence for causation. Since both of the exposure and outcome were examined on a continuous scale in a linear model, a dose-response relationship was seen between OAP during the day and time in bed that night. This, provides some support for a causal relationship.

Consistency is an aspect of causality that refers to finding similar results in different populations across different settings. The observation of the positive relationship between OAP and time in bed contradicts all previous observational studies that have found no or negative association between daytime physical activity and time in bed among children. Therefore, this finding was not consistent with the literature. It is, however, important to note that the present study is not directly comparable to previous studies because it focused on OAP and not total/other physical activity.

With respect to biological plausibility, there is reason to believe that higher level of daytime OAP would stimulate a longer time in bed at night. As described in Chapter 2, there are several potential mechanisms that could explain this association.

In a strict sense, causation can be indicated only by experimental evidence and control of all (relevant) conditions. This kind of evidence is limited to only one experimental study, wherein no association was observed between physical activity intervention and sleep quantity. However, as discussed in Chapter 2, laboratory-based experimental studies have limited utility for studying the association between physical activity and sleep among children.

Collectively, based on the aforementioned causality criteria, it is very unlikely that the observed association between OAP and time in bed is causal in nature, given that only the temporality criterion was met.
4.5 Future Research Directions

Although this study looked at the temporal and bi-directional associations between nighttime sleep and daytime OAP using objective measures, one limitation of the research is substantial proportion (~30%) of days with missing OAP data (data not shown), which was mainly explained by technical issues with the GPS watch, such as the loss of satellite signal. Future studies may benefit from using multiple imputation rather than deleting the missing data from the dataset.

Although the presence of a sleep disorder was not an exclusion criterion for the study, none of the children who participated had a diagnosed sleep disorder. According to the floor and ceiling effects in sleep research, the presence of sleep problems might moderate the relationship between sleep and physical activity. In other words, OAP might benefit sleep quantity and/or quality only for children with sleep disorders but not normal sleepers. Therefore, future studies should assess the bi-directional relationship between sleep and physical activity among children with sleep disorders.

Investigation of the interrelationship between daytime physical activity and nighttime sleep is an emerging field in behavioural research, and mixed findings have been reported in this literature. This could reflect the lack of specificity of the physical activity measures, and more studies that look at specific types of physical activity are needed. Furthermore, a key limitation of the only 2 experimental studies is the artificial nature of the sleep and physical activity conditions, which do not reflect normal child behaviours. Future experimental studies should
attempt to mimic the real-world living situations of children’s physical activity and sleep behaviours.

4.6 Public Health Implications

Some of the findings from this manuscript have important public health implications. First, we observed that ~20% of the participants did not meet the sleep guidelines and that they accumulated no OAP on ~20% of the measurement days. Therefore, both of these behaviours require public health attention. Second, since OAP was positively associated with time in bed, a positive (albeit small) side effect of interventions aimed at increasing OAP might be an improvement in time in bed.

4.7 Summary of M.Sc. Experience

My experiences as an M.Sc. student have allowed me to broaden my knowledge and skills in the field of epidemiology, biostatistics and public health. Through my initial year of coursework, I gained an understanding of the field of epidemiology, biostatistics, public health, and especially physical activity epidemiology. Outside of the classroom, my role as a research assistant for the Active Play Study provided me with invaluable insight into study design and the benefits associated with primary data collection and data processing. In this position, which lasted the duration of my degree, I contributed to the data entry, data cleaning, and data reduction for the Active Play Study.
In my second year, I co-authored and collaborated with a Ph.D. student from the Active Play Study in 2 sub-study projects, both of which contributed to my own thesis project’s exposure and outcome measurements. Throughout these projects, I gained a comprehensive understanding of SAS statistical programming software through the complex formatting, manipulating and merging of datasets, as well as the application of advanced biostatistics. I also interpreted the results from these statistical analyses, presented my findings orally at an international research conference (International Society of Behavioural Nutrition and Physical Activity, June 2017) and prepared my research for publication in this thesis as well as for a peer-reviewed journal. Lastly, it is worth mentioning that as an international student from China, my English has improved the most rapidly during the past 2 years’ of M.Sc. study and research work, which has benefited my ability to read, write, and speak in the universal language of science. As a whole, through this combination of coursework, independent thesis research, practical experience and language improvement as a M.Sc. student, I have developed the knowledge and skills required to work as a future professional in the field of epidemiology.

4.8 Conclusion

This study assessed the temporal and bi-directional relationships between sleep characteristics and OAP in a sample of 10- to 13-year-olds. Daytime OAP was weakly associated with time in bed on the following night. None of the other associations were statistically or clinically significant.
4.9 References


Appendix A

Active Play Study Recruitment Advertisement
Physical Activity in Kingston Children

We are looking for 10-13 year olds to participate in a physical activity study at Queen's University.

Children who complete the study will earn $40!

This study will determine where and when children are physically active. It will also determine how different types of physical activity influence children's health.

All 10-13 year olds who live and go to school in Kingston can participate.

Participation in this study involves the following:
1. Simple physical measures such as height, weight, and blood pressure.
2. Completing a survey on a computer
3. Wearing a small activity measurement device for 7 days

The total time commitment for participating is about 4 hours.

For more information please contact us:

Email: Queens.Physical.Activity@gmail.com
Phone: (613)533-6000 ext. 75401
Website: https://sites.google.com/site/paepilab/
Appendix B

Active Play Study Participant Letter of Information/Consent
LETTER OF INFORMATION / CONSENT FOR CHILD

Physical Activity Levels in Kingston Children

Principal Investigator: Dr. Ian Janssen
School of Kinesiology & Health Studies, Queen’s University
Kingston, Ontario
Phone: (613)533-6000 ext. 78631
E-mail: ian.janssen@queensu.ca

Co-Investigator: Dr. Michael McIsaac
Department of Public Health Sciences, Queen’s University
Kingston, Ontario
Phone: (613)533-6000 ext. 77460
E-mail: mcisaacm@queensu.ca

Research sponsor: Heart and Stroke Foundation of Canada

Purpose of the study
We want you to participate in this study. It is about children’s physical activity. Children’s physical activity levels are getting worse. We want to know why.

The purposes of this study are:
1. To determine how much active play, sport, and walking and biking children do.
2. To determine where children get physically active. Several locations will be looked at. These include homes, streets, playgrounds, fields, forests, schools, and arenas.
3. To determine how families, friends, and neighbourhoods affect physical activity.
4. To determine how physical activity affects health.
What will happen during the study?
You and your parent will come to Queen’s University for two visits. The visits will be 8 to 11 days apart. Each visit will last about 45 minutes. Your physical activity will be measured for 7 days between the two visits.

At the first visit we will explain the study to you. We will answer any questions you have. We will measure how tall you are and how much you weigh. We will measure your belt size. We will measure your heart rate and blood pressure using a small machine. These measures should not cause any pain or discomfort.

At the end of the first visit we will give you two small electronic devices. You will wear them for 7 days. They will measure your physical activity. The first device will measure how much physical activity you get. You will wear it around your waist on a belt. The second device looks like a watch. It will record your location on a map about every 30 seconds. It will tell us where you got your physical activity.

On the 7 days your physical activity is measured you should write when you remove the electronic devices. You should also write down times you go to bed and wake up. We will give you a diary to write this down.

On the second visit to Queen’s University you will return the two electronic devices. You will also answer some questions on a computer. This will take about 25 minutes. The questions will ask about things you do in your free time. The questions will also ask about your health.

Are there any risks to participating in the study?
Participating should not cause any harms. You do not have to answer questions that make you uncomfortable.

Are there any benefits to participating in the study?
The research will not benefit you directly. We hope to learn more about physical activity in children. We hope this will help to us think of ways to get children to be more active.

Payment for participating
You will be given up to $40. You will receive $10 at the end of the first visit. You will be given $20 at the start of the 2nd visit if you return the electronic devices in good condition. You will be given $10 at the end of the 2nd visit. If you drop out of study, you can keep the money you have already received.

Confidentiality and privacy
We will make every effort to keep the information we obtain from you private. When we show the research findings we will not include private information about you. The information we obtain about you will be protected on our computers.
**Legally required disclosure**

Although we will protect your privacy, if the police request information we may be required to give it to them.

**What if I change my mind about being in the study?**

All parts of a research study are voluntary. You can drop out of the study at any time before it is done. There will be no penalties if you drop out. Also, any information you gave us will be destroyed if you choose.

**Questions about the study**

Questions can be asked to Dr. Ian Janssen. His contact information is shown at the top of this letter. Ethical concerns can be asked to the Chair of the General Research Ethics Board at chair.GREB@queensu.ca or 613-533-6081.

*This study has been granted clearance according to the recommended principles of Canadian ethics guidelines, and Queen’s policies.*
Physical Activity Levels in Kingston Children

CONSENT FORM FOR CHILD – Participant’s Copy

I have read and understood the attached information sheet or had it explained to me. I know that there may be no direct benefit to me for participating. I know that it is my choice to participate. I have been told about the study. I have had all of my questions answered. I know that any information collected about me will be kept private. No one will know that I participated in the study except for the research team. I know I am free to drop out of the study at any time. If I drop out it will not affect me or my family. I also know that I do not have to answer questions that make me feel uncomfortable. I have received a copy of the information sheet and consent form. I agree to participate in the study.

Your full name (Printed) ___________________________________

Your signature: __________________________________________

Date: __________________________________________________

Would you be willing to be contacted about a potential follow-up study, understanding that you can always decline the request?

☐ Yes

☐ No
CONSENT FORM FOR CHILD – Research Team’s Copy

I have read and understood the attached information sheet or had it explained to me. I know that there may be no direct benefit to me for participating. I know that it is my choice to participate. I have been told about the study. I have had all of my questions answered. I know that any information collected about me will be kept private. No one will know that I participated in the study except for the research team. I know I am free to drop out of the study at any time. If I drop out it will not affect me or my family. I also know that I do not have to answer questions that make me feel uncomfortable. I have received a copy of the information sheet and consent form. I agree to participate in the study.

Your full name (Printed) ___________________________________

Your signature: __________________________________________

Date: __________________________________________________

Would you be willing to be contacted about a potential follow-up study, understanding that you can always decline the request?

☐ Yes

☐ No
Appendix C

Ethics Letter of Approval for this Thesis
QUEEN'S UNIVERSITY HEALTH SCIENCES & AFFILIATED TEACHING HOSPITALS
RESEARCH ETHICS BOARD (HSREB)

HSREB Initial Ethics Clearance

October 19, 2016

Miss Yingyi Lin
Department of Public Health Sciences
Queen's University

ROMEO/TRAQ: 46019410
Department Code: EPID-566-16
Study Title: Bidiirectional association between active outdoor play and sleep among 10 to 13-year-old children
Co-Investigators: Dr. I. Janssen
Review Type: Delegated
Date Ethics Clearance Issued: October 19, 2016
Ethics Clearance Expiry Date: October 19, 2017

Dear Miss Lin,

The Queen's University Health Sciences & Affiliated Teaching Hospitals Research Ethics Board (HSREB) has reviewed the application and granted ethics clearance for the documents listed below. Ethics clearance is granted until the expiration date noted above.


Documents Acknowledged:

- CORE Certificate – Y. Lin
- CREB Original Application Materials – GPHE-178-14
- CREB Renewal Clearance – GPHE-178-14

Amendments: No deviations from, or changes to the protocol shall be initiated without prior written clearance of an appropriate amendment from the HSREB, except when necessary to eliminate immediate hazard(s) to study participants or when the change(s) involves only administrative or logistical aspects of the trial.

Renewals: Prior to the expiration of your ethics clearance you will be reminded to submit your renewal report through ROMEO. Any lapses in ethical clearance will be documented on the renewal form.

Completion/Termination: The HSREB must be notified of the completion or termination of this study.
through the completion of a renewal report in ROMEO.

**Reporting of Serious Adverse Events**: Any unexpected serious adverse event occurring locally must be reported within 2 working days or earlier if required by the study sponsor. All other serious adverse events must be reported within 15 days after becoming aware of the information.

**Reporting of Complaints**: Any complaints made by participants or persons acting on behalf of participants must be reported to the Research Ethics Board within 7 days of becoming aware of the complaint. **Note:** All documents supplied to participants must have the contact information for the Research Ethics Board.

Investigators please note that if your trial is registered by the sponsor, you must take responsibility to ensure that the registration information is accurate and complete.

Yours sincerely,

Albert J. Clark
Chair, Health Sciences Research Ethics Board

The HSREE operates in compliance with, and is constituted in accordance with, the requirements of the Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans (TCPS2); the International Conference on Harmonization Good Clinical Practice Consolidated Guideline (ICH GCP); Part C, Division 5 of the Food and Drug Regulations; Part 4 of the Natural Health Products Regulations; Part 3 of the Medical Devices Regulations, Canadian General Standards Board, and the provisions of the Ontario Personal Health Information Protection Act (PHIPA 2004) and its applicable regulations. The HSREE is qualified through the CTO REB Qualification Program and is registered with the U.S. Department of Health and Human Services (DHHS) Office for Human Research Protection (OHRP). Federalwide Assurance Number: FWA# 00004184, IRB# 00001173

HSREE members involved in the research project do not participate in the review, discussion or decision.
Appendix D

Sleep and Activity Log
# Sleep, Organized Sport, and Outside Chores Diary

**Participant ID:** ____________________________  **Today's Date (day/month/year):** ____________________________

<table>
<thead>
<tr>
<th>Day</th>
<th>What time did you get out of bed in the morning?</th>
<th>What time did you go to sleep at night?</th>
<th>If you participated in organized sports or programs, what time did they start and stop?</th>
<th>What organized sports or programs did you participate in?</th>
<th>If you worked or did chores outside, what time did they start and stop?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Example</td>
<td>7:30 am</td>
<td>9:30 pm</td>
<td>4:00 pm 6:30 pm</td>
<td>karate soccer</td>
<td>7:50 am 8:10 am</td>
</tr>
<tr>
<td>Day 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Day 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Day 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Day 4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Day 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Day 6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Day 7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
# Activity Monitor and Location Monitor Diary

**Participant ID:** ________________  
**Today's Date (day/month/year):** ________________

<table>
<thead>
<tr>
<th>Day</th>
<th>If you took the Activity Monitor off, what time did you take it off and put it back on?</th>
<th>What were you doing when the Activity Monitor was off?</th>
<th>If you left home without the Location Monitor, what time did you leave and come back home?</th>
<th>Where did you go without the Location Monitor?</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Time Off</td>
<td>Time Back On</td>
<td>Time Left Home</td>
<td>Time Came Back Home</td>
</tr>
<tr>
<td>Example</td>
<td>6:30 pm</td>
<td>7:30 pm</td>
<td>3:45 pm</td>
<td>4:45 pm</td>
</tr>
<tr>
<td></td>
<td>4:00 pm</td>
<td>4:30 pm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Day 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Day 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Day 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Day 4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Day 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Day 6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Day 7</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Appendix E

Relevant Questions from Child Survey
Participant ID
Enter 4 digit Participant ID

How often do you eat in a fast food restaurant (e.g., McDonald's, Burger King, Wendy's)?
○ Never
○ Rarely (less than once a month)
○ About once a month
○ 2-3 times a month
○ Once a week
○ 2 or 3 times a week
○ 4 times a week or more

How many days of the week do you... (Please mark one box for each line)

<table>
<thead>
<tr>
<th></th>
<th>0 days</th>
<th>1 day</th>
<th>2 days</th>
<th>3 days</th>
<th>4 days</th>
<th>5 days</th>
<th>6 days</th>
<th>7 days</th>
</tr>
</thead>
<tbody>
<tr>
<td>Snack while watching TV (including videos, DVDs, YouTube)?</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Snack while working or playing on a computer or games console?</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Have an evening meal together with your mother or father (or other adult family member)</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
</tbody>
</table>
Appendix F

Relevant Questions from Parent Survey
Participant ID
Enter 4 digit Participant ID

How would you describe your child’s race? Please select all races that are relevant.

☐ White or Caucasian
☐ Hispanic or Latin American (eg. Mexican, Puerto Rican, Brazilian)
☐ Black or African American (eg. Kenyan, Jamaican, Somali)
☐ Aboriginal or Native (eg. First Nations, Metis, Inuit)
☐ Asian (eg. Chinese, East Indian, Japanese, Vietnamese)
☐ Arabic / Middle Eastern (eg. Saudi Arabian, Israeli, Iranian)
☐ Other race not listed above
☐ Prefer not to say

Does a physical condition or health problem reduce the amount or kind of physical activity or exercise your child can do?

☐ No
☐ Yes, sometimes
☐ Yes, often

Has a health professional diagnosed any of the following long-term conditions for your child? Please select "Yes" or "No" for each condition.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Allergies</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Bronchitis</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Diabetes</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Heart condition or disease</td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>
Epilepsy
Cerebral Palsy
Kidney condition or disease
Mental handicap
Learning disability
Attention deficit disorder (with or without hyperactivity)
Emotional, psychological, or nervous disorder
Asthma
Any other long term condition

What is your marital status?
- Married
- Living common-law
- Separated or divorced
- Widowed
- Single and never married
- Prefer not to say

During the past 12 months, what was your household income from wages and salaries (before taxes and deductions)?
- Less than $25,000
- $25,000 to $50,000
- $50,001 to $75,000
- $75,001 to $100,000
- More than $100,000
- Prefer not to say
Appendix G

Sleep Time Cleaning Protocol
Data Cleaning Guidelines: Sleep Times

Before You Start: Things to Keep in Mind
Sleep time refers to the duration someone sleeps at night. In the Active Play Study, participants wore their accelerometer during both waking hours and sleep time, and it is important that we accurately distinguish between the two before we process the accelerometer data. To help us with this, participants were asked to record the time that they went to bed each night and the time they got up in the morning. The objective of the data cleaning outlined in this protocol is to correct errors in the recorded sleep times (e.g., the participant recorded that they went to bed at 9:30 p.m. but they actually went to bed at 10:00 p.m.).

Sleep time is recognizable in the Actical accelerometer data by a period of several hours of little or no movement with accelerometer counts at or close to zero. Because people move when they sleep (e.g., roll over in bed), there will be brief bursts of lower intensity movement during sleep time that are interspersed within long periods with no movement.

Sleep time is generally preceded and followed by at least a few minutes of movement. For example, getting ready for bed (e.g., brushing teeth, going to the bathroom, walking to bedroom, changing clothes) will be recorded as light intensity movement by the accelerometer. In combination with the sleep diaries, this predictable movement pattern will help us determine exact sleeping times for study participants.

When you work on the time verification and correction, commit to verify and correct full days of all recorded sleep times, organized sport times, and non-wear times of a participant. Do Not stop in the middle of a day of a participant.

Sleep Time Verification

1. Enter your name on the sleep time tracking sheet pinned on the bulletin board in Room 501G every time after you start verifying the sleep time for a new participant. Select the next participant on the tracking sheet that has not been started by another researcher. Write down your name in the "Researcher Name" column on the tracking sheet.

2. Obtain the photocopied Sleep and Activity Diary of the Participant ID you wish to verify sleep time for. The photocopied Sleep and Activity diaries are located in the middle filing cabinets in Room 501G. Sleep times include get-up times and bed times.

3. Ensure that you have a coloured pen to make changes on the photocopied diary. All edits should be made on the photocopy and not on the original diary used by the participant.

4. Open the Actical software and Actical accelerometer file.
   a) Open the Actical 3.10 software.
   b) Click File, then click Open...
   c) Select and open the .AWC file of the participant ID you are verifying. These files can be found in the following directory: Epi-Server ➔ EPI lab ➔ Actical. For example, for participant 147, open the 0147.AWC file in the Epi-Server ➔ EPI lab ➔ Actical directory.
   d) Click Tools, then click Actogram
A new screen containing several activity graphs will appear

e) At the top of the screen above the activity graphs, ensure the Identity is the participant ID you are verifying.

f) Adjust the Scale value on the left hand side of the actogram to 1500.
   - This will change the scale on each y-axis to show a maximum value of 1500, making it easier to observe low-intensity movements around the wake-up and sleep times.

5. Determine the correct Day 1 date of the participant you are verifying.
   a) Open the Database Access file located in the Epi-Server → EPI lab → Database folder.
   b) Double click and open the Visit #1 table.
   c) In column two, search for the Date of Visit of the participant ID you are verifying. This date + 1 will be the Day 1 date.

6. Verify Get-up Time:
   a) On the actogram, double click on the activity graph corresponding to the Day 1 date. You will now see an Expanded Actogram for Day 1. An example actogram is shown below in Figure 1.
   b) Ensure the date on the Expanded Actogram is the Day 1 date (see A on Figure 1).
   c) Adjust the Display Center time using the left and right arrows (see B on Figure 1) to match the get-up time recorded for Day 1 on the photocopied diary (i.e., A on Figure 1 matches C on Figure 2).

Figure 1.
c) Check to see if the get-up time that was recorded in the diary is accurate to within one minute of the time registered on the Actical accelerometer. In general, you are looking for the start point of continual movements that occurs around the get-up time that was recorded on the diary. These continual movements will indicate that the participant got-up and started their day.

Keep in mind that the pattern of movements that occurred during the sleep period can help to determine whether the low intensity movements observed close to the recorded get-up times are part of the sleep period or indicate the participant has gotten up. Also, it may be useful to consider the get-up times recorded for the rest of the week. Children often have very similar get-up times on school days and on the weekend.

c) You are asked to determine a reasonable get-up time for Day 8 (the day following the last day of study participation) based on your experience for the participant you are verifying times for.

d) If there is any day when the participant clearly did not wear the activity monitor to sleep, there are 2 options for this step.

- **Option 1** - you will **not** change the recorded get-up time if this time is within the non-wear period, as there is no evidence suggesting the recorded get-up time is wrong.

- **Additionally**, if the period from the recorded get-up time to the time when the first movement is seen on the Actogram is no longer than 20 minutes, please indicate this period in the non-wear period section. For example, if the recorded get-up time is 6:30 a.m. and the first movement is observed at 6:45 a.m., make sure that you write down 6:30 a.m. to 6:45 a.m. as a non-wear period. If this period is greater than 20 minutes, you do not need to indicate it on the non-wear period section.

- **Option 2** - if the recorded get-up time is outside the non-wear period, please change the get-up time to the point where first movement is seen. For example, if the data shows that the participant did not put the activity monitor back on until 6:30 a.m., but the participant indicated the get-up time for that morning was 6:45 a.m., please change the get-up time to 6:30 a.m., as the participant has to be awake to put the monitor back on.
Three illustrative examples for verifying get-up times can be found in Examples 1-3 on pages 7-8.

8) There are 2 options for this step. **Option 1** - If you determine that the recorded get-up time was accurate to the nearest minute, place a checkmark beside the get-up time on the photocopied diary. **Option 2** - If you determine that the recorded get-up time is different from what is recorded on the diary, use a coloured pen to write the corrected time underneath the original time on the photocopied diary. Please **always** write down the words Day 8 in the white space at the bottom of the diary and aligned with the Column for days. Then put down the Day 8 get-up time you determined beside it.

*Note: if you are not sure of the times you have corrected, make a note of this in the “Issues occurred?” column of the tracking sheet. Please get a second opinion (ideally from Chao, Mike, or Emily) on this issue. The data should not be entered into database (Step 10) until the issue has been resolved.*

7. **Verify Bed Time:**

   **Figure 3.**
a) Adjust the Display Center time using the right arrow to match the bed time recorded for Day 1 on the photocopied diary (i.e. D on Figure 3 matches E on Figure 4).

b) Check to see if the bed time that was recorded in the diary is accurate to within 1 minute of the time registered on the Actical accelerometer. Please keep in mind that we cannot determine the exact time when the participant fell asleep, so we are looking for the time they turned off the lights to go to sleep. Thus, if there is some low-intensity movement after the recorded bed time, we would consider the recorded bed time as accurate. Such low-intensity movements might indicate that the participant was trying to fall asleep (e.g., tossing and turning in bed). However, if there is any movement or epoch after the recorded bed time above 375 counts on the y-axis of the actogram, this would typically indicate that the participant was still out of bed doing some moderate intensity movements. During this step it may be useful to consider the bed times recorded for the rest of the days. Children often have the same bedtime on school nights, for example.

c) If there is any day when the participant clearly did not wear the activity monitor to sleep, there are 2 options for this step.

Option 1 - you will not change the recorded bed time if this time is within the non-wear period, as there is no evidence suggesting the recorded bed time is wrong.

Additionally, if the period from the time when the last movement is seen on the Actogram to the recorded bed time is no longer than 20 minutes, please indicate this period in the non-wear period section. For example, if the last movement is observed at 9:45 p.m., and the recorded bed time is 10 p.m., make sure that you write down 9:45 p.m. to 10 p.m. as a non-wear period. If this period is greater than 20 minutes, you do not need to indicate it on the non-wear period section.

Option 2 - if the recorded bed time is outside the non-wear period, please change the bed time to the point where last movement is seen. For example, if the data shows that
the participant did not take off the activity monitor until 10 p.m., but the participant indicated the bed time for that night was 9:45 p.m., please change the get-up time to 10 p.m., as the participant has to be awake to take off the activity monitor.

*Three illustrative examples for verifying bed times can be found in Examples 4-8 on pages 8-9.*

**d)** There are 2 options for this step. **Option 1** - If you determined that the recorded sleep time was accurate, place a checkmark beside the sleep time on the photocopied diary. **Option 2** - If you determine that the recorded sleep time is different from what was recorded on the diary, use a coloured pen to write the corrected time underneath the original time on the photocopied diary.

*Note: if you are not sure of the times you have corrected, make a note of this in the “Issues occurred?” column of the tracking sheet. Please get a second opinion (ideally from Chao, Mike, or Emily) on this issue. The data should not be entered into database (Step 10) until the issue has been resolved.*

8. **Repeat the Sleep Time Data Verification Process.** The processes that were explained in Steps 6 and 7 for Day 1 should be repeated for Day 2 through Day 7 for the same participant ID.

9. **Indicate that all Sleep Times has been verified and corrected on the data cleaning tracking sheet pinned on the bulletin board in Room 501G.** Every time you have completed all the sleep time, organized sports time, and non-wear time verification and correction for a same day of a participant’s, put a check mark in the corresponding day in the “All 7 days verified & corrected?” column. **The next time you start working on the data verification you should pick-up where you left off with this participant.**

10. **Enter Corrected Sleep Time Information into Database**
    a. All of the sleep time information for all 7 days plus the Day 8 get-up time for the participant ID, including data on the diary that was accurate and data that was corrected, should be entered in the electronic study database. This should be entered in the “Sleep and Activity Diary Day [1-7] – Cleaned” table in the **Database-Cleaned** Access file located in the Epi-Server → EPI Lab → Database folder.
    b. Enter your name in the **Researcher Name** column beside the participant ID in the **Database-Cleaned** Access file.

11. **Indicate that all verified and corrected data on the data cleaning tracking sheet pinned on the bulletin board in Room 501G.** Every time you have entered all the verified and corrected sleep times, organized sports times, and non-wear times for a same day of a participant, put a check mark in the corresponding day in the “All data entered into database?” column. **The next time you start working on the data entry you should pick-up where you left off with this participant.**
Appendix H

Power Calculations
There are a total of 6 relationships of interest in this thesis, and the time in bed→OAP analysis is used as an example for power calculation. Since the study design of the thesis is a two-level study of sleep - OAP (n = 2253) pairings nested within participants (n = 433), the power should be based on effective sample size, which is calculated from the total sample size, design effect, the average cluster size and the intra-class correlation coefficient (ICC) through the following two formulas: 1) design effect = 1 + (average cluster size - 1) * ICC; 2) effective sample size = total sample size / design effect.\(^1\)\(^2\) The average cluster size is 5.2 (2253 / 433). In the present study, ICC for OAP is 0.3 (data not shown). Thus, the design effect is 2.3. Therefore, the effective sample size used for the power calculation was 979 (2253 / 2.3) for time in bed→OAP analysis.

The “power analysis for linear regression” function from XLSTAT (2017) software is used for the power calculation. For linear regression models, power can be determined by specifying the desired significance level, the degrees of freedom associated with the model (u), degree of freedom associated with F-test error term (v), and the desired effect size (Cohen’s \(f^2\)) through the following formula: \(\lambda = f^2 * (u + v + 1)\). All of my power calculations are based on a significance level of 0.05. For sleep - OAP analysis, there are a total of 13 predictors included in the final regression model. As indicated in the previous paragraph, the effective sample size was 979. Therefore, the power calculation was based on having 12 degrees of freedom for the numerator (u = number of variables - 1) and 966 degrees of freedom for the denominator (v = sample size - number of variables) in the F-test. Further, because there is a lack of a prior knowledge about the bi-directional relationships between OAP and sleep, and no clear indication what a clinically relevant relationship would be, power estimates are based on Cohen’s \(f^2\) derived from the formula \(f^2 = R^2 / (1 - R^2)\), where \(R^2\) is the squared multiple correlation.\(^3\) This effect size
measure is commonly used in the behavioural epidemiology literature. Small, medium and large
effect size $f^2$ can be represented by the values of 0.02, 0.15 and 0.35, respectively. Based on all
of these information, I have a power of 83.3% to detect a small effect size and 100% to detect
medium or large effect sizes.

Estimated power of detecting associations of interest while controlled for selected confounders

<table>
<thead>
<tr>
<th>Associations</th>
<th>Small</th>
<th>Medium</th>
<th>Large</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time in bed→OAP</td>
<td>83.3%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>Sleep duration→OAP</td>
<td>83.3%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>Sleep efficiency→OAP</td>
<td>83.3%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>OAP→Time in bed</td>
<td>96.5%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>OAP→Sleep duration</td>
<td>88.4%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>OAP→Sleep efficiency</td>
<td>80.0%</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

References