Sleep and Obesity among Young Adults:
Examining the Effectiveness of a Text Message-Based Intervention on Improving Sleep Habits

by

A. Jordan Filion

A Thesis
presented to
The University of Guelph

In partial fulfilment of requirements
for the degree of
Master of Science
in
Family Relations and Applied Nutrition
(Applied Human Nutrition)

Guelph, Ontario, Canada

© A. Jordan Filion, July 2014
ABSTRACT

SLEEP AND OBESITY AMONG YOUNG ADULTS:
EXAMINING THE EFFECTIVENESS OF A TEXT MESSAGE-BASED
INTERVENTION ON IMPROVING SLEEP HABITS

A. Jordan Filion
Advisor: Professor Jess Haines
University of Guelph, 2014

This thesis examined the effectiveness of a text message-based intervention on improving sleep habits among a national sample of young adults. Cross-sectional and longitudinal associations between sleep measures and adiposity (i.e., body mass index (BMI) and weight status) were also examined. Longitudinal data were collected from 129 young adult smokers (mean age = 21.8 years; mean BMI of analytical sample = 25.4 kg/m²) enrolled in a smoking cessation study. Sleep measures were self-reported and assessed using items adapted from valid and reliable indices. No significant intervention effects were observed among the total sample or among adequate sleepers (≥ 6 hours/night). Among short sleepers (< 6 hours/night), participants who received text messages about sleep/physical activity reported getting significantly more sleep on work/school nights at follow-up, as compared to those who received text messages focused on smoking cessation. In our secondary objective analyses, a significant inverse association was found between sleep quantity on non-work/non-school nights and both BMI and weight status in the cross-sectional models; however, the association with BMI was no longer significant after adjustment for covariates. No significant longitudinal associations were found. This study provides preliminary evidence that a text message-based sleep intervention may be a promising approach for improving sleep habits among young adults, especially short sleepers, and should be further explored as a novel approach for obesity prevention.
ACKNOWLEDGEMENTS

Completing graduate school has been one of the most incredible and rewarding learning experiences of my life, and has greatly contributed to my growth as a person, student, researcher, and aspiring dietitian. There are several people I would like to acknowledge who have been instrumental in my decision to pursue graduate studies, have supported me throughout the process, and have made this experience an unforgettable one.

Foremost, I would like to thank my advisor and mentor, Dr. Jess Haines. You were the reason I chose to pursue my Masters, and I cannot begin to tell you how grateful I am to have had this experience. Outside of my thesis research, I would like to thank you for all of the learning opportunities that you have given me. The many skills that I have developed through having these opportunities will be invaluable as I move into the next phase of my career. Over these past two years, I have accomplished things that I never thought would be possible, and I would like to thank you for always challenging me to reach my highest potential. Your dedication to your students and your research is truly inspiring, and I can tell that you genuinely love what you do.

Next, I would like to thank the rest of my advisory committee. Dr. Gerarda Darlington, thank you for all of the statistical expertise that you have contributed to this project and for taking time out of your hectic schedule throughout the year to sit down and help me with my data analysis. The clarity with which you explain statistical concepts has really enhanced my understanding of statistics and has allowed me to cultivate my analytic skills. Dr. Jean-Philippe Chaput, I would also like to thank you for all of the expertise you have contributed to this project and for helping me select my research questions. I remember citing some of your research back
when I was completing a term paper in my fourth year of undergraduate studies, and am
honoured to have you on my advisory committee. You have already accomplished so much as a
new investigator, and I wish you many years of continued success in your research career. I
would also like to acknowledge and thank Dr. Andrea Buchholz for chairing my defense and
supporting my applications to both graduate school and dietetic internships. I am very grateful to
have had you as a professor during my undergraduate studies – the way in which you engaged
your students really made learning enjoyable and fostered my understanding of the complexities
of clinical nutrition.

To all of my fellow graduate students that I have had the privilege of working alongside
these past two years – I have enjoyed getting to know each and every one of you and want to
thank you for making graduate school such an enjoyable experience. All of you are such bright
and talented young women, and I am looking forward to seeing where we all end up ten years
down the road. Best of luck to all of you as you complete your studies and move on to the next
chapter of your lives. I would also like to say a special thank you to Kathryn Walton for all of the
advice and support that she has given me – even before I started my Masters. Kathryn, you are
one of the most driven people I have ever met, and I wish you all the best as you finish your
dietetic internship and begin your PhD studies this fall.

To my family – Mom, Dad and Ian – you have been there for me since day one, and I am
truly lucky to have the three of you in my life. You always know how to make me laugh – even
during the times I have called you in tears – and I want to thank you for all of the support and
encouragement that you have given me throughout my years as a student. It seems like just
yesterday that I was stepping onto the school bus to go to my first day of kindergarten! Ian – this
is a special year for both of us, as we graduate from university and enter the real world. I am so
proud of all that you have accomplished over the past four years, both as a student and athlete, and know that you have a very bright future ahead of you.

To all of the lovely ladies that I have had the pleasure of living with over my two years as a graduate student – Nicole Osinga, Coleen North, Samantha Slater, Steph Tirelli, Jess Whitehead, and Vanessa Zukiwski. I honestly could not have asked for a better group of girls to live with, and my graduate experience certainly would not have been the same without you. The friendship and many laughs that we have shared will never be forgotten, and I want to thank you for all of the support and encouragement you have given me when I needed it most. To one of my best friends, Robin Harper – you have always been there to support me through graduate school, and I am truly grateful to have you as a friend.

Last, but certainly not least, I would like to thank Dr. Michele Ybarra and her colleagues at the Center for Innovative Public Health Research, Michigan State University, and the University of Texas Health Science Center at Houston for the data that were used for this project.
Table of Contents

Acknowledgements ........................................................................................................ iii

List of Figures and Tables ............................................................................................. ix

List of Abbreviations ..................................................................................................... x

1.0 Introduction ................................................................................................................ 1

2.0 Review of the Literature .......................................................................................... 5

2.1 Obesity Among Young Adults .................................................................................... 5

2.1.1 Prevalence of Obesity Among Young Adults ...................................................... 5

2.2 Health Risks Associated with Obesity in Young Adulthood ...................................... 7

2.3 Sleep Habits Among Young Adults ........................................................................... 9

2.4 Sleep and Obesity ..................................................................................................... 12

2.4.1 Proposed Relationships Between Sleep and Body Mass Index ............................ 12

2.4.2 Proposed Mechanisms of the Effect of Sleep on Body Mass Index ..................... 21

2.5 Interventions to Improve Sleep Habits Among Young Adults .................................. 28

2.6 Mobile Phone and Text Messaging Usage Among Young Adults ......................... 34

2.7 Text Message-Based Health Behaviour Change Interventions ................................ 35

3.0 Rationale for the Current Study ............................................................................... 46

4.0 Study Objectives and Hypotheses .......................................................................... 48

5.0 Methodology ............................................................................................................ 49

5.1 Stop My Smoking (SMS) USA Study Design ......................................................... 49

5.1.1 Recruitment and Eligibility ............................................................................... 49

5.1.2 Procedures ......................................................................................................... 50

5.1.3 Participants ......................................................................................................... 54

5.1.4 Ethical Considerations ....................................................................................... 55
5.2 Measures

5.2.1 Body Mass Index

5.2.2 Sleep Quantity

5.2.3 Sleep Quantity Variability

5.2.4 Sleep Quality

5.2.5 Sleep Hygiene

5.3 Confounding Variables

5.3.1 Confounders Included in Primary Objective Analyses

5.3.2 Confounders Included in Secondary Objective Analyses

5.3.3 Measurement of Confounders

5.4 Data Analysis

5.4.1 Data Analysis Protocol for Primary Objective

5.4.2 Data Analysis Protocol for Secondary Objective

5.5 Summary of Methods

6.0 Results

6.1 Primary Research Objective

6.1.1 Study Sample

6.1.2 Linear Regression Results

6.2 Secondary Research Objective

6.2.1 Study Sample

6.2.2 Linear Regression Results

6.2.3 Logistic Regression Results

7.0 Discussion
7.1 Comparison of Primary Objective Findings to the Literature......................... 94
  7.1.1 Effectiveness of Interventions to Improve Sleep Habits among Young Adults........................................................................................................................................ 94
  7.1.2 Effectiveness of Text Message-Based Health Behaviour Change Interventions........................................................................................................... 101
7.2 Comparison of Secondary Objective Findings to the Literature..................... 106
  7.2.1 Sleep Quantity.................................................................................................. 107
  7.2.2 Sleep Quantity Variability.............................................................................. 113
  7.2.3 Sleep Quality.................................................................................................. 116
7.3 Contribution to the Literature........................................................................... 119
7.4 Limitations........................................................................................................... 120
7.5 Strengths........................................................................................................... 128
7.6 Next Steps.......................................................................................................... 132
8.0 Conclusions........................................................................................................ 134
9.0 References......................................................................................................... 136
10.0 Appendices...................................................................................................... 161

  Appendix A: University of Guelph Research Ethics Approval......................... 161
  Appendix B: Other MSc Contributions................................................................. 163
List of Figures and Tables

Table 1: Sample Text Messages Received by SMS USA Participants………………………….. 52
Figure 1: SMS USA study design and participant flow……………………………………….. 55
Table 6.1: Demographic/Baseline Characteristics of Participants in the SMS USA Study (Overall
and by Intervention Assignment)………………………………………………………….. 79
Table 6.2: Change in Sleep Outcomes from Baseline to 12-Week Follow-Up by Intervention
Assignment………………………………………………………………………………………….. 81
Table 6.3: Change in Sleep Outcomes from Baseline to 12-Week Follow-Up by Intervention
Assignment for Short Sleepers (<6 hours/night)……………………………………… 82
Table 6.4: Change in Sleep Outcomes from Baseline to 12-Week Follow-Up by Intervention
Assignment for Adequate Sleepers (≥6 hours/night)……………………………………… 83
Table 6.5: Demographic/Baseline Characteristics of Participants in the SMS USA Study (Overall
and by Intervention Assignment)………………………………………………………….. 86
Table 6.6: Results of Cross-Sectional Linear Regression Analyses of Sleep Outcomes with Body
Mass Index………………………………………………………………………………………… 87
Table 6.7: Results of Longitudinal Linear Regression Analyses of Sleep Outcomes with Body
Mass Index………………………………………………………………………………………… 88
Table 6.8: Results of Cross-Sectional Logistic Regression Analyses of Weight Status with Sleep
Outcomes………………………………………………………………………………………… 90
Table 6.9: Results of Longitudinal Logistic Regression Analyses of Weight Status with Sleep
Outcomes………………………………………………………………………………………… 91
List of Abbreviations

aOR = Adjusted Odds Ratio Estimate
BMI = Body Mass Index
BRFSS = Behavioral Risk Factor Surveillance System
BSE = Breast Self-Examination
CCHS = Canadian Community Health Survey
CDC = Centers for Disease Control and Prevention
CDC-ACSM = Centers for Disease Control and Prevention - American College of Sports Medicine
CESD-R = Center for Epidemiologic Studies Depression Scale Revised
CHMS = Canadian Health Measures Survey
CI = Confidence Interval
CVD = Cardiovascular Disease
EPIC = European Prospective Investigation into Cancer and Nutrition
ESS = Epworth Sleepiness Scale
FCI-II = Food-Craving Inventory
fMRI = Functional Magnetic Resonance Imaging
IOM = Institute of Medicine
MVPA = Moderate-to-Vigorous Physical Activity
NHANES = National Health and Nutrition Examination Survey
NHIS = National Health Interview Survey
NLSAH = National Longitudinal Survey of Adolescent Health
OR = Odds Ratio Estimate
PHAC = Public Health Agency of Canada
PHQ-9 = Patient Health Questionnaire
PSQI = Pittsburgh Sleep Quality Index
PSQI-A = Pittsburgh Sleep Quality Index (adjusted version)
REM = Rapid Eye Movement
SAFER = Sleep, Alertness & Fatigue Education in Residency
SD = Standard Deviation
SES = Socioeconomic Status
SHAPS = Sleep Hygiene Awareness and Practices Scale
SHI = Sleep Hygiene Index
SMS USA = Stop My Smoking USA
SQI = Sleep Quality Index
SSB = Sugar-Sweetened Beverage
STEPS = Sleep Treatment and Education Program for Students
TEE = Total Energy Expenditure
1.0 Introduction

The issue of obesity is of universal importance and does not spare any age group, including young adults. In the context of the current study, young adults were defined as those individuals between the ages of 18 and 25 years. Although there is no published obesity prevalence estimate exclusively for the 18 to 25 year age category, recent Canadian survey data using direct measures of height and weight suggest that the combined prevalence of overweight (defined as a body mass index (BMI) of 25.0 kg/m\(^2\) to 29.9 kg/m\(^2\)) and obesity (defined as a BMI of 30.0 kg/m\(^2\) or greater) among adults ages 18 to 39 years is approximately 47% (Statistics Canada, 2013). Using recent population estimates for the 18 to 39 year age group, this translates to approximately 5 million Canadian young adults being overweight or obese (Statistics Canada, 2012). This is particularly concerning because obesity in young adulthood is associated with many adverse health consequences including reduced psychological well-being (Public Health Agency of Canada (PHAC), 2011; Puhl & Heuer, 2010) and increased risk for the development of chronic disease in later adulthood (PHAC, 2011).

Although obesity rates have begun to level off in recent years, little progress has been made in reducing overall prevalence rates (Lau et al., 2007). Traditionally, most obesity prevention and treatment efforts have targeted dietary and physical activity habits, which have been shown to produce little change in weight parameters and result in short-lasting treatment effects (Epstein, Myers, Raynor, & Saelens, 1998, as cited in Hart & Jelalian, 2008, p. 252). This indicates that there may be factors we are overlooking when attempting to address obesity as a public health issue.
Interestingly, the continuing rise in overweight and obesity rates that has been observed in our society over the last few decades coincides with a decline in average nighttime sleep duration (e.g., Cappuccio et al., 2008). Within the last decade, there has been a profusion of research identifying sleep as one of several modifiable risk factors for obesity across different geographic populations and age groups (e.g., Hasler et al., 2004). Among the young adult age group, inadequate sleep is a prevalent issue, with over 20% of young adults getting less than 7 hours of sleep on most nights (Steptoe, Peacey, & Wardle, 2006). Therefore, behaviour change interventions designed to improve sleep duration and quality of sleep may be effective in reducing the level of obesity among young adults, as sleep has been shown to impact eating and physical activity behaviours (for a review, see Patel & Hu, 2008).

Emerging evidence on sleep behaviour change interventions among young adults has shown mixed results, with some demonstrating no effects on sleep (Lamberti, 2012), some demonstrating small effects on sleep (Arora, Georgitis, Woodruff, Humphrey, & Meltzer, 2007; Farias, 2012; Tsai & Li, 2004a), and others demonstrating larger, statistically significant effects on sleep (Ball & Bax, 2002; Brown, Buboltz, & Soper, 2006; Clark, 2010; Prestwich, Rankin, & Housman, 2007; Trockel, Manber, Chang, Thurston, & Barr Tailor, 2011). All of these interventions, however, were evaluated exclusively using participants enrolled in post-secondary education, so it remains unknown whether such interventions can meaningfully change behaviour among the broader population of young adults.

In the health behaviour intervention literature, text message-based interventions have recently been applied to various health behaviours such as smoking (Free et al., 2011; Haug, Meyer, Schorr, Bauer, & John, 2009; Obermayer, Riley, Asif, & Jean-Mary, 2004; Rodgers et al., 2005), diet (Haapala, Barengo, Biggs, Surakka, & Manninen, 2009; Joo & Kim, 2007;
Patrick et al., 2009; Shapiro et al., 2008), with varying success. To date, however, a text message-based intervention designed to improve sleep habits has not yet been developed. Therefore, this study builds upon the existing sleep, obesity, and health behaviour change intervention literature by examining the effectiveness of a text message-based intervention in improving sleep habits among a U.S. national sample of young adults.

The primary objective of this study was to determine the extent to which participants who received text messages aimed at improving sleep and physical activity habits (compared with individuals receiving text messages aimed at smoking cessation) improved their sleep quantity, sleep quantity variability (i.e., difference between usual sleep quantity on work/school nights and non-school/non-work nights), and sleep quality. All sleep measures were self-reported and assessed using items adapted from valid and reliable indices. Longitudinal data from the Stop My Smoking (SMS) USA Study (Ybarra, Holtrop, Prescott, Rahbar, & Strong, 2013) conducted nationally in the United States in 2011 and 2012 were used to address this objective. We hypothesized that greater improvements in sleep quantity, sleep quantity variability, and sleep quality would be observed among those participants in the group receiving text messages aimed at improving sleep habits, and also among those participants with a shorter self-reported sleep duration (i.e., less than 6 hours) on work/school nights at baseline.

The secondary objective of the current study was to explore cross-sectional and longitudinal associations between sleep measures (i.e., sleep quantity, sleep quantity variability, and sleep quality) and adiposity (i.e., BMI and weight status). BMI was assessed using self-reported height and weight. In the cross-sectional analyses, we hypothesized that sleep quantity
and sleep quality would be negatively associated with BMI at baseline, sleep quantity variability would be positively associated with BMI at baseline, and poorer sleep habits at baseline (i.e., lower sleep quantity, higher sleep quantity variability, and lower sleep quality) would be associated with higher odds of being overweight/obese at baseline. In the longitudinal analyses, we hypothesized that positive changes in sleep quantity and quality, as well as reductions in sleep quantity variability, would be associated with a lower BMI, and that poorer sleep habits at follow-up would be associated with higher odds of being overweight/obese at follow-up.

To develop effective obesity prevention interventions, we need a clear understanding of the full range of modifiable risk factors associated with obesity and how to improve such risk factors at the population level. Recent research examining the impact of sleep on weight outcomes in all age groups suggests that a direct association exists between these two variables, pinpointing sleep as a potential modifiable risk factor for the development of obesity (e.g., Hasler et al., 2004). Results from this study can help inform the development of future obesity prevention interventions and behavioural interventions aimed at improving sleep habits through illustrating whether a text message-based intervention can produce meaningful changes in sleep habits and adiposity among a national sample of young adults. This research is of particular interest to the broad population of young adults since these individuals are the heaviest users of mobile phone technology and may therefore be more receptive to an intervention platform that is already heavily embedded into their daily lives (Smith, 2010).

In the following section, a thorough review of the literature is presented pertaining to the current state of knowledge on obesity and sleep habits among young adults, including proposed relationships and mechanisms for how these variables are associated. This is followed by a
review of interventions designed to improve sleep habits among young adults, and other health behaviour interventions using a text message-based platform.

2.0 Review of the Literature

2.1 Obesity Among Young Adults

2.1.1 Prevalence of Obesity Among Young Adults

Over the last few decades, increases in the prevalence of obesity across all age groups have not only been observed in Canada, but in virtually every country around the globe (Zimmermann-Belsing & Feldt-Rasmussen, 2004). According to results from the 2009-2011 Canadian Health Measures Survey (CHMS), approximately 19% of adults ages 18 to 39 years are obese (i.e., have a BMI greater than 30 kg/m$^2$) and an additional 28% are overweight (i.e., have a BMI between 25 and 29.9 kg/m$^2$; Statistics Canada, 2013). These are the most current Canadian estimates using measured heights and weights, which are higher than estimates using self-report data from the 2007-2008 Canadian Community Health Survey (CCHS), where the prevalence of obesity among 18 to 34 year-olds was estimated to be 10% (PHAC, 2011).

Looking at Canadian rates of overweight and obesity according to sex, it appears that the prevalence of class I obesity (i.e., BMI between 30 and 34.9 kg/m$^2$) is slightly higher among female young adults (14.6%) compared to male young adults (13.3%), yet the prevalence of overweight is markedly higher among male young adults (33.7%) compared to female young adults (23.0%; Statistics Canada, 2013). Prevalence estimates for class II obesity (i.e., BMI between 35.0 kg/m$^2$ and 39.9 kg/m$^2$) and class III obesity (i.e., BMI above 40.0 kg/m$^2$) among this age group were deemed too unreliable to publish (Statistics Canada, 2013). Obesity rates among both sexes, however, tend to increase with age, starting at approximately age 20 and continuing until age 65 (PHAC, 2009). Therefore, intervening during this critical period can
assist young adults in forming healthy weight-related habits that they can maintain throughout the rest of their adult years in order to minimize weight gain over time.

Although Canadian trends in obesity prevalence are beginning to level off, rates are still remarkably higher than they were a few decades ago. To put this into perspective, overweight rates have doubled in the past 25 years, while obesity rates have further tripled (PHAC, 2011). Over time, obesity has also become more severe in the sense that the heaviest individuals (i.e., those in the obesity class III category with a BMI greater than 40 kg/m²) are now even heavier (PHAC, 2011). In order to maintain accurate records of obesity prevalence in Canada, more frequent BMI surveillance is needed using directly measured height and weight data (versus self-report data; PHAC, 2009).

Similar to Canada, the United States has recently begun to experience a plateau in obesity prevalence rates (Flegal, Carroll, Kit, & Ogden, 2012). The National Health and Nutrition Examination Survey (NHANES) is a national survey conducted in the United States that is designed to assess the health and nutritional status of Americans using a combination of interviews and physical exams, and is one of the few adult BMI surveillance measures that uses measured height and weight data to derive national obesity prevalence rates (Centers for Disease Control and Prevention (CDC), 2013). Based on survey data from the 2009-2010 NHANES, it is estimated that 33% of Americans 20 to 39 years of age are obese and an additional 29% are overweight (Flegal et al., 2012). Similar to what has been observed in Canada, it appears that the prevalence of overweight in the U. S. is markedly higher among males (33.9%) compared to females (23.9%) yet, unlike Canada where obesity rates are slightly higher among female young adults, the prevalence of obesity is slightly higher among American males in this age group (33.2%) compared to females (31.9%; Flegal et al., 2012). In the current study, U. S. obesity
prevalence rates are relevant since the SMS USA study was conducted in the United States with American participants.

2.2 Health Risks Associated with Obesity in Young Adulthood

It is well documented that obesity in adulthood is associated with a wide range of health risks including type 2 diabetes, hypertension, cardiovascular disease (CVD), and some types of cancer (PHAC, 2011; Tjepkema, 2005). Guh et al. (2009) recently conducted a meta-analysis of prospective cohort studies to estimate the incidence of 18 weight-related comorbidities among adults who are overweight and obese. Results showed that obesity (defined by a BMI greater than 30 kg/m²) was most strongly associated with risk for type 2 diabetes (the relative risk was calculated to be 12.41 (9.03-17.06) among females and 6.74 (5.55-8.19) among males), with statistically significant associations also being observed between obesity and 6 types of cancer (including breast, endometrial, ovarian, colorectal, kidney and pancreatic cancers), all major types of CVD (including hypertension, stroke, coronary artery disease and congestive heart failure), asthma, gallbladder disease, osteoarthritis, and chronic back pain (Guh et al., 2009).

Although much work has been done in studying the health risks associated with obesity in adulthood, the magnitude of these associations in young adults remains unknown (Koebnick et al., 2012). Obese young adults, however, are not completely exempt from disease risk, as many weight-related chronic diseases (e.g., type 2 diabetes) once thought to be an issue only among middle-aged and older adults are now being observed in obese children and young adults with increasing frequency (Daniels, 2006).

Aside from impacting one’s risk for developing weight-related diseases, another short-term consequence of obesity in young adulthood is reduced psychological well-being, resulting
from the stigma attached to being obese (PHAC, 2011; Puhl & Heuer, 2010). Specifically, it has been found that weight stigmatization among both clinical and non-clinical populations of obese adults is a risk factor for depression (e.g., Chen, 2007, as cited in Puhl & Heuer, 2010, p. 1023), low self-esteem (e.g., Carr & Friedman, 2005, as cited in Puhl & Heuer, 2010, p. 1023), and body dissatisfaction (e.g., Matz, Foster, Faith, & Wadden, 2002, as cited in Puhl & Heuer, 2010, p. 1023). Furthermore, a study conducted by Hatzenbuehler, Keyes and Hasin (2009) examining the association between perceived weight discrimination and prevalence of psychiatric disorders among a nationally representative sample of non-institutionalized obese adults in the United States found that those who perceived they were being discriminated against based on their weight had 2.5 times the risk of developing a mood disorder and 2.6 times the risk of developing an anxiety disorder (after controlling for demographic variables, perceived stress, and BMI). In his paper on the relationship between stigma and weight-related disease, Muennig (2008) offers additional insight into the mechanism underlying the association between stigma and disease, contending that stigma-induced stress experienced by obese individuals can explain some of the weight-related morbidity that has conventionally been attributed solely to adiposity (as cited in Puhl & Heuer, 2010, p. 1023).

Due to the short- and long-term health risks associated with obesity in young adulthood, it is imperative that we develop a clear understanding of the modifiable risk factors associated with obesity, and how such risk factors can be improved at the population level. Having this knowledge will ultimately lead to the development of more effective prevention interventions to reduce obesity and its related comorbidities.
2.3 Sleep Habits among Young Adults

It has been estimated that one spends approximately a third of his/her life sleeping, which serves as a period of rejuvenation for the human body (National Sleep Foundation, 2011a). During sleep, several restorative processes occur in the body: energy is replenished, blood supply to the muscles increases, hormones are released, and tissue growth and repair occurs (National Sleep Foundation, 2011a). As a result, detrimental health effects occur when this period of restoration is consistently cut short. Aside from its more obvious effects on energy levels and alertness, chronic sleep deprivation has also been linked with poor immune function, increased risk for psychiatric conditions including depression, and increased risk for chronic diseases such as type 2 diabetes, CVD and obesity (Harvard Medical School, 2008; National Sleep Foundation, n.d.).

Over the past few decades, average nighttime sleep duration has declined in many nations around the world, which can be attributed to changes in lifestyle that have occurred over this time period (e.g., Cappuccio et al., 2008). For example, compared to 50 years ago, many people in today’s society choose to sacrifice sleep in order to accommodate changes in their daily schedules or to prioritize other activities. This practice is particularly prevalent among the large proportion of young adults who are attending university or college, where social and academic demands often take priority over getting adequate sleep (Pilcher, Ginter, & Sadowsky, 1997). A recent study by Jean-Louis et al. (2014) used data from the National Health Interview Survey (NHIS), collected from 1977 through 2009, to determine whether the prevalence of short sleep duration has increased over the past 32 years. The NHIS is a nationally representative cross-sectional study of non-institutionalized American adults ages 18 and older (Jean-Louis et al., 2014). The authors found that from 1977 to 2009, the prevalence of very short sleep (i.e., < 5
hours/day) increased from 1.7% to 2.4%, and the prevalence of short sleep (i.e., 5 to 6 hours/day) increased from 19.7% to 26.7% (Jean-Louis et al., 2014). Another review on trends in adult sleep duration in 15 different countries across North America, Europe and Asia, however, suggests that little evidence exists for the claim that sleep duration has declined (Sun Bin, Marshall, & Glozier, 2012). Specifically, it was found that sleep duration had increased by 14 minutes a day in Canada from 1985 to 2005, and mixed evidence supporting both an increase and decrease in average adult sleep duration was found among American studies included in the meta-analysis (Sun Bin et al., 2012). For the one Canadian study (Michelson, 2011) and two American studies (Luckhaupt, Tak, & Calvert, 2010; Robinson & Michelson, 2010) providing evidence of an increase in average sleep duration, potential differences in weekend and weekday sleep durations were not accounted for (Sun Bin et al., 2012). Thus, it is possible that observed increases in sleep duration can be attributed solely to getting more sleep on weekends, as was found by Hale (2005) and Choo, Lee and Song (2006; as cited in Sun Bin et al., 2012, p. 228). One notable limitation of the available data on sleep habits in Canada and other countries, however, is that it is self-reported by participants. Therefore, it is likely that some participants over-report the amount and quality of sleep that they get, which may lead to biased estimates. To enhance the accuracy of sleep quantity and quality estimates at the population level, more objective measures of sleep habits (i.e., sleep quantity and quality) are needed.

According to the National Sleep Foundation, it is recommended that adults over the age of 18 years should get between 7 and 9 hours of sleep per night in order to be adequately rested (National Sleep Foundation, n.d.). It is important to note that individual variation exists within this recommended range, with some individuals requiring more sleep to function optimally than others of the same age and sex (National Sleep Foundation, n.d.). International sleep data
collected in 2006 from young adults across 27 universities in 24 countries revealed that the average amount of nighttime sleep in this population was 7 hours and 27 minutes per night (Steptoe et al., 2006). Although this statistic may create the illusion that young adults are generally well rested, of particular concern is the sizable proportion (i.e., 21%) of young adults who reported that they were habitual short sleepers, defined as getting less than 7 hours of sleep on most nights (Steptoe et al., 2006). More recent sleep duration estimates taken from a sample of over 1500 young adults ages 19 to 29 years (including those not enrolled in post-secondary education) were slightly lower at 7 hours and 1 minute per night for sleep on weekdays, yet sleep duration estimates for weekend days were found to be markedly higher at 8 hours and 5 minutes (National Sleep Foundation, 2011b).

Aside from sleep duration, another equally important (and often overlooked) component of sleep relates to the quality of one’s sleep. Examining sleep quality in populations is critical because it is possible that people are getting the recommended quantity of sleep, but the quality of that sleep could be poor, leading to many of the same problems observed with short sleep duration.

Population based research suggests that a large proportion of young adults report experiencing sleep-related problems (Buboltz et al., 2009). In their study examining sleep habits and patterns of U.S. undergraduate students (N = 742), Buboltz et al. (2009) used the Sleep Quality Index (SQI; Urponen, Partinen, Vuori, & Hasan, 1991) to measure the frequency of general sleep difficulties experienced by respondents in the sample (possible scores on this measure ranged from 0 to 16, with higher scores on an item representing a higher frequency of that particular sleep-related problem). Results showed that only 11.5% of the sample had a SQI score of 0 or 1 (indicating good sleep quality), with 65.9% of respondents scoring between 2 and
8 (indicating occasional sleep difficulties), and the remaining 22.6% scoring between 9 and 16 (indicating poor sleep quality; Buboltz et al., 2009). Compared with results from their 2001 study with 191 undergraduate students, Buboltz et al. (2009) found an increase in the prevalence of poor self-reported sleep quality in their 2009 study. Specifically, a higher proportion of students reported taking more than 30 minutes to fall asleep on most nights (24.2% in 2009 versus 19.9% in 2001), suffering from insomnia at least 3 times per week (11.1% in 2009 versus 4.2% in 2001), experiencing difficulties falling asleep at least 3 times per week (17.3% in 2009 versus 12.1% in 2001), experiencing disturbed nighttime sleep at least 3 times per week (19.7% in 2009 versus 14.7% in 2001), waking up during the night on most nights (20.1% in 2009 versus 13.6% in 2001), waking up too early at least 3 times per week (18.0% in 2009 versus 13.6% in 2001), and using sleep medications at least once per week (3.0% in 2009 versus 1.0% in 2001; Buboltz et al., 2009). Both samples had similar proportions of respondents reporting morning tiredness (54.4% in 2009 versus 54.5% in 2001; Buboltz et al., 2009). This upward trend in the prevalence of poor sleep quality is also supported by longitudinal results from research by Hicks, Fernandez and Pellegrini (2001), who found that the percentage of American college students who reported being dissatisfied with the quality of their sleep rose from 24% in 1978 to 53% in 1988, and again to 71% in 2000.

2.4 Sleep and Obesity

2.4.1 Proposed Relationships Between Sleep and Body Mass Index

2.4.1.1. Sleep Quantity and Body Mass Index

Interestingly, the continuing rise in overweight and obesity rates that has been observed in our society over the last few decades coincides with a decline in average nighttime sleep duration (e.g., Cappuccio et al., 2008). Many researchers have begun to explore the association
between sleep duration and obesity in the adult population, yet there are no published studies exclusively examining the general population of 18 to 25 year-old young adults. Among adults, numerous cross-sectional studies have found a significant inverse relationship between self-reported sleep duration and BMI, specifically, that adults with shorter sleep durations are at an increased risk of being obese (for a review, see Cappuccio et al., 2008 or Patel & Hu, 2008). For example, Jean-Louis et al. (2014) found that very short sleepers (i.e., < 5 hours/day) had 30% greater odds of being overweight and were twice as likely to be obese, compared to normal sleepers (i.e., 7 to 8 hours/day). In addition, those individuals who were classified as short sleepers (i.e., 5 to 6 hours/day) were found to have 20% greater odds of being overweight and 57% greater odds of being obese, compared to normal sleepers (Jean-Louis et al., 2014). This finding of an inverse relationship between sleep duration and adiposity is also supported by results from a recent cross-sectional analysis conducted by Moraes et al. (2013) using objective measures of sleep duration (i.e., actigraphy and polysomnography). When examining potential gender differences in the relationship between sleep duration and BMI among a sample of 2006 adults, another team of researchers found that sleep was inversely associated with BMI among males (i.e., a one hour increase in sleep was associated with a 0.38 kg/m² decrease in BMI), but not females (Meyer, Wall, Larson, Laska, & Neumark-Sztainer, 2012). Conversely, another cross-sectional study found a U-shaped relationship between sleep duration and BMI, where the lowest BMI was predicted at 7.7 hours of habitual nighttime sleep (Taheri, Lin, Austin, Young, & Mignot, 2004). Although the authors found that odds of being highly physically active (i.e., exercising more than 7 hours per week, assessed via self-report) decreased with longer sleep time, controlling for this variable did not change the observed results (Taheri et al., 2004). A main concern with studying this relationship cross-sectionally, however, is the possibility of
reverse causation. For example, it is possible that short sleep duration leads to a higher BMI, but it is also possible that having a higher BMI may predispose individuals to developing sleep disorders that reduce both the quantity and quality of their sleep.

Longitudinal research on the nature of the relationship between sleep duration and BMI or weight gain over time (ranging from 1-year follow-up to 16-year follow-up) has also demonstrated mixed results, with the majority of studies on adults demonstrating an inverse association (Hasler et al., 2004; Kobayashi, Takahashi, Deshpande, Shimbo, & Fukui, 2012; Patel, Malhotra, White, Gottlieb, & Hu, 2006), some demonstrating a U-shaped association (Chaput et al., 2008; Watanabe, Kikuchi, Tanaka, & Takahashi, 2010), and others demonstrating no longitudinal association between sleep duration and BMI or weight gain over time (Gangwisch, Malaspina, Boden-Albala, & Heymsfield, 2005; Lauderdale et al., 2009; Stranges et al., 2007). Similar to the cross-sectional study by Meyer et al. (2012), Watanabe et al. (2010) only found a significant relationship between sleep duration and weight gain among male participants, with no observed relationship among females in the sample. When examining the effect of changing sleep habits on future risk for weight gain, Chaput, Després, Bouchard and Tremblay (2012) found that short sleepers (i.e., adults getting 6 hours of sleep or less per night) who maintained their short sleep habits over a 6-year period experienced a greater increase in BMI than short sleepers who adopted healthier sleep habits (i.e., increasing sleep duration to between 7 and 8 hours per night) over the same time frame.

To illustrate the magnitude of the contribution that short sleep duration has on obesity risk in adulthood, Chaput et al. (2009) examined the independent contributions of 9 previously documented risk factors for obesity, including high alcohol intake (i.e., ≥10 g/day), high dietary fat intake (i.e., >40% total calories from fat/day), non-consumption of multivitamins/dietary
supplements, high dietary restraint behaviour (i.e., a restraint score ≥ 8 on the Three-Factor Eating Questionnaire; Stunkard & Messick, 1985), nonparticipation in high-intensity physical activity, high susceptibility to hunger behaviour (i.e., a hunger score ≥ 5 on the Three-Factor Eating Questionnaire), low dietary calcium intake (i.e., < 600mg/day), high disinhibition eating behaviour (i.e., a disinhibition score ≥ 6 on the Three-Factor Eating Questionnaire), and short sleep duration (i.e., < 6 hours/day). After adjusting for age, sex and socioeconomic status (SES), short sleep duration was found to be associated with the highest risk of overweight and obesity (OR = 3.81; Chaput et al., 2009). In addition, longitudinal analyses revealed that short sleepers gained 1.65 kg more over the 6-year follow-up period than participants who reported sleeping at least 7 hours per day (Chaput et al., 2009).

Despite the lack of research conducted exclusively with young adults between the ages of 18 and 25 years, Hasler et al. (2004) found that the inverse cross-sectional association between sleep duration and weight gain diminished after the age of 34, suggesting that the relationship between these two variables is stronger in younger adults. Taken collectively, the above studies suggest that the relationship between sleep duration and BMI is stronger when examined cross-sectionally, and that short sleep duration is a potential risk factor for future weight gain and increases in BMI in the adult population. More research is needed, however, to determine whether findings on the relationship between sleep duration and obesity from the broader adult population hold true for young adults.

2.4.1.2 Sleep Quantity Variability and Body Mass Index

In recent years, some researchers have moved beyond examining sleep duration to studying day-to-day variability in sleep duration as a risk factor for obesity (Kjeldsen et al.,
For example, one study by Kjeldsen et al. (2014) was the first study to examine whether large variability in objectively measured sleep duration (i.e., using actigraphy) was associated with specific dietary risk factors for obesity. Using a sample of 676 Danish school children ages 8 to 11 years, the researchers found that sleep duration variability (assessed in minutes per night over a one-week period by adding the absolute difference between the individual’s mean sleep duration and sleep duration on each measurement day, divided by the number of measurement days) was positively associated with intake of sugar-sweetened beverages (SSBs; \( p = 0.03 \); Kjeldsen et al., 2014). This association was independent of several potential confounders, including sleep duration, age, sex, pubertal status, height, weight, screen time, moderate-to-vigorous physical activity (MVPA), parental education, and ethnicity (Kjeldsen et al., 2014). Similarly, another study by Spruyt et al. (2011) examined the impact of sleep schedule regularity on children’s BMI and metabolic regulation. The sleep patterns of 308 children ages 4 to 11 years were measured objectively over a one-week period using wrist actigraphy, in addition to BMI being calculated for each child, and fasting morning plasma levels of glucose, insulin, lipids, and high-sensitivity C-reactive protein being collected on a subsample of participants (Spruyt et al., 2011). Results showed that obese children (defined as those children with BMI z-scores \( \geq 1.65 \)) exhibited more variability in sleep duration on weekend days than school days (\( p = 0.02 \)), compared with overweight children (i.e., those with a BMI z-score \( > 1.04; p = 0.49 \)) and normal-weight children (\( p = 0.20 \)) who exhibited little variability in sleep duration (Spruyt et al., 2011). Specifically, obese children tended to have shorter sleep durations as the week progressed, with the shortest sleep durations occurring on weekend nights; overweight children tended to have longer sleep durations as the week progressed, with the longest sleep durations occurring on weekend nights; and normal-weight
children tended to have relatively stable sleep durations during the week, with slightly longer durations on weekend nights (Spruyt et al., 2011). When examining the effect of sleep duration variability on biochemical indicators, Spruyt et al. (2011) found that sleep duration on school nights was positively correlated with plasma triglyceride levels among obese children \((r = 0.31, p < 0.05)\), with no other significant associations being found.

Two other studies have examined the relationship between sleep quantity variability and BMI/obesity using a sample of adults (Kobayashi et al., 2013) and older adults (Patel et al., 2014). Kobayashi et al. (2013) used a longitudinal study design to examine the effect of variability in sleep duration on BMI among a sample of 21,148 adults (mean age = 51 years). The authors found that greater individual variability in sleep duration (i.e., the extent to which self-reported average nighttime sleep duration varied over the 3-year study period; calculated by dividing the standard deviation of sleep duration over the 3-year period by the square root of the number of data points) was independently associated with an increase in BMI over a 3-year period, after adjusting for age, sex, alcohol use, smoking status, physical activity, baseline BMI, baseline sleep duration, comorbidities (i.e., hypertension, diabetes, and dyslipidemia) and past medical history (i.e., acute cardiovascular syndrome and cerebral vascular accident; Kobayashi et al., 2013). In a more recent study by Patel et al. (2014), the authors used a cross-sectional study design to examine whether an association existed between objectively measured sleep patterns (including timing and regularity of sleep) and obesity among a sample of 3,053 men (mean age = 76.4 years) and 2,985 women (mean age = 83.5 years). Results showed that among both men and women, there was a significant positive association between sleep duration variability and BMI, which was found to be independent of nighttime sleep duration (Patel et al., 2014). Specifically, each hour increase in the standard deviation of nighttime sleep duration was associated with 1.63
times higher odds of obesity among men and 1.22 times higher odds of obesity among women, after adjusting for a multitude of covariates including age, race, site, alcohol use, smoking status, caffeine use, education, medical history (i.e., diabetes, stroke, coronary artery disease, and congestive heart failure), use of antidepressants, use of benzodiazepines, physical activity, cognitive function, depression, self-reported health, and mean nighttime sleep duration (Patel et al., 2014).

2.4.1.3 Sleep Quality and Body Mass Index

To a lesser extent than sleep quantity, researchers have begun to examine the association between sleep quality and BMI. Cross-sectionally, one study examining the association between sleep quality, cardiorespiratory fitness, and BMI/obesity status among a sample of 1,726 adolescent girls (age 10 to 18 years) did not find a significant association between sleep quality and BMI (Mota & Vale, 2010). However, it can be argued that the single subjective measure used to assess sleep quality (i.e., “In general, how is your sleeping time”, with possible response options including “poor”, “fair”, “good”, “very good” and “excellent”) was vague and did not examine the many different facets of sleep quality. In another study on adolescents in Taiwan ($N = 2,113$), researchers explored the relationship between sleep quality and BMI, using three sleep quality scales (i.e., difficulty in initiating sleep, difficulty in maintaining sleep, and non-restorative sleep; Chen, Truong, & Tsai, 2013). Results showed that 20.9% of the sample experienced at least one sleep quality problem, and that teenagers who reported experiencing difficulty in initiating sleep had significantly higher BMIs than those who did not report experiencing this sleep quality problem (Chen et al., 2013). Interestingly, these results were found despite the small variation in BMI within the study sample (i.e., mean BMI for boys was 21.1 kg/m$^2$ (standard deviation ($SD$) = 3.26) and mean BMI for girls was 19.9 kg/m$^2$ ($SD$ = 2.78);
Chen et al., 2013). When assessing sleep quality using actigraphy (i.e., objective measures), Tworoger, Davis, Vitiello, Lentz, and McTiernan (2005) found higher BMI to be associated with poorer sleep quality among women, although BMI variation within the sample, similar to Chen et al.’s (2013) study, was small (mean BMI = 23.8 kg/m$^2$, $SD = 3.7$ kg/m$^2$; Tworoger et al., 2005). This is consistent with research by Meyer et al. (2012), who found evidence of a significant positive cross-sectional association between trouble falling or staying asleep (assessed via self-report) and BMI in women, but not men.

Three studies examining the relationship between sleep quality and BMI among the general adult population have also reported significant associations between the two variables (Pearson, Johnson, & Nahin, 2006; Resta et al., 2003; Yeh & Brown, 2014). For example, Pearson et al. (2006) used data from the NHIS to explore the association between insomnia, trouble sleeping, and risk for obesity. Sleep quality was assessed subjectively, using a single item (i.e., “During the past 12 months, have you regularly had insomnia or trouble sleeping”, with possible response options including “yes” or “no”), and it was found that 17.4% of the sample reported regularly experiencing insomnia or trouble sleeping in the past year (Pearson et al., 2006). Results illustrated a strong positive association between experiencing insomnia/trouble sleeping in the past year and odds of being obese (adjusted odds ratio (aOR) = 1.15, 99% CI (1.01, 1.31)), even after adjusting for several covariates including age, sex, education, race, ethnicity, and the presence of several comorbidities (i.e., hypertension, congestive heart failure, diabetes, and anxiety/depression). In a study by Resta et al. (2003), 78 severely obese subjects were compared to 40 healthy sex- and age-matched controls to determine whether sleep quality, sleep-related symptoms and excessive daytime sleepiness were associated with obesity. Sleep quality was measured using the Epworth Sleepiness Scale (ESS; Johns, 1991), in addition to
items assessing frequency of snoring, daytime sleepiness, and other sleep-related symptoms (i.e., stopping breathing at night, waking up at night, choking during the night, and unrefreshing sleep; Resta et al., 2003). Polysomnography was also used as a more objective measure of sleep to calculate total sleep time, time spent in rapid eye movement (REM) sleep, sleep efficiency (i.e., the proportion of time in bed spent sleeping), and sleep latency (i.e., the time it takes to fall asleep after going to bed; Resta et al., 2003). Although results showed that obese and healthy controls had similar sleep latency and REM sleep latency, there were significant between-groups differences in all of the other polysomnographic measures, ESS scores, and items assessing snoring, daytime sleepiness and other sleep-related symptoms, indicating that obese individuals were poorer sleepers (Resta et al., 2003). In a recent study by Yeh and Brown (2014), the authors explored the relationship between poor sleep quality (assessed via the Pittsburgh Sleep Quality Index (PSQI; Buysse, Reynolds, Monk, Berman, & Kupfer, 1989)) and high BMI through assessing disordered eating as a potential mediator. The PSQI assesses 7 subjective dimensions of sleep quality, including sleep duration, sleep disturbance, sleep latency, daytime dysfunction, sleep efficiency, subjective sleep quality, and use of sleep medications, in order to compile a total sleep quality score distinguishing good sleepers from poor sleepers (Buysse et al., 1989). The researchers found that high BMI was associated with short sleep duration, increased sleep latency, and use of sleep medications, and that disordered eating was a partial mediator of this relationship (Yeh & Brown, 2014). Specifically, binge eating partially mediated the association between sleep quality and BMI, whereas night eating was found to partially mediate the reverse association between BMI and sleep quality, even after adjusting for age, relationship status and depression (Yeh & Brown, 2014). Therefore, results from this study offer more insight into the mechanism of how sleep quality and BMI are related.
Longitudinally, one study examining the relationship between sleep quality (assessed via a 4-item questionnaire) and obesity found that three measures of sleep quality (i.e., trouble falling asleep, waking up several times per night, and trouble staying asleep) were associated with weight gain of at least 5 kilograms over the 5- to 7-year study period, yet waking up tired was not (Lyytikainen et al., 2011). Furthermore, similar to Meyer et al.’s (2012) finding, this association was only observed among women (Lyytikainen et al., 2011). Conversely, results from Hasler et al.’s (2004) longitudinal study did not support an association between measures of sleep quality (assessed via interview with a clinical health professional) and obesity.

### 2.4.2 Proposed Mechanisms of the Effect of Sleep on Body Mass Index

#### 2.4.2.1 Sleep and Eating Behaviour

When examining how sleep is associated with obesity, the first and most widely accepted mechanism to date relates to changes in eating behaviour – specifically, increases in energy intake – that accompany reductions in sleep quantity and/or quality (Chaput, in press). In his recent review examining sleep patterns, diet quality and energy balance, Chaput (in press) identified six mechanisms by which inadequate sleep may increase energy intake. First and foremost, inadequate sleep may lead to weight gain and obesity through increasing one’s exposure to the obesogenic eating environment (Chaput, 2010; Chaput, in press). For example, in our current environment where individuals have virtually constant access to highly palatable foods and beverages, it is possible that caloric intake is proportional to the amount of time spent awake (Chaput, 2010). Recent findings from the largest randomized controlled trial of experimental sleep deprivation on eating behaviour support this argument, where it was found that participants who underwent 5 consecutive nights of sleep restriction to 4 hours per night consumed excessive calories (i.e., on average, 130% of their daily caloric intake required for
weight maintenance, calculated using the Harris Benedict equation; Harris & Benedict, 1918), compared with control group participants spending 10 hours in bed per night over the same 5-day period (who consumed, on average, 101% of their daily caloric intake required for weight maintenance; Spaeth, Dinges, & Goel, 2013). In addition, there is evidence that lack of sleep may not only impact hunger and satiety, but may also affect one’s nutritional choices and eating patterns. One study by Weiss et al. (2010) found that, compared to adolescents with habitual nighttime sleep durations of 8 hours or more, those sleeping less than 8 hours per night had a 2.2% higher average daily intake of calories from fat and 3.0% lower average daily intake of calories from carbohydrates. Weiss et al. (2010) also found that for each hour increase in sleep duration, the odds of consuming 475 calories per day or more from snack foods decreased by 21%. This is consistent with research by Kim, De Roo and Sandler (2010), who found that women with shorter habitual sleep durations tended to snack more frequently than they ate meals, which was related to higher consumption of calories from fats and sweets, and lower consumption of calories from fruits and vegetables. Interestingly, Kim et al. (2010) also found that participants with long habitual sleep durations (i.e., sleeping 10 hours or more per night) also ate a high number of snacks and a lower number of meals, which could be explained by the tendency of some long sleepers to sleep through meals (e.g., breakfast).

When examining the relationship between sleep and food cravings among adolescents, one study by Landis, Parker and Dunbar (2009) found that increased daytime sleep (which was related to decreased nighttime sleep) was associated with higher scores on the Food-Craving Inventory (FCI-II; White, Whisenhunt, Williamson, Greenway, & Netemeyer, 2002), which measures subjective cravings for sweets, carbohydrates-starches, high fat foods and fast foods. Higher scores on each subscale of the inventory are indicative of more frequent cravings for
these energy-dense foods (White et al., 2002). Taken collectively, the above studies indicate that short sleepers have a greater opportunity to eat, and are more likely to both crave and consume high calorie foods with poor nutritional value, all of which favour weight gain.

Second, a great deal of research (e.g., Spiegel, Tasali, Penev, & Van Couter, 2004) has demonstrated that inadequate sleep can trigger changes in the neuroendocrine control of appetite (Chaput, in press). Two hormones, in particular, have been implicated in this mechanism: leptin, an appetite-suppressing hormone secreted by adipose tissue, and ghrelin, an appetite-stimulating hormone secreted by endocrine cells in the stomach (Zigman & Elmquist, 2003). During periods of nutritional abundance, an increase in levels of leptin (and simultaneous decrease in levels of ghrelin) normally occurs to prevent excess energy consumption, while an opposite shift in levels of these hormones occurs during periods of fasting or energy insufficiency (Zigman & Elmquist, 2003). When sleep quantity and/or quality is reduced, however, several studies have found that circulating levels of these two hormones are affected, with decreases in leptin levels and increases in ghrelin levels being observed (for a review, see Schmid, Hallschmid, & Schultes, 2014). For example, among a sample of 12 healthy young adult males, Spiegel et al. (2004) found that restricting nighttime sleep duration to 4 hours for two consecutive nights was associated with an 18% mean decrease in serum leptin levels and a 28% mean increase in total ghrelin levels, along with increases in subjective hunger and appetite. In this scenario, the appetite-suppressing effects of leptin are therefore blunted while the appetite-stimulating effects of ghrelin are enhanced, favouring positive energy balance and subsequent weight gain (Chaput et al., 2007, as cited in Chaput et al., 2008, p. 517). It is important to note, however, that Spiegel et al.’s (2004) study was conducted under highly controlled conditions – specifically, intravenous glucose infusion was used to restrict participants’ caloric intake and physical activity was
restricted by having participants spend extra hours of wakefulness either lying down or sitting. Furthermore, when participants in Spiegel et al.’s (2004) study were in the sleep restriction (i.e., 4 hours of sleep/night) condition, they were awake 3 hours earlier compared to when they were in the sleep extension (i.e., 10 hours of sleep/night) condition. Therefore, it is intuitive that sleep-restricted participants would feel hungrier at breakfast because they have been awake longer. In recent studies (e.g., Nedeltcheva et al., 2009) where participants’ wake times remained consistent and only bedtimes were delayed, an up-regulation of appetite-stimulating hormones has generally not been observed.

In Chaput’s (in press) recent review cited at the beginning of this section, it was found that changes in hormones implicated in hunger and satiety signalling may not play as large a role as previously thought in increasing energy intake, when examining results from studies conducted in free-living conditions. For example, Chaput (in press) highlighted a cross-over study conducted by Markwald et al. (2013), who examined the effects of 5 days of sleep restriction (i.e., to 5 hours of sleep per night) on energy intake and expenditure, compared with 5 days of adequate sleep (i.e., 9 hours per night). Interestingly, the researchers observed normal neuroendocrine responses for the hunger and satiety hormone levels measured (i.e., leptin, ghrelin, and peptide YY) in both study conditions, yet energy intake (especially of carbohydrates) was higher among participants in the 5-hour sleep condition (Markwald et al., 2013).

The third mechanism Chaput (in press) identified by which inadequate sleep can lead to weight gain/obesity is through increasing the amount of energy one needs to sustain wakefulness during the additional hours spent awake. For example, animals have evolved to increase their caloric consumption during times they need to stay awake to hunt or avoid predators, so that
sufficient energy can be supplied to the brain and nervous system to maintain alertness (Chaput, in press). Therefore, it is plausible that humans may respond the same way in periods of sleep deprivation, and this may also explain why short sleepers tend to crave/consume more energy-dense foods, as found in studies by Kim et al. (2010), Landis et al. (2009) and Weiss et al. (2010).

Fourth, inadequate sleep may lead to weight gain/obesity through its effects on mood and psychological functioning (Chaput, in press). In his review, Chaput (in press) cited a recent study conducted by Moubarac, Cargo, Receveur, and Daniel (2013) that examined associations between consumption of sweetened products (e.g., cakes, cookies, chocolate, candies), daytime sleepiness, and psychological distress (all measured via self-report). Moubarac et al. (2013) found psychological distress to be a partial mediator of the relationship between daytime sleepiness and consumption of sweetened products, which Chaput (in press) suggested could be attributed to individuals with high levels of daytime sleepiness reaching for these “comfort foods” to alleviate psychological distress or increase energy. Similarly, the fifth proposed mechanism for how inadequate sleep may lead to weight gain/obesity relates to its influence on other aspects of psychological functioning, such as sensitivity to food reward (Chaput, in press). For example, Chaput (in press) highlighted a new cross-over study by St-Onge, Wolfe, Sy, Shechter and Hirsch (2014), which used functional magnetic resonance imaging (fMRI) to determine whether there were differences in neuronal responses when viewing unhealthy foods versus healthy foods after five nights of sleep restriction (i.e., to 4 hours of sleep per night), compared to five nights of adequate sleep (i.e., 9 hours of sleep). These researchers found that after experiencing a 5-day period of restricted sleep, there was increased activation in areas of the brain associated with reward when viewing images of unhealthy foods, compared with
images of healthy foods (St-Onge et al., 2014). When fMRI scans were taken after 5 nights of adequate sleep, however, there were no differences between brain activation patterns when viewing images of unhealthy foods versus healthy foods (St-Onge et al., 2014).

Lastly, Chaput (in press) identified decreased dietary restraint (i.e., the tendency to overeat in response to certain situations) as another mechanism through which inadequate sleep is related to weight gain/obesity. For example, Chaput (in press) cited Markwald et al.’s (2013) study examining the effects of sleep restriction on energy intake and expenditure, where the researchers found that short sleep led to decreased dietary restraint among women, increasing their risk for subsequent weight gain.

Overall, the above studies clearly demonstrate that sleep influences eating behaviour in a multitude of ways, with weight gain and increased risk for overweight/obesity being favoured during periods of inadequate sleep.

**2.4.2.2 Sleep and Physical Activity**

The other proposed mechanism for how sleep is associated with obesity relates to decreased levels of physical activity among short sleepers. Although short sleepers spend more time awake and thus have a greater opportunity to expend energy, these individuals tend to experience daytime fatigue and tiredness, which typically acts as a deterrent to engaging in physical activity (Bromley, Booth, Kilkus, Imperial, & Penev, 2012; Chaput, 2010; Patel et al., 2006; Schmid et al., 2009). One study by Schmid et al. (2009) supporting this proposed mechanism examined the effect of short-term sleep loss on daytime physical activity (assessed via wrist actigraphy) under free-living conditions among a sample of 15 healthy, normal-weight men. Results showed that daytime physical activity was significantly reduced after one night of
sleep restriction (i.e., to 4 hours of sleep) and, furthermore, a shift in the intensity of physical activity performed by participants was observed, where those individuals in the 4-hour sleep condition performed a significantly higher proportion of low-intensity physical activities (i.e., 57.6% versus 52.3% after getting 8 hours of sleep) and a significantly lower proportion of high-intensity physical activities (i.e., 22.6% versus 25.4% after getting 8 hours of sleep; Schmid et al., 2009). Bromley et al. (2012) reported similar findings in their crossover study examining the effect of sleep on physical activity (measured via wrist actigraphy and waist accelerometry) among a sample of 18 young adults with parental history of type 2 diabetes. Specifically, compared to when participants were in the 8.5-hour time-in-bed condition, after one week of spending 5.5 hours in bed per night, Bromley et al. (2012) observed a 31% decrease in total activity counts, a 24% decrease in MVPA, and an increase in sedentary activity by a mean of 21 minutes per day. Interestingly, the magnitude of the decrease in total activity counts was greater among participants who exercised regularly (-39%) compared to non-exercisers (-4%; Bromley et al., 2012). These researchers agree, however, that more research in this area is needed to determine whether similar results are seen with longer-term sleep loss in everyday settings (Bromley et al., 2012; Schmid et al., 2009).

More recently, however, the evidence supporting the impact of sleep on energy expenditure – specifically, the adverse impact of inadequate sleep on physical activity – is less compelling (Klingenberg, Sjodin, Holmback, Astrup, & Chaput, 2012). In their review of the literature on experimental studies investigating the impact of inadequate sleep on energy expenditure, Klingenberg et al. (2012) did not find strong evidence to suggest that sleep had a meaningful effect on energy expenditure. For example, one of the studies cited in Klingenberg et al.’s (2012) review was a cross-over study measuring energy intake from meals and snacks and...
total energy expenditure (TEE) among 11 mildly overweight (but otherwise healthy) adults after 14 days of restricted sleep (i.e., to 5.5 hours per night), and also after 14 days of adequate sleep (i.e., 8.5 hours per night; Nedeltcheva et al. (2009). When comparing results from the two sleep conditions (i.e., restricted versus adequate sleep), no significant differences in TEE were found; however, significant differences were found between groups with respect to energy intake from snacks, with participants consuming more energy from snacks when their sleep was restricted (Nedeltcheva et al., 2009). In Markwald et al.’s (2013) two-week inpatient study, results showed that restricted sleep (i.e., 5 hours of sleep/night) increased TEE by approximately 5%. Therefore, these results suggest that the evidence supporting changes in eating behaviour as a causal mechanism for which inadequate sleep can lead to weight gain/obesity is stronger than evidence supporting changes in energy expenditure as a causal mechanism.

2.5 Interventions to Improve Sleep Habits Among Young Adults

Within the past decade, researchers have begun to investigate whether interventions designed to improve knowledge about proper sleep hygiene can result in meaningful changes in sleep habits among young adults. Sleep hygiene is a term coined by Dr. Peter Hauri in 1977 to describe those behaviours that promote improved sleep quality and quantity (Stepanski & Wyatt, 2003). Interventions ranged from being as brief as a 30-minute oral presentation (Brown et al., 2006; Clark, 2010) to a more involved college course (100 minutes per week) offered over an 18-week semester (Tsai & Li, 2004a). Emerging evidence on the efficacy of these interventions has shown mixed results, with some demonstrating no effects on sleep (Lamberti, 2012), some demonstrating small effects on sleep (Arora, Georgitis, Woodruff, Humphrey, & Meltzer, 2007; Farias, 2012; Tsai & Li, 2004a), and others demonstrating larger, statistically significant effects
on sleep (Ball & Bax, 2002; Brown, Buboltz, & Soper, 2006; Clark, 2010; Prestwich, Rankin, & Housman, 2007; Trockel, Manber, Chang, Thurston, & Barr Tailor, 2011).

One of the interventions tested a 2-week web-based sleep hygiene intervention delivering information regarding good and poor sleep hygiene behaviours and found that the intervention was successful in improving undergraduate students’ sleep hygiene knowledge, but such knowledge was not translated into behaviour change (i.e., improvements in sleep quality; Farias, 2012). Results from another intervention conducted by Lamberti (2012) suggest that participation in an hour-long group discussion session followed by a 1-month online educational sleep intervention targeting first year college students was not successful in terms of improving sleep quality or sleep hygiene habits – in fact, sleep quality (assessed by responses on the PSQI) declined over the study period. However, missing data throughout the study period reduced the number of sleep measure surveys available for analysis which, in turn, reduced the amount of statistical power to detect treatment effects (Lamberti, 2012).

Arora et al. (2007) studied the effectiveness of a 60- to 90-minute lecture on sleep loss and recovery sleep for residents in medical school, called the “Sleep, Alertness & Fatigue Education in Residency” (SAFER) program. Wrist actigraphy was used to collect sleep quantity data for the purpose of measuring how much sleep interns obtained the night before they were on-call (i.e., pre-call or preventive sleep), while they were on-call, the first day post-call, the second day post-call, and total post-call sleep (i.e., the sum of first-day and second-day post-call sleep, defined as restorative sleep). Objective sleep data was collected in a one-year period both before and after the sleep lecture was delivered. Results showed that the SAFER program did not significantly increase interns’ sleep quantity during any of the call conditions; however, the mandated 80-hour work week for medical school interns makes it exceedingly difficult for these
individuals to obtain the recommended amount of sleep in the presence of other competing life demands (Arora et al., 2007).

Tsai and Li (2004a), who evaluated the effectiveness of a semester-long course (involving lectures, group discussions, and homework assignments) on improving sleep habits of college students in Taiwan, also found that their intervention had a limited effect on sleep habits. Specifically, both intervention group and control group participants exhibited significant changes in several sleep measures, including bed time, rise time, sleep latency, number of awakenings, time asleep, time in bed, sleep efficiency, and total sleep, with only sleep quality and nap time showing significant improvements among intervention group participants (Tsai & Li, 2004a). One major limitation of this study, however, was that control group participants were friends of intervention group participants (Tsai & Li, 2004a). Therefore, it is quite possible that some of the sleep intervention information was passed along to control group participants, causing these participants to improve their sleep habits (Tsai & Li, 2004a).

Of the interventions that were successful in improving young adults’ sleep quality, two consisted of a 30-minute in-person oral presentation (Brown et al., 2006; Clark, 2010), and the remaining three consisted of an 8-week online cognitive behavioural program to improve sleep (Trockel et al., 2011), a 10- to 15-minute sleep education session and/or filling out sleep logs for a 2-week period (Prestwich et al., 2007), and receiving individual feedback on responses to a sleep scale or participating in a 1.5 hour educational session involving a lecture, group discussion, and written information regarding the effects of health habits (including sleep) on learning and memory (Ball & Bax, 2002). In Brown et al.’s (2006) study, 177 undergraduate students were recruited from two introductory psychology courses and assigned to one of two groups: a control group who received a 30-minute oral presentation on the importance of the
scientific method, and an intervention group who received the 30-minute Sleep Treatment and Education Program for Students (STEPS). In addition to the oral presentation, individuals in the intervention group were administered supplemental handouts covering topics such as sleep hygiene and caffeine-containing substances (Brown et al., 2006). Brown et al. (2006) found that, at 6 weeks post-intervention, students receiving the STEPS reported significantly improved sleep quality (assessed via the PSQI) and sleep hygiene practices (assessed via the Sleep Hygiene Practices subscale of the Sleep Hygiene Awareness and Practices Scale (SHAPS); Lacks & Rotert, 1986), with the greatest effect size being found for sleep hygiene practices (eta-squared or $\eta^2 = 0.15$, compared with $\eta^2 = 0.05$ for sleep quality). Interestingly, no significant differences were found between the two groups with respect to sleep hygiene knowledge (assessed via the Sleep Hygiene Awareness subscale of the SHAPS).

In Clark’s (2010) study, a sample of 668 freshmen attending a college in the U.S. were randomly assigned to either a sleep intervention group who received a 30-minute oral presentation aimed at improving sleep habits, or an active control group who received a 25-minute oral presentation about general health and stress reduction strategies. Analysis of intervention data showed that sleep quality scores for poor sleepers on the adjusted version of the PSQI (i.e., the PSQI-A, which uses the same cut-off points as the PSQI and is identical to the PSQI except that it asks for separate estimates for weekday and weekend sleep habits for 4 items) improved in both groups from baseline to 9-weeks post-intervention, however, greater improvements were observed among individuals in the sleep intervention group (Clark, 2010). In addition, there were sex and racial differences with respect to changes in sleep quality over the study period (Clark, 2010). For example, males in both the sleep intervention and active control groups demonstrated self-reported improvements in sleep quality, yet such improvements were
only observed among female participants in the sleep intervention group (Clark, 2010). In addition, improvements in sleep quality were observed among Caucasian participants in both groups and only multiracial participants in the sleep intervention group but, interestingly, no improvements were observed among African American or Latino participants in either group (Clark, 2010).

Other research by Trockel et al. (2011) examined the effects of a cognitive behavioural program to improve sleep using a sample of 101 first-year college students from two on-campus residence halls. Students from one hall were assigned to an 8-week online sleep health program called “Refresh”, while students from the other residence hall were assigned to a different 8-week program called “Breathe”, which focused on improving mood and increasing students’ resilience to stress (Trockel et al., 2011). Results showed that, among participants who were classified as poor sleepers at baseline (i.e., scored > 5 on the PSQI), participation in the Refresh program was associated with significantly larger improvements in sleep quality than participation in the Breathe program (Trockel et al., 2011). Interestingly, among participants who were classified as good sleepers at baseline (i.e., scored ≤ 5 on the PSQI), no significant difference in sleep quality was observed between the Refresh and Breathe programs.

Prestwich et al. (2007) studied a sample of 54 college students attending personal health classes to determine the effect of sleep education and recording sleep patterns via sleep logs on sleep quantity and daytime sleepiness. At baseline, participants completed a 3-day recall of how much sleep they had obtained over the previous three days, in addition to the ESS, which is an 8-item self-administered survey designed to measure an individual’s general level of daytime sleepiness. After these measures were completed, participants were then randomly assigned to one of four groups: (a) a control group that only completed the recall and sleep scale measures at
baseline and follow-up, (b) a group that received 10 to 15 minutes of sleep education after completing baseline measures, (c) a group that completed sleep logs over the 2 weeks following completion of baseline measures, or (d) a group that received sleep education and completed sleep logs (Prestwich et al., 2007). Although changes in ESS scores were not statistically significant, results from sleep recalls showed that participants in the group receiving both of the intervention components (i.e., sleep education and sleep logs) reported sleeping 2.68 hours more over the 3-day recall period at follow-up, which translates to an increase in sleep quantity of approximately 54 minutes per night (Prestwich et al., 2007). No significant improvements were observed in any of the other study arms.

In Ball and Bax’s (2002) study, a sample of 54 medical school students (mean age = 24.0 years) recruited from a first-year introductory course at an American university was used to examine changes in health habits and the effects of an educational intervention on the emotional and academic adjustment of students in their first year of medical school. All participants completed a questionnaire assessing a series of health habits, including sleep, socialization, exercise, caffeine and alcohol use, as well as depression and life satisfaction, at the start of the semester, at mid-term, and again at the end of the semester (Ball & Bax, 2002). At mid-term, approximately half of participants (n = 29) were randomized to receive a self-awareness intervention, where they received written feedback on their questionnaire scores assessing depression, sleepiness and alcohol use (Ball & Bax, 2002). The other half of participants (n = 23) were randomized to receive a self-care intervention, which involved a 1.5-hour educational session that included a lecture, group discussion, and written information regarding the effects of health habits (including sleep) on learning and memory (Ball & Bax, 2002). Results showed that participants receiving the self-awareness intervention reported significant reductions in daytime
sleepiness, compared with participants in the self-care intervention (Ball & Bax, 2002). Participants receiving the self-care intervention, however, were significantly more likely to have improved in maintaining a consistent wake time and were also significantly less likely to have trouble falling asleep at follow-up, compared with those in the self-awareness intervention (Ball & Bax, 2002). A major gap that remains in the literature on interventions designed to improve the sleep habits of young adults, however, is that all of the studies to date were evaluated exclusively using samples of university or college students. Therefore, it remains unknown whether such interventions can meaningfully change behaviour among the broader population of young adults.

2.6 Mobile Phone and Text Messaging Usage Among Young Adults

Although text message-based interventions can be criticized for marginalizing individuals who do not own a mobile phone, rates of mobile phone ownership among American young adults are overwhelmingly high, with 95% of young adults ages 18 to 24 owning such devices (Smith, 2011). Among the proportion of young adults who own a mobile phone, 97% report using the text messaging function and, on average, send or receive 109.5 text messages per day (with almost one quarter (23%) of young adults sending/receiving over 100 text messages per day; Smith, 2011). Comparing the 109.5 text messages sent/received per day by young adults to usage rates observed among other age categories, this is more than double the amount observed among adults ages 25 to 34, and 23 times the amount observed among adults age 65 and above (Smith, 2011).

In Smith’s (2011) report on text messaging behaviour among American adults, rates of text messaging usage obtained from the Pew Research Center’s Internet & American Life Project
Spring Tracking Survey were presented according to different demographic variables. It was found that non-Caucasian adults above the age of 18 text more than Caucasians, and that those adults above the age of 18 with lower incomes and levels of education tend to text more frequently than those who were more affluent and better educated (Smith, 2011). Based on these statistics, interventions employing a text message-based platform have incredible potential to reach mass numbers of young adults. Along with greater reach, using a text message-based intervention platform offers several other advantages compared with interventions involving face-to-face contact with participants, including cost-effectiveness (Irvine et al., 2012), unobtrusiveness (Irvine et al., 2012), the ability to collect data in real-time (Irvine et al., 2012), and the ability to intervene anywhere, anytime (i.e., reducing barriers relating to time of day and location; Patrick, Griswold, Raab, & Intille, 2008).

2.7 Text Message-Based Health Behaviour Change Interventions

In the health behaviour intervention literature, text message-based interventions have recently been applied to a multitude of health behaviours such as smoking (Free et al., 2011; Haug et al., 2009; Obermayer et al., 2004; Rodgers et al., 2005), diet (Haapala et al., 2009; Joo & Kim, 2007; Patrick et al., 2009; Shapiro et al., 2008), screen time (Shapiro et al., 2008), physical activity (Haapala et al., 2009; Hurling et al., 2007; Joo & Kim, 2007; Newton, Wiltshire, & Raina Elley, 2009; Patrick et al., 2009; Shapiro et al., 2008), sunscreen use (Armstrong et al., 2009), breast self-examination (BSE; Khokar, 2009), and vaccination against disease (Stockwell et al., 2012), with varying success.

Examination of the literature pertaining to text message-based smoking cessation interventions has yielded promising results, with participation in these interventions being
associated with increases in self-reported and/or biochemically verified abstinence from cigarette smoking (Free et al., 2011; Rodgers et al., 2005; Obermayer et al., 2004). Intervention studies conducted by Free et al. (2011; N = 5792) and Rodgers et al. (2005; N = 1705) were similar in design, where adult participants (above age 16 years (mean age = 37 years) in Free et al.’s (2011) study, and above age 15 years (mean age = 25 years) in Rodgers et al.’s (2005) study) were recruited from the general population and either randomized to a treatment group who received text messages designed to motivate and encourage behaviour change among participants (Free et al., 2011) or provide advice, support and distraction (Rodgers et al., 2005), or were randomized to a control group receiving text messages that were unrelated to quitting smoking. In both studies, intervention group participants also had access to a “quit buddy” when social support was desired, and could text the word “crave” to receive automated text messages to support and distract him/her during periods when he/she was craving a cigarette (Free et al., 2011; Rodgers et al., 2005). Results showed that 4 weeks (Free et al., 2011) and 6 weeks (Rodgers et al., 2005) after beginning the intervention, self-reported smoking cessation rates for the intervention group were more than twice as high as those reported by the control group (i.e., 29% among intervention group participants versus 12% among control group participants in Free et al.’s (2011) study, and 28% among intervention group participants versus 13% among control group participants in Rodgers et al.’s (2005) study). At 6-month follow-up, however, rates of biochemically verified abstinence from cigarette smoking (assessed via salivary cotinine levels, a metabolite of nicotine) in Free et al.’s (2011) study decreased to 11% among intervention group participants and 5% among control group participants, and rates of self-reported abstinence in Rodgers et al.’s (2005) study decreased to 5% among intervention group participants and 3% among control group participants (with some degree of uncertainty due to differential drop-out
rates between the intervention and control groups). In another text message-based smoking cessation intervention study conducted by Obermayer et al. (2004; N = 46), young adults ages 18 to 25 years were recruited from local colleges and were provided access to a 6-week integrated web- and text message-based smoking cessation intervention. Participants received individually tailored text messages based on their responses to questions in the initial online assessment, and were also given the option of providing specified support individuals with online access to their progress in quitting smoking, where support individuals could leave messages of encouragement on the webpage (Obermayer et al., 2004). This intervention (in addition to several others that will be presented in this section) used varied text messages that were randomly selected from a large database, in order to avoid habituation to a standard text message (Obermayer et al., 2004).

Based on intent-to-treat analysis of data from the 46 participants who enrolled in the study, 43% reported at least one 24-hour quit attempt and 22% had met the 7-day abstinence criteria at 6 weeks post-intervention (Obermayer et al., 2004). However, such findings have to be interpreted cautiously, due to the study’s high attrition rate (i.e., 33%) and lack of control group (Obermayer et al., 2004).

Conversely, findings from Haug et al.’s (2009) pilot study suggest that a text message-based smoking cessation intervention is not effective in improving a variety of smoking-related variables. In their 3-month study, 174 participants were randomized to one of three groups: a control group who did not receive the intervention (n = 64), a group receiving one weekly text (n = 50), or a group receiving three weekly texts (n = 60), with participants in both intervention groups receiving individualized feedback texts based on their responses in the baseline assessment and weekly assessments of quit status and intention to quit (completed via text message; Haug et al., 2009). Results did not reveal any significant differences at post-
intervention between the three study groups with respect to number of cigarettes smoked per day, number of quit attempts, intention to quit, smoking cessation self-efficacy, and decisional balance (i.e., perception of pros and cons of not smoking; Haug et al., 2009).

Examination of the literature pertaining to text message-based interventions targeting physical activity behaviour has yielded mixed results, with one intervention being associated with significant increases in physical activity (Hurling et al., 2007) and another demonstrating no significant effect (Newton et al., 2009). In Hurling et al.’s (2007) study, the physical activity behaviour of 77 healthy adult participants between the ages of 30 and 55 years was objectively assessed over a 12-week period using actigraphy measures. After being recruited for the study, participants were randomized to either an intervention group where they received personalized solutions for barriers they identified to engaging in physical activity, a weekly schedule for planning time for physical activity with the additional option of receiving email and/or text message reminders for planned activities, access to a web-based message board where they could share their experiences with other participants, and individual feedback on their objectively assessed physical activity levels, or were randomized to a control group who received no support (Hurling et al., 2007). Results showed that, at 6 weeks post-intervention, the intervention group reported significantly higher values for perceived control (assessed via 2 self-report items) and intention/expectation to exercise (assessed via 2 self-report items), compared with the control group (Hurling et al., 2007). In terms of objective measures, it was found that intervention group participants performed, on average, 2 hours and 18 minutes more moderate physical activity per week than control group participants, which is meaningful considering that adult recommendations are 2 hours and 30 minutes per week (Hurling et al., 2007). In the study by Newton et al. (2009), 78 adolescents between the ages of 11 and 18 years with type 1 diabetes
were enrolled in a 12-week randomized controlled trial to assess whether wearing a pedometer and receiving a weekly motivational text message would increase physical activity among participants. At 12 weeks, it was found that average daily step count had decreased from baseline among participants in both groups (i.e., decreased by 22 steps in the intervention group and 840 steps in the control group), yet average daily self-reported MVPA increased by 48 minutes per week in the intervention group and 39 minutes per week in the control group (Newton et al., 2009).

Other studies in the health behaviour change intervention literature employing a text message-based platform have targeted multiple health behaviours, including combinations of diet and physical activity (Haapala et al., 2009; Joo & Kim, 2007; Patrick et al., 2009) and diet, physical activity and screen time (Shapiro et al., 2008). Interventions conducted by Joo and Kim (2007), Patrick et al. (2009), and Haapala et al. (2009) were similar in the sense that they all targeted diet and physical activity behaviour in order to promote long-term weight control among adult participants. In Joo and Kim’s (2007) study, 927 adults were recruited to participate in an initial assessment at a public health centre, followed by a 12-week anti-obesity program comprised of receiving one weekly motivational or behaviour modification text message aimed at diet and/or physical activity behaviour, in addition to weekly educational brochures containing information about diet and exercise. Although diet and physical activity habits were not monitored throughout the study period, at 12 weeks post-intervention, results showed that the 433 participants (the majority of whom were between the ages of 30 and 60 years) who successfully completed the program had average reductions in weight, waist circumference and BMI of 1.6 kg, 4.3 cm, and 0.6 kg/m², respectively (Joo & Kim, 2007). However, this was an uncontrolled study, so it is impossible to determine the true effect of the intervention on weight
parameters (Joo & Kim, 2007). In the study by Patrick et al. (2009), 75 overweight/obese men and women between the ages of 25 and 55 years were recruited from the community to participate in a 16-week study, where they were either randomized to an intervention group who received personalized text messages 2 to 5 times daily (approximately half of which required a response from the participant), monthly printed materials about weight control and monthly phone calls from a health counsellor, or were randomized to a control condition who only received monthly printed materials about weight control (which differed from those received by the intervention group). Of the 65 participants who were included in the analysis, results at 16 weeks post-intervention showed that the intervention group lost 1.97 kg more than the control group, after adjusting for age, time, and sex (Patrick et al., 2009). In a study by Haapala et al. (2009) examining the short- and long-term effectiveness of a text message-based weight loss program, 125 overweight/obese men and women between the ages of 25 and 44 years were either randomized to receive a text message-based weight loss program ($n = 62$) or were randomized to a control group that received no intervention ($n = 63$). Assessments for intervention group participants were conducted at baseline, 3 months, 6 months, 9 months, and 12 months, while control group assessments were conducted at baseline and 12 months. Height, weight, and waist circumference were measured objectively by trained nurses, and dietary and physical activity habits were assessed via self-reported questionnaire items (3-day food records were also used to assess dietary intake; Haapala et al., 2009). Participants in the intervention group received text messages aimed at reducing intake of high-fat, high-sugar foods and alcohol, increasing physical activity, and encouraging regular weight reporting, with such messages being tailored to participants’ self-reported dietary and physical activity habits that were collected at each assessment (Haapala et al., 2009). Results showed that the text messaging program was effective
in producing both short-term and long-term weight loss among participants (Haapala et al., 2009). Specifically, by the 12-month assessment, the intervention group had lost significantly more weight and had significantly lower waist circumference measures compared to control group participants, with most of the weight loss occurring within the first three months of the program (Haapala et al., 2009).

In Shapiro et al.’s (2008) study, not only did the researchers target an additional health behaviour (i.e., screen time), but they also chose to intervene on children’s health behaviours rather than adults’ (eligibility criteria required children to be between the ages of 5 and 13). Fifty-eight parent-child dyads were recruited to participate in an 8-week study, where the dyads were randomized to one of three groups: a text message group who received three 90-minute group education sessions for parents and children relating to the targeted health behaviours (i.e., physical activity, screen time, and SSB consumption), along with a text messaging program where both the parent and child were required to send two daily text messages (i.e., one from the parent, and one from the child with the assistance of his/her parent) indicating the number of steps on the child’s pedometer that day, how many SSBs the child had consumed that day, and how many minutes of television the child had watched that day (with immediate, automated feedback on their responses); a paper diary intervention group who received the same three group education sessions and were asked to record answers to the same three questions using paper diaries that were filled out daily by both the child and parent (with weekly verbal feedback on their responses); and a third group who received the three educational sessions, but were not required to self-monitor and received no feedback (Shapiro et al., 2008). Of the 31 parent-child dyads that completed the study, results at 8 weeks post-intervention showed no differences between treatment conditions with respect to physical activity or SSB consumption (Shapiro et
al., 2008). When examining screen time, however, the text messaging group was the only group to demonstrate a significant reduction in screen time when participants were asked to recall their behaviour over the last week at baseline and post-intervention (Shapiro et al., 2008).

Other health behaviours, including sunscreen use (Armstrong et al., 2009), BSE (Khokar, 2009), and vaccination against disease (Stockwell et al., 2012), are also starting to become the targets of text message-based interventions. Armstrong et al.’s (2009) study evaluated the effectiveness of a text message-based intervention on improving adherence to sunscreen use among a sample of 70 adults (mean age = 33.6 years) recruited from the community. All participants attended an initial visit where research staff showed participants how to properly apply sunscreen using the study device (which electronically notified the study database whenever participants unscrewed the sunscreen cap). Half of the participants were randomized to receive daily text message reminders for 6 weeks, which were comprised of daily local weather information followed by a reminder prompting participants to apply sunscreen, while the other half of participants were randomized to a control group that did not receive text message reminders (Armstrong et al., 2009). At the end of the 6-week period, results showed that the daily adherence rate for the intervention group (56.1%) was significantly higher compared to the adherence rate for the control group (30.0%; Armstrong et al., 2009). These results must be interpreted in light of the fact that the researchers were not able to measure how much sunscreen was applied to which areas of the body (Armstrong et al., 2009). Another study by Khokar (2009) used a community-based sample (N = 106) of working women between the ages of 22 and 54 years to evaluate the effectiveness of text message reminders to perform a BSE. Women attended a 90- to 120-minute session where they were trained on how to perform a BSE through the use of verbal instruction, live demonstration on a breast model, video clips, and giving
volunteers the opportunity to perform a BSE on a breast model and receive feedback (Khokar, 2009). Reminder texts were sent once a month towards the end of each participant’s menstrual period, with the content of messages focusing on reminding the participant to perform a BSE and notify the investigator whether they had actually performed the BSE or not (Khokar, 2009). Although the researchers found a significant increase in the practice of BSE among participants after two months of receiving text message reminders, the lack of a control group makes it impossible to determine the true effect of the intervention on practice of BSE (Khokar, 2009).

Finally, another randomized controlled trial of 9 213 children and adolescents was conducted by Stockwell et al. (2012) to test the effectiveness of a text message-based intervention on increasing influenza vaccination rates among children and adolescents (between the ages of 6 months and 18 years) attending community-based pediatric clinics. Parents of children/adolescents who were randomized to receive the text message-based intervention received five weekly text message reminders, with the first three messages providing parents with information on vaccine safety and the seriousness of the virus (tailored to the child’s/adolescent’s age) and the last two messages providing parents with information on upcoming vaccination clinics (Stockwell et al., 2012). Of the 9 213 children/adolescents in the study, 7 574 had not been vaccinated before receiving the first text message, and were included in the analysis (Stockwell et al., 2012). Results showed a small, although significant, increase in the proportion of children/adolescents obtaining influenza vaccinations, with 39.9% of usual care group participants obtaining vaccinations before the end of the 6-week program and 43.6% of intervention group participants doing the same (Stockwell et al., 2012). Since usual care involved receiving a phone message outlining the seriousness of influenza and vaccination clinic dates,
between-groups differences may have been higher if a true control group was used (i.e., who received no influenza-related information).

There are several potential explanations for the mixed results observed among these studies with respect to the effectiveness of the described interventions in producing behaviour change. First, factors relating to the study sample, including sample size, attrition rates and participant adherence to the prescribed intervention, may have influenced results. For example, in Newton et al.’s (2009) study, the authors acknowledge that the study sample was underpowered and therefore less likely to detect statistically significant effects that may have been associated with participation in the intervention. In Rodgers et al.’s (2005) study, differential drop-out rates between the intervention and control groups made it difficult to determine intervention effects at 6-month follow up, and both Haapala et al. (2009) and Obermayer et al. (2004) reported relatively high attrition rates (i.e., 27% and 33%, respectively) for their text message-based interventions. Newton et al. (2009) also reported having an issue with adherence to the intervention, with 37% of participants stopping pedometer use by the end of the study period. Second, the frequency with which participants sent and received text messages varied considerably between interventions, with some participants receiving up to 5 text messages per day (Free et al., 2011; Patrick et al., 2009; Rodgers et al., 2005), and others only receiving one text message per week (Haug et al., 2009; Joo & Kim, 2007; Newton et al., 2009) or one text message per month (Khokar, 2009) which, in some cases (Haug et al., 2009; Newton et al., 2009), may not have been sufficient to facilitate behaviour change. Third, some of the interventions integrated text messaging with other components such as web-based technology (Haapala et al., 2009; Hurling et al., 2007; Obermayer et al., 2004), making it difficult to determine the degree to which the text messaging component contributed to the observed
intervention effects. Fourth, the studies differed with respect to the objectivity of the measures used by the researchers to assess study outcomes. For example, in Free et al.’s (2011) study, where both self-reported 28-day continuous abstinence and biochemically verified continuous abstinence from cigarette smoking were measured at 6 months post-intervention, results revealed sizable discrepancies between objective and subjective measures of smoking abstinence (i.e., self-reported abstinence rates were 19.8% and biochemically verified rates were 10.7% for the intervention group and, when examining results for the control group, self-reported abstinence rates were 13.5% and biochemically verified rates were 4.9%). Similarly, Rodgers et al. (2005) also found over-reporting of smoking abstinence when self-reported measures were compared with results from salivary cotinine tests. Therefore, true intervention effects may be exaggerated in studies that only use subjective measures of outcome variables. Fifth, two of the studies (Free et al., 2011; Rodgers et al., 2005) allowed intervention group participants to use other supports/services to assist in improving health outcomes (i.e., quitting smoking), which could have led to an overestimation of intervention effects. Lastly, some of the above studies used an uncontrolled design (Joo & Kim, 2007; Khokar, 2009; Obermayer et al., 2004), making it impossible to determine whether the intervention produced significantly higher behaviour change rates than would be observed in a no-treatment condition.

Although the majority of studies in the literature found statistically significant effects of a text message-based intervention on the targeted health behaviour(s), it is important to note that these effects may not be particularly meaningful when assessing significance from a clinical standpoint. For example, in the studies by Joo and Kim (2007) and Patrick et al. (2009) that targeted dietary and physical activity habits to promote weight loss among overweight/obese adults, the effect of the interventions on weight loss was rather modest, with Joo and Kim (2007)
reporting a mean weight loss of 1.6 kg among participants enrolled in the intervention, and Patrick et al. (2009) reporting a mean difference in weight loss of 1.97 kg between the intervention and control group. Furthermore, it is unknown whether such intervention effects are sustained over time, after participants discontinue the text messaging program. Changing health behaviours – especially over the long term – is extremely difficult, primarily because health behaviour change interventions typically do not target the root causes of the problem. For example, just telling individuals to sleep more or exercise more does not address the factors (e.g., lack of time, screen time) perpetuating the practice of poor health behaviours.

Collectively, the above studies highlight the application of a text message-based platform to a broad array of health behaviours; however, researchers have yet to develop a text message-based intervention aimed at improving sleep habits. Therefore, the current study will build on the existing sleep, obesity, and health behaviour change intervention literature by examining the effectiveness of a text message-based intervention on improving sleep habits among a U.S. national sample of young adults.

3.0 Rationale for the Current Study

Despite all of the attention directed toward the treatment and prevention of obesity among all age groups, little progress has been made in reducing overall prevalence rates (Lau et al., 2007). Traditionally, most efforts have targeted dietary and physical activity habits, which have been shown to produce little change in weight parameters and result in short-lasting treatment effects (Epstein et al., 1998, as cited in Hart & Jelalian, 2008, p. 252). Thus, this indicates that there may be factors we are overlooking when attempting to address obesity as a public health issue. The abundance of research published within the last couple of decades
identifying an association between sleep and obesity (for a review, see Patel & Hu, 2008) suggests that sleep may be one of these factors, as sleep loss is prevalent in today’s world and has been shown to impact energy balance (e.g., Schmid et al., 2014).

To date, most interventions designed to change sleep habits among young adults have been conducted exclusively among university or college (i.e., higher education) students, so it remains unknown whether results from these interventions can be generalized to the broader population of young adults. Furthermore, although a text message-based intervention platform has been applied with varying success to other health behaviours (e.g., smoking, diet, screen time, physical activity), this type of intervention has not yet been used to examine sleep habits. Given the remarkable amount of time that young adults spend on mobile devices, implementing a text message-based sleep intervention could be a simple and promising approach for improving young adults’ sleep habits.

The current study addressed the above gaps in the literature by examining the effectiveness of a text message-based intervention on improving sleep habits among a U.S. national sample of young adults. This study will provide a basis for understanding how receiving educational and motivational text messages relating to improving sleep habits may lead to behaviour change among young adults, and will also provide additional insight into whether changing sleep habits leads to more favourable weight outcomes among members of the young adult population. Results from our study will build on the existing literature to inform future obesity prevention interventions aimed at this age group.
4.0 Study Objectives and Hypotheses

The primary objective of the current study was to determine the extent to which participants who received text messages aimed at improving sleep and physical activity habits (compared with individuals receiving a smoking cessation texting intervention) improved their sleep quantity, sleep quantity variability between work/school nights and non-work/non-school nights, and sleep quality (assessed via self-report). Longitudinal data from the Stop My Smoking (SMS) USA Study (Ybarra et al., 2013) conducted nationally in the United States in 2011 and 2012 was used to examine this objective. We hypothesized that greater improvements in sleep quantity, sleep quantity variability, and sleep quality would be observed among those participants in the group who received text messages aimed at improving sleep/physical activity habits, and also among those participants with a shorter self-reported sleep duration (i.e., less than 6 hours) on work/school nights at baseline.

The secondary objective of the current study was to explore potential cross-sectional and longitudinal associations between sleep measures (i.e., sleep quantity, sleep quantity variability, and sleep quality) and adiposity (i.e., BMI and weight status). In the SMS USA study, BMI was assessed using self-reported height and weight. In the cross-sectional analyses, we hypothesized that sleep quantity and quality would be negatively associated with BMI at baseline, sleep quantity variability would be positively associated with BMI at baseline, and that poorer sleep habits at baseline (i.e., lower sleep quantity, higher sleep quantity variability, and lower sleep quality) would be associated with higher odds of being overweight/obese at baseline. In the longitudinal analyses, we hypothesized that positive changes in sleep quantity and quality, as well as reductions in sleep quantity variability, would be associated with a lower BMI, and that
poorer sleep habits at follow-up would be associated with higher odds of being overweight/obese at follow-up.

5.0 Methodology

5.1 Stop My Smoking (SMS) USA Study Design

To examine whether participants changed their sleep habits as a result of receiving text messages aimed at improving sleep quantity and quality (and physical activity), an analysis of secondary data was conducted using baseline and 12-week follow-up data collected from the SMS USA study (Ybarra et al., 2013). SMS USA is a two-arm pilot randomized controlled trial designed for young adults who are trying to quit smoking, with some participants randomized to receive text messages that were tailored to their quit status and focused on smoking cessation, and others randomized to receive text messages aimed at improving sleep and physical activity habits within the context of how these behaviours may help participants quit smoking. At baseline and follow-up, the sleep habits (i.e., sleep quantity and quality) of participants \( n = 129 \) in the SMS USA study were assessed, which provided the basis for our longitudinal analysis. The study sample for the SMS USA study was a racially and economically diverse sample of American young adults (including those not enrolled in post-secondary education).

5.1.1 Recruitment and Eligibility

In the SMS USA study, young adults ages 18 to 25 were recruited nationally through online advertisements on websites such as Craigslist between May 3, 2011 and August 4, 2011. In addition to meeting the specified age criteria, eligible participants had to be able to read and write in English, own a cell phone and be enrolled (or intend to enroll) in an unlimited text messaging plan, be familiar with how to send and receive text messages, smoke 24 cigarettes or
more per week (i.e., at least 4 per day on at least 6 days per week), be seriously thinking about quitting in the next 30 days, and agree to smoking cessation status verification by a significant other (i.e., family member or friend).

**5.1.2 Procedures**

Young adult smokers were asked to express their interest in the study by completing an online screener form, which was then emailed to the project coordinator. Those meeting eligibility criteria for the study were contacted by the project coordinator, who then scheduled a telephone appointment to confirm eligibility, explain study details, obtain verbal consent, and complete the registration process.

Upon enrolling in the SMS USA study, participants were randomly assigned to receive text messages focused on either smoking cessation or sleep and physical activity habits using a computerized adaptive randomization program (Taves, 1974) that balanced the study arms according to biological sex and intensity of smoking (i.e., heavy smokers were classified as those individuals smoking ≥ 20 cigarettes per day). Participants were assigned at a higher ratio (i.e., 2:1) to the smoking cessation group in order to increase the amount of information obtained about the intervention experience (i.e., participants receiving sleep/physical activity text messages served as the active control group). This was a single-blind study where participants, but not researchers, were blind to arm allocation.

All participants (irrespective of study arm) were asked to identify a quit date that was at least 15 days (but no more than 30 days) from their registration date. In accordance with clinical guidelines published by the Agency for Health Research and Quality (2012), participants who smoked 10 cigarettes or more per day were counselled to consider pharmacotherapy to assist in
their quitting. After registering, participants were then emailed a link for the online baseline survey and instructed to complete the survey at their earliest convenience. The baseline survey had to be completed in order to start receiving text messages.

Both smoking cessation and sleep/physical activity text messages began 14 days prior to one’s established quit date. Smoking cessation group participants were exposed to a 6-week smoking cessation program, where content of the text messages was tailored to where participants were in the quitting process (i.e., Day 1 to 14 or the Pre-Quit phase, Day 15 to 21 or the Early Quit phase, or Day 22 to 42 or the Late Quit phase). All smoking cessation group participants received two weeks of Pre-Quit messages aimed at encouraging them to clarify reasons for quitting and to understand their smoking patterns, in addition to their tempting situations, triggers and urges. Early Quit messages (sent on Quit Day and throughout the first week post-quit) talked about common difficulties and discomforts associated with quitting smoking, and emphasized the use of coping strategies. Late Quit messages (sent throughout the last 3 weeks of the study period) were designed to encourage participants to recognize relapse in a different way and provide information about how to deal with issues that arise as a non-smoker (i.e., effects on stress and mood).

Smoking cessation group participants received 4 messages per day during the two week-long Pre-Quit phase, with the exception of Day 1 and Day 14 (when they received 5 and 6 messages, respectively). In the Early Quit phase, participants received 9 messages on both Quit Day and Post-Quit Day 2, eight messages on the third day, and then one fewer message each day until the last day of the week when 4 messages were received. In the Late Quit phase, participants received 2 messages per day for two weeks, and then 1 message per day during the final week.
Sleep/physical activity group participants received a text messaging program that was similar to the intervention group with respect to the number of text messages received per day across the 6-week study period. For example, participants in both groups received 9 messages on their Quit Day and the day after, but sleep/physical activity group messages did not mention that it was the participant’s quit day. Content of the text messages was aimed at improving participants’ sleep and physical activity habits, within the context of how it would help the participant quit smoking (refer to Table 1 for a list of sample text messages received by participants in each study arm). Messages, however, were not tailored based on where the participant was in the quitting process (i.e., Pre-Quit, Early Quit, or Late Quit).

Survey data were collected online for the baseline survey, via text message at 4 weeks post-quit (i.e., 6 weeks post-intervention), and via a combination of text and online for the 12-week post-quit follow-up. Participants in both groups received incentives of $10 and $20 after completing the 4-week and 12-week post-quit follow-ups, respectively. A third of participants received an additional $10 if they responded within 48 hours, another third of participants received $10 if they completed the online survey within 48 hours of receiving a second reminder text, and a different third received $10 if they completed a mini-survey via text messaging at 3 months. Participants could opt out of the study at any time by texting “end” to the program or by contacting project staff.

Table 1. Sample Text Messages Received by SMS USA Participants

<table>
<thead>
<tr>
<th>Day Sent</th>
<th>Smoking Cessation Group Text Message</th>
<th>Sleep/Physical Activity Group Text Message</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day 1 (Pre-Quit)</td>
<td>“Congratulations! The hardest part-deciding to quit- is already behind you. Write down your quit date [insert day] and post it where you can see it every day.”</td>
<td>“Hi there! Welcome to the SMS USA project. We’re happy you’re here. We look forward to working with you!”</td>
</tr>
</tbody>
</table>

52
<table>
<thead>
<tr>
<th>Day Sent</th>
<th><strong>Smoking Cessation Group Text Message</strong></th>
<th><strong>Sleep/Physical Activity Group Text Message</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Day 1 (Pre-Quit)</td>
<td>“The SMS USA program is like a recipe book to help you quit smoking. Not every text will work for you, but try each one before you judge—just to see!”</td>
<td>“These next several weeks we’re going to be working with you to improve your sleep and physical activity. Why? Because both will help you to quit smoking.”</td>
</tr>
<tr>
<td>Day 2 (Pre-Quit)</td>
<td>“Write down a list of reasons why you want to quit smoking. Put the list in a place where you’ll see it every day.”</td>
<td>“How much sleep are you getting? Keep a log for the next week. Note when you go to bed, wake up; Have trouble going to sleep? Wake up in the middle of the night?”</td>
</tr>
<tr>
<td>Day 2 (Pre-Quit)</td>
<td>“Want to connect with other people quitting in the SMS USA program? Hear about how they are getting ready to quit? Go to <a href="http://www.stopmysmoking/discuss.%E2%80%9D">www.stopmysmoking/discuss.”</a></td>
<td>“The Centers for Disease Control recommends adults get 30 min of physical activity at least 5 days/week. Sound hard? Relax. We’ll figure it out together.”</td>
</tr>
<tr>
<td>Day 3 (Pre-Quit)</td>
<td>“Got stress? Maybe it’s your cigarettes. In between cigarettes, your body goes through withdrawal and makes you feel stressed out and anxious.”</td>
<td>“Sleeping and exercising go hand-in-hand when you’re trying to quit smoking. You have more energy, you sleep better, and it gives you the strength to quit.”</td>
</tr>
<tr>
<td>Day 15 (Quit Day)</td>
<td>“I bet you’re feeling cranky and annoyed right now. This is all normal. Just take a deep breath and get through the next 5 min.”</td>
<td>“Each time you meet a sleep or physical activity goal, no matter how small, be sure to give yourself a reward.”</td>
</tr>
<tr>
<td>Day 20 (Early Quit)</td>
<td>“Right now, you’re learning to quit. Just like learning to ride a bike or drive a car, it takes time. Before you know it, you’ll learn to be a non-smoker too.”</td>
<td>“Quitting smoking is hard work. Sleeping well can help your body prepare for quitting physically and emotionally.”</td>
</tr>
<tr>
<td>Day 31 (Late Quit)</td>
<td>“Encouragement from your friends and family might be starting to wane about now, but remember that they are probably still proud of you for quitting.”</td>
<td>“Regular exercise has a lot of benefits: Better sleep and relief from stress are just a couple. Remind yourself of YOUR reasons to make these life changes.”</td>
</tr>
</tbody>
</table>

*Source: Ybarra et al. (2013)*
5.1.3 Participants

At the outset of the SMS USA study, 1916 smokers were assessed for eligibility. Of those 1916 individuals, 211 met the study’s eligibility criteria and consented to participate. Because the computer program did not retain the randomization sequence of individuals who failed to complete the baseline survey \((n = 47)\), the true number of participants randomized to each study arm remains unknown. Of the 164 participants who successfully enrolled in the study and completed baseline measures, 101 were randomized to receive smoking cessation text messages, and 63 were randomized to receive text messages aimed at improving sleep and physical activity habits. A total of 35 participants were lost to follow-up (21 participants in the smoking cessation group and 14 participants in the sleep/physical activity group). Refer to Figure 1 below for a visual of the SMS USA study design and participant flow. Reasons for eligibility were not mutually exclusive; therefore, a participant could be ineligible for more than one reason. The number of participants completing 4-week follow-up was excluded from Figure 1, since sleep, height, and weight data were not collected at the 4-week time point. Participants were racially and economically diverse and comprised a nationally representative sample of American young adults (See Table 2: Baseline Demographic Characteristics and Behaviours of Participants in the SMS USA Study).
5.1.4 Ethical Considerations

Ethical approval for the SMS USA study was obtained through Chesapeake Research Review Incorporated, and ethical approval for the current secondary analysis was obtained through the University of Guelph Institutional Review Board (refer to Appendix A for the full Research Ethics Board approval form). When SMS USA participants were initially enrolled in the study, they were contacted via telephone by the project coordinator, who explained details of the study and obtained verbal consent. For the purposes of the current study, the risk to participants is considered to be very low due to the secondary nature of the analysis. The data for this secondary analysis were provided to the researchers in a de-identified format by Internet.

Figure 1. SMS USA study design and participant flow.
Solutions for Kids Incorporated, where the SMS USA study was based. The data set only contained identification numbers, with no names or birthdates attached to the data. Access to the file linking study identification numbers to participant names was not available to the University of Guelph researchers.

5.2 Measures

In the current study, six main outcomes were examined: BMI, sleep quantity on work/school nights and non-work/non-school nights, sleep quantity variability between work/school nights and non-work/non-school nights, sleep quality, and sleep hygiene. In the following sections, the measures used to assess each of these outcomes are described.

5.2.1 Body Mass Index

While completing the original online baseline survey, participants were asked to indicate their self-reported height in feet and inches. At both baseline and 12-week follow-up, participants were also asked to indicate their self-reported weight in pounds. For the purposes of our study, participant height and weight data were converted to metric units (i.e., metres and kilograms, respectively) and used to calculate BMI, which served as a proxy for obesity. BMI is a ratio of weight to height (measured in kg/m$^2$) and is conventionally used as an indicator for body fatness in populations (CDC, 2011). In the statistical analyses for the secondary study objective, both continuous (linear regression models) and categorical (logistic regression models) measures of BMI (i.e., the outcome variable) were used. In the logistic regression models, BMI was dichotomized into “normal weight” and “overweight/obese”. To define overweight and obesity, we used the Canadian Guidelines for Body Weight Classification in Adults (Health Canada, 2003), which defines overweight as a BMI within the 25.0 to 29.9 kg/m$^2$ range and
obesity as a BMI of 30.0 kg/m$^2$ or higher. Therefore, all participants with a BMI $\geq$ 25 kg/m$^2$ were placed in the “overweight/obese” category.

### 5.2.2 Sleep Quantity

At baseline and follow-up, sleep quantity was assessed using two self-report items adapted from the Pittsburgh Sleep Quality Index (PSQI). The PSQI is a 19-item valid and reliable brief self-administered assessment tool that is able to differentiate poor sleepers from good sleepers and compares favourably with clinical and laboratory assessment of sleep disturbances (Buysse et al., 1988). The two sleep quantity items used in the SMS USA study were: “Thinking about the past month…On a day when you have to go to work or school in the morning, how many hours of actual sleep do you get at night?” and “Thinking about the past month…On a day when you don’t have work or school in the morning, how many hours of actual sleep do you get at night?”. Participants were asked to indicate their responses in hours per night, rounded to the nearest hour. Combined, these items provided insight into the individual’s habitual sleep duration.

### 5.2.3 Sleep Quantity Variability

For the purposes of this study, sleep quantity variability was calculated for each participant by subtracting self-reported sleep quantity on work/school nights from sleep quantity on non-work/non-school nights. Greater differences were therefore indicative of greater variability in sleep quantity, with positive differences indicating longer sleep duration on non-work/non-school nights compared to work/school nights, and negative differences indicating longer sleep duration on work/school nights compared to non-work/non-school nights.
5.2.4 Sleep Quality

Sleep quality was measured using 8 items adapted from the PSQI, which all began with the stem “During the past month, how often have you…”, and included the following: (a) not been able to get to sleep within 30 minutes, (b) woken up in the middle of the night or early morning, (c) had to get up from sleeping to use the bathroom, (d) had trouble sleeping because you could not breathe comfortably, (e) had trouble sleeping because you were coughing or snoring loudly, (f) had trouble sleeping because you felt too cold or hot, (g) had bad dreams, and (h) had trouble sleeping because you were in pain. Response options for each item were as follows: “not at all during the past month”, “less than once a week”, “once or twice a week”, “three or more times a week”, and “do not want to answer”. For the purposes of the current study, sleep quality scores were calculated for each participant by summing participants’ responses to the 8 sleep quality items adapted from the PSQI. Response options for each item were coded with numbers (i.e., 1 = “not at all during the past month”, 2 = “less than once a week”, 3 = “once or twice a week”, 4 = “three or more times a week”), which allowed for quantification of sleep quality. Possible scores ranged from 8 to 32, with higher scores being indicative of poorer sleep quality. This adapted version of the PSQI has not yet been validated.

5.2.5 Sleep Hygiene

Sleep hygiene was measured using 9 items adapted from the Sleep Hygiene Index (SHI; Mastin, Bryson, & Corwyn, 2006). The SHI is a 13-item valid and reliable brief self-administered assessment tool that demonstrates psychometric properties comparable to lengthier sleep hygiene measures (Mastin et al., 2006). Similar to sleep quality items, items pertaining to sleep hygiene all began with the stem “During the past month…”, and included the following: (a)
I go to bed at different times day to day (time I go to bed varies by more than two hours), (b) I get out of bed at different times from day to day (time I get out of bed varies by more than two hours), (c) I use alcohol, tobacco, or caffeine within 4 hours of going to bed, (d) I do something that may wake me up before bedtime (e.g., play video games, use the internet, clean), (e) I go to bed feeling stressed, angry, upset, or nervous, (f) I use my bed for things other than sleeping or sex (e.g., watching television, reading, eating, studying), (g) I sleep in an uncomfortable bedroom (e.g., too bright, too stuffy, too hot, too cold, too noisy), (h) I do important work before bedtime (e.g., pay bills, schedule, study), and (i) I think, plan, or worry when I am in bed.

Response options for each item were as follows: “not at all during the past month”, “less than once a week”, “once or twice a week”, “three or more times a week”, and “do not want to answer”. For the purposes of the current study, sleep hygiene scores were calculated for each participant by summing participants’ responses to the 9 sleep hygiene items adapted from the SHI. Response options for each item were coded with numbers (i.e., 1 = “not at all during the past month”, 2 = “less than once a week”, 3 = “once or twice a week”, 4 = “three or more times a week”), which allowed for quantification of sleep hygiene. Possible scores ranged from 9 to 36, with higher scores being indicative of poorer sleep hygiene practices. This adapted version of the SHI has not yet been validated.

5.3 Confounding Variables

In any intervention study, there may be extraneous variables (i.e., other than the intervention itself) that may confound the results and affect the outcome variable(s) (Field, 2009). Such variables reduce the internal validity of study results, since they are associated with both the independent variable(s) and dependent variable(s), and can therefore be responsible for some of the observed effects that otherwise appear to be attributed to the intervention (McGeoch,
In the current study, failing to control for potential confounding variables could lead to an under- or overestimation of the magnitude of intervention effects, as well as the magnitude of the association between sleep quantity/variability/quality and BMI/weight status. Although randomization of participants in the SMS USA study should theoretically eliminate the potential for confounding, we still examined potential confounders in the proposed study to ensure that valid conclusions were being drawn from the research findings.

5.3.1 Confounding Variables Included in Primary Objective Analyses

With respect to the first research objective, which was to determine the extent to which participants who received text messages aimed at improving sleep and physical activity habits (compared with individuals receiving a smoking cessation texting intervention) improved their sleep quantity, sleep quantity variability, and sleep quality, separate models were run for each sleep measure (i.e., sleep quantity on work/school nights, sleep quantity on non-work/non-school nights, sleep quantity variability, sleep quality, and sleep hygiene) while controlling for baseline levels of the respective sleep measure. In each model, the following potential confounding variables were adjusted for: change in physical activity (from baseline to 12-week follow-up), smoking status at follow-up, daily text messaging usage, sex, educational attainment/current post-secondary enrollment, and race.

5.3.1.1 Rationale for Including the Selected Confounding Variables

Although not all of these variables produced a 10% or greater change in the regression coefficient estimate for the key explanatory variable (i.e., intervention status) in all five of the sleep models, we decided to retain the above potential confounders in all models due to their
known associations, described below, with the outcome variable (i.e., sleep quantity/variability/quality) in the literature.

**Physical activity:** Since participants who received text messages aimed at improving sleep habits also received messages aimed at improving physical activity, it was important to adjust for this variable to ensure that changes in physical activity habits were not responsible for explaining sleep habits at follow-up. According to results from the National Sleep Foundation’s 2013 *Sleep in America®* poll, those individuals who identified as regular exercisers reported sleeping better than those who were not exercisers, despite sleeping the same amount of time (National Sleep Foundation, 2013). This finding is similar to findings from Ekstedt, Nyberg, Ingre, Ekblom and Marcus (2013) in their study on 6- to 10-year old children, who found that engaging in physical activity (specifically, MVPA) increased objectively measured sleep efficiency (i.e., the proportion of time in bed spent actually sleeping) the following night. Therefore, improvements in physical activity may account for improvements in sleep habits over the course of the study period, independent of receiving text messages aimed at improving sleep habits. Since physical activity varies with time, change in physical activity was examined in the longitudinal models as a potential confounder instead of baseline levels.

**Smoking status at follow-up:** Research conducted within the last two decades has shown an association between sleep quality and smoking status. For example, a longitudinal study of 3,516 adults by Wetter and Young (1994) found that among both sexes, smoking was associated with poorer sleep quality; specifically, difficulty initiating sleep and waking up. Interestingly, some sex-specific findings emerged, where an association between smoking and excessive daytime sleepiness was only found among female participants, and an association between smoking and nightmares was only found among male participants (Wetter & Young, 1994).
These findings are consistent with research by Hu, Sekine, Gaina and Kagamimori (2007), who also examined the association between sleep quality and smoking among current, former, and non-smokers. These researchers not only found an association between components of sleep quality (i.e., sleep latency and subjective sleep quality) and smoking status, but also found that sleep quality was different based on whether the participant was a current, former, or non-smoker. Among males, being a current smoker or former smoker was associated with a significantly higher score on the PSQI (indicating poorer sleep; Hu et al., 2007). Among females, however, only being a current smoker was associated with poorer PSQI scores (Hu et al., 2007). Therefore, differences in sleep scores at follow-up could, in part, be explained by one’s smoking status.

Daily text messaging usage: Usage of the text messaging feature on mobile devices has been found to be associated with both sleep quantity and quality, especially when used at night. For example, in their recent study on a sample of college students ($N = 236$), Adams and Kisler (2013) found that 47% of participants reported answering text messages after falling asleep. For those students who reported using mobile devices after sleep onset, sleep was disturbed for an average of 27 minutes throughout the week (Adams & Kisler, 2013). These are similar to results from Van den Bulck (2007), who found that only 38% of her sample of 1,656 adolescents never used their cell phones after going to bed, and that cell phone usage after going to bed more than doubled one’s odds of being very tired the next day (odds ratio (OR) = 2.2; 95% confidence interval (CI) = 1.4-3.4; Van den Bulck, 2007). In addition to its impact on sleep quantity, technology use can also impact the quality of one’s sleep. Several studies have found that exposure to artificial light between dusk and bedtime can negatively impact sleep quality through suppressing the production of melatonin, a hormone that is responsible for regulating sleep (e.g.,
Wood, Rea, Plitnick, & Figueiro, 2013). In addition to its effects on sleep, daily text messaging usage can also affect “dose” of the intervention in the sense that those participants who do not typically use the text messaging feature on their mobile phones may not check their text messages regularly which, in turn, reduces the likelihood of the intervention impacting those participants’ sleep habits.

*Educational attainment/current post-secondary enrollment:* Among the several studies reporting an association between socioeconomic factors and sleep quantity/quality, results from a recent study of 5,578 Finnish adults by Lallukka et al. (2012) showed that having low education, low income, and being unemployed were all associated with frequent insomnia-related symptoms. In the current study, educational attainment/current post-secondary enrollment was used as a proxy for SES because annual income is likely not the most accurate indicator of SES among this population group. For example, because the majority of the analytical sample (i.e., 58.4%) was enrolled in post-secondary education at the time of the study, most of these individuals may be relying on sources other than personal income (e.g., parents, student loans), and therefore may not include money from these sources when reporting total annual income. Those participants currently enrolled in post-secondary education may also be at increased risk for poor sleep quantity/quality as a result of the many academic and social demands that come with being a post-secondary student.

*Sex & Race:* One study conducted by Lauderdale et al. (2006) showed evidence of a strong association ($p < 0.001$) between both sex and race and four objectively measured sleep parameters, including time in bed, sleep duration, time required to fall asleep, and percentage of time in bed spent sleeping (i.e., sleep efficiency), even after adjusting for several SES and lifestyle factors. Specifically, white women were found to have the most favourable scores on all
four sleep parameters, while black men had the poorest scores (Lauderdale et al., 2006).
Evidence of racial differences in sleep quality has also been found by Baldwin et al. (2010), who found that self-reported excessive daytime sleepiness was significantly more common among black participants. Another study examining gender differences in sleep patterns among college students through the use of sleep logs, however, found that, on average, females reported significantly poorer subjective sleep quality, taking significantly longer to fall asleep, and having significantly more nighttime awakenings compared to males (Tsai & Li, 2004b). Therefore, observed differences in follow-up sleep parameters could, in part, be explained by sex and racial differences.

5.3.2 Confounding Variables Included in Secondary Objective Analyses

With respect to the second research objective, which was to explore cross-sectional and longitudinal associations between sleep measures (i.e., sleep quantity, sleep quantity variability, and sleep quality; explanatory variables) and adiposity (i.e., BMI and weight status; outcome variables), we also ran separate models to examine the association between each sleep measure and BMI/weight status. In the cross-sectional baseline models, we adjusted for physical activity (baseline), number of cigarettes smoked per day (baseline), sex, educational attainment/current post-secondary enrollment, and race. In the longitudinal models, we adjusted for baseline BMI, change in physical activity (from baseline to 12-week follow-up), smoking status, intervention status, sex, educational attainment/current post-secondary enrollment, and race.

5.3.2.1 Rationale for Including the Selected Confounding Variables

Although not all of these variables produced a 10% or greater change in the regression coefficient estimate for the key explanatory variable (i.e., baseline sleep in the cross-sectional
models and change in sleep in the longitudinal models), in each of the five models using a different measure of sleep as the key explanatory variable, we decided to retain the above potential confounders in all models due to their known associations with the outcome variables (i.e., BMI and weight status) in the literature.

*Physical activity:* It has been well documented in the literature that an inverse association exists between physical activity and BMI (for a review see Rauner, Mess, & Woll, 2013). For example, research by Sharpe, Granner, Hutto, Ainsworth and Cook (2004) found a significant association between BMI category (i.e., normal weight/underweight = BMI < 25 kg/m\(^2\), overweight = 25 kg/m\(^2\) ≤ BMI < 30 kg/m\(^2\), and obese = BMI ≥ 30 kg/m\(^2\)) and physical activity. Specifically, those participants in the overweight or obese category were at significantly lower odds of meeting both the Centers for Disease Control and Prevention – American College of Sports Medicine (CDC-ACSM) physical activity recommendations (i.e., 30 minutes per day of MVPA most days a week) and the Institute of Medicine (IOM) physical activity recommendations (i.e., 60 minutes per day of MVPA every day; Sharpe et al., 2004). Therefore, to ensure that physical activity was not responsible for potential associations observed between sleep and BMI/weight status, we adjusted for baseline physical activity in the cross-sectional models and change in physical activity in the longitudinal models.

*Number of cigarettes smoked per day at baseline:* Several sources have reported that the amount of weight gained after quitting smoking is correlated with the number of cigarettes smoked per day (H. Lee Moffitt Cancer Center & Research Institute, 2000; Komiyama et al., 2013; Williamson et al., 1991). For example, results from the study by Komiyama et al. (2013) suggest that there is a significant positive association between number of cigarettes smoked per day and weight gain after initiating smoking cessation (\(p = 0.04\), and Williamson et al. (1991)
found that compared to light smokers (smoking < 15 cigarettes per day), heavy smokers (smoking ≥ 15 cigarettes per day) were at significantly higher risk of major weight gain (> 13 kg) after initiating smoking cessation (OR = 4.7 for women and 5.7 for men). Therefore, we thought it was important to control for this variable in the cross-sectional models that examined potential associations between baseline sleep and baseline BMI/weight status.

*Smoking status at follow-up:* In the longitudinal models, we decided to adjust for smoking status at follow-up because of the collection of literature identifying the tendency for smokers to gain weight after quitting smoking (for a review see Aubin, Farley, Lycett, Lahmek, & Aveyard, (2012). In a study by Klesges et al. (1997), the researchers found that weight gain and rate of weight gain were both significantly greater among those participants who were continuously abstinent from smoking at one-year follow-up, compared with those who were still smoking. Furthermore, these effects remained robust after adjusting for gender, baseline weight, smoking and dieting history, age and education (Klesges et al., 1997). This trend is consistent with results from another study comparing weight gain among quitters and non-quitters over a one-year period, where quitters gained an average of 3.5 kg (SD = 6.9 kg) and non-quitters gained an average of 0.9 kg (SD = 6.8 kg; Swan & Carmelli, 1995). When examining weight gain over shorter follow-up periods, a meta-analysis of 62 studies examining weight gain in smokers who quit smoking without treatment or drugs found that, on average, those who quit smoking gained 1.12 kg (95% CI = 0.76 to 1.47) after one month, 2.26 kg (95% CI = 1.98 to 2.54) after two months, and 2.85 kg (95% CI = 2.42 to 3.28) after three months of abstaining from cigarettes (Aubin et al., 2012). For those participants in the current study who reported quitting at 12-week follow-up, it is therefore possible that changes in BMI/weight status could be attributed to the initiation of smoking cessation, rather than intervention effects.
Educational attainment/current post-secondary enrollment: Similar to the previous objective, this variable was used as a proxy for SES. In developed countries such as Canada and the United States, an inverse association is typically observed between SES and BMI/weight status (for a review see McLaren, 2007). In a study by Hermann et al. (2011), researchers were interested in examining the association between education and BMI (as well as waist circumference), using a sample of 141,230 males and 336,637 females who participated in the European Prospective Investigation into Cancer and Nutrition (EPIC) study. Results showed that, compared with having a high school education or less, both BMI and waist circumference were significantly lower for the higher education categories (including vocational school education, other post-secondary education, and university education; Hermann et al., 2011). When compared to members of their sex with a high school education or less, on average, females with a university education had a BMI that was 2.1 kg/m² lower, and males with a university education had a BMI that was 1.3 kg/m² lower (Hermann et al., 2011). These results were statistically significant after adjusting for age, smoking status, physical activity, alcohol consumption and total energy intake (Hermann et al., 2011). Cross-sectionally, it is possible that better educated participants in our study may have had a lower BMI or weight status at baseline which, given the reported associations between education/SES and sleep (i.e., lower education is associated with poorer sleep), may account for any observed associations between baseline sleep and BMI/weight status. Longitudinally, when examining potential associations between changes in sleep measures and changes in BMI/weight status, it is possible that better educated participants may not have a lot of room to improve their sleep habits or BMI, which may mask potential intervention effects (i.e., negative confounding).
**Sex:** Referring back to Section 2.1.1 (Prevalence of Obesity Among Young Adults), when examining Canadian rates of overweight and obesity according to sex, it appears that the prevalence of class I obesity (i.e., BMI between 30 and 34.9 kg/m$^2$) is slightly higher among female young adults (14.6%) compared to male young adults (13.3%); however, the prevalence of overweight is markedly higher among male young adults (33.7%) compared to female young adults (23.0%; Statistics Canada, 2013). In Meyer et al.’s (2012) study, gender differences were found when examining the association between sleep duration and BMI in a population-based sample of 2,006 young adults. Specifically, the researchers observed an inverse association between sleep duration and odds of obesity (OR = 0.84, 95% CI = 0.71 to 0.98) only among males and, interestingly, also observed a significant positive association between measures of sleep quality (i.e., trouble falling asleep or staying asleep) and mean BMI only among female participants ($p = 0.01$; Meyer et al., 2012). Similar results were reported in a study by Knutson (2005) on adolescents, who found that sleep duration significantly predicted BMI z-score ($\hat{\beta} = 20.08; 95\% \text{ CI} = 20.12, 20.03$) and risk for overweight (OR = 0.90; 95% CI = 0.82, 1.00) only among males. In a recent study employing actigraphy to assess sleep measures, however, Mezick, Wing and McCaffery (2014) found that shorter actigraphy-assessed total sleep time was related to higher BMI in women, but not men. Therefore, in the current study, sex may not only have a direct impact on the outcome of interest (i.e., BMI or weight status), but could also have an indirect impact through its association with sleep.

**Race:** In the literature, several studies have reported racial/ethnic differences in BMI, which appear to be more pronounced in women (for a review see Wang & Beydoun, 2007). In their review of racial differences in obesity prevalence using data from three nationally representative American surveys (i.e., the NHANES, Behavioral Risk Factor Surveillance
System (BRFSS), and National Longitudinal Survey of Adolescent Health (NLSAH)), Wang and Beydoun (2007) found that rates of obesity were highest among African Americans and lowest among Asian Americans. When just examining NHANES data, Wang and Beydoun (2007) also found that minority groups (which included African Americans and Mexican Americans) had almost a 10% higher rate of obesity, combined, when compared to Caucasians. Similar trends were found in studies by Seo and Torabi (2006) and Albrecht and Gordon-Larsen (2013), with the latter pair of researchers also finding that such results were not attributable to a variety of factors including smoking status, screen time, physical activity, regularly skipping breakfast, age and sex. In order to ensure that potential cross-sectional and longitudinal associations between sleep and BMI/weight status were not accounted for by participants’ race, we therefore adjusted for this variable in both models.

5.3.3 Measurement of Confounding Variables

Measurement of all confounding variables was based on self-reported data at baseline and 12-week follow-up, except for smoking status at follow-up, which was verified by a significant other. Physical activity and number of cigarettes smoked in an average day at baseline were measured as continuous variables, in hours per week and cigarettes per day, respectively. In the SMS USA study, physical activity was separated into three categories (i.e., vigorous leisure-time physical activity, light to moderate leisure-time physical activity, and strengthening leisure-time physical activity); however, for the purposes of our study, we collapsed these three items into a single measure of physical activity by calculating the sum of responses (reported in hours per week) to the three physical activity items for each participant.
Smoking status at follow-up, daily text messaging usage, sex, educational attainment/current post-secondary enrollment, and race were all measured as categorical (binary) variables in the present study. Smoking status at follow-up was categorized as “quit” versus “not quit” (participants with missing data for this variable were assumed to be “not quit” in order to provide a conservative estimate of the smoking cessation rate within the sample), daily text messaging usage was categorized as “light texter” versus “heavy texter”, sex was categorized as “male” versus “female”, educational attainment/current post-secondary enrollment was categorized as “high school or less/post-secondary non-completer” versus “currently enrolled in post-secondary education/post-secondary completer”, and race was categorized as “white or Caucasian” versus “other”. In the SMS USA study, daily text messaging usage was measured as a continuous variable in terms of number of text messages sent on an average day. Given the skewness associated with responses to this item, we calculated the median number of text messages sent per day in the sample (i.e., 50 text messages), and used this as the cut-point to differentiate light texters from heavy texters. In the SMS USA study, educational attainment/current post-secondary enrollment was separated into two variables (i.e., educational attainment and current post-secondary enrollment). Educational attainment was comprised of the following categories: “less than high school” (n = 1), “some high school” (n = 4), “high school or equivalent” (n = 30), “some college, but no degree” (n = 70), “associates degree” (n = 10), “college degree (e.g., B.A., B.S.)” (n = 12), “some graduate school, but no degree” (n = 1), and “graduate school (e.g., M.S., M.D., Ph.D.)” (n = 1). Participants were also asked if they were currently enrolled in a 4-year college or university program, or a junior college/community college program, with possible response options including “no” (n = 34), “yes, full-time” (n = 17), and “yes, part-time” (n = 78). In the current study, however, we condensed the number of categories for both variables and
combined these measures due to their similarity and the low number of cases in each category. Similarly, the race variable also had to be scaled down to a binary variable due to the low number of cases in each category. Therefore, in the current study, race was coded as “white or Caucasian” and “other”, with the “other” category being comprised of the following races/ethnicities: black or African American \( (n = 15) \), Asian \( (n = 4) \), Native Hawaiian or other Pacific Islander \( (n = 1) \), Native American or Alaskan Native \( (n = 2) \), mixed racial background \( (n = 19) \), and other \( (n = 1) \).

### 5.4 Data Analysis

All statistical analyses were conducted using version 21 of IBM SPSS Statistics for Windows (PASW, IBM, New York, USA). In the current study, results from the linear regression models were considered statistically significant if the corresponding 95% confidence intervals for the regression coefficients did not include zero, and results from the logistic regression models in the secondary study objective were considered significant if the corresponding 95% confidence intervals for the odds ratios did not include 1. Data on participant demographic and baseline characteristics were analyzed by calculating means (± SD), frequencies, or medians (25%, 75% quartiles). The protocol for data analysis for both study objectives is outlined below.

#### 5.4.1 Data Analysis Protocol for Primary Objective

The primary objective of the current study was to determine the extent to which participants who received text messages aimed at improving sleep and physical activity habits (compared with individuals receiving a smoking cessation texting intervention) improved their sleep quantity, sleep quantity variability, and sleep quality (assessed via self-report) over the 12-
week study period. Of the 164 participants who enrolled in the study and completed baseline measures, 129 participants completed 12-week follow-up measures and were included in the analyses. Four of these participants were considered to be “sleep outliers”, reporting that they typically slept either 0 hours or 1 hour on a work/school night or non-work/non-school night at baseline or follow-up. Since getting such a short amount of sleep on a regular basis seemed implausible, we excluded these 4 individuals from the analyses, reducing the final analytical sample for our primary study objective to 125 participants.

Separate multiple linear regression models for each sleep variable (i.e., sleep quantity on work/school nights, sleep quantity on non-work/non-school nights, sleep quantity variability, sleep quality score, and sleep hygiene score) were used to test the effect of the sleep intervention on each of the sleep outcome variables (adjusting for baseline scores for the respective outcome). Because of the relatively weak correlation ($r = 0.35$) observed between the two measures of sleep quantity (work/school night and non-work/non-school night), we decided to keep these measures separate, rather than collapse them into one variable assessing average sleep quantity.

To determine whether multicollinearity was an issue in our models, relationships between potential confounding variables (i.e., change in physical activity, smoking status at follow-up, daily text messaging usage, sex, educational attainment/current post-secondary enrollment, and race) were examined through t-tests and Chi-squared tests of association. No significant associations were found between any of the potential confounders. Variance inflation factor values for the covariates of interest were examined and ranged from 1.01 to 1.06, indicating that there were no obvious violations of the assumption of independent explanatory variables.
In all five sleep models, sex was also examined as a potential effect modifier (i.e., included in the models as a “sex x intervention” interaction term), due to some evidence in the literature suggesting that mobile health interventions have differential effects when stratified by gender (Burner, Menchine, Taylor, & Arora, 2013). In addition, separate models with sleep as the outcome variable were run for short sleepers (i.e., participants who reported sleeping less than 6 hours on a typical work/school night at baseline) and adequate sleepers (i.e., participants who reported sleeping 6 hours or more on a typical work/school night at baseline) to examine whether the intervention had differential effects when comparing both categories of sleepers. Although one could argue that individuals getting less than 7 hours of sleep per night could technically be defined as short sleepers since these individuals are not meeting the national recommendations for sleep, we chose to use 6 hours as the cut-off because several studies have found that the negative health effects of short sleep tend to emerge at this magnitude of sleep duration (Kobayashi et al., 2012; Patel, 2004; Patel et al., 2006; Shigeta, Shigeta, Nakazawa, Nakamura, & Yoshikawa, 2001; Steptoe et al., 2006; Stranges et al., 2007). The negative health outcomes assessed in these studies were mostly weight-related and included weight gain (Kobayashi et al., 2012; Patel et al., 2006; Stranges et al., 2007), increased risk of obesity (Kobayashi et al., 2012; Patel et al., 2006; Shigeta et al., 2001; Stranges et al., 2007), high waist circumference (Stranges et al., 2007), increased risk of poor health (Steptoe et al., 2006), and increased risk of death (Patel et al., 2004). In addition, using this cut-point (i.e., versus the 7-hour cut-point) allowed us to maximize statistical power in the current study.

5.4.2 Data Analysis Protocol for Secondary Objective

The secondary objective of the current study was to explore potential cross-sectional and longitudinal associations between sleep measures (i.e., sleep quantity, sleep quantity variability,
and sleep quality; explanatory variables) and adiposity (i.e., BMI and weight status; outcome variables). Of the 129 participants who completed 12-week follow-up measures, 31 participants were considered to be “weight change outliers”, meaning that the difference between these participants’ self-reported weight at baseline and self-reported weight at 12-week follow-up was 35 pounds or greater. After examining the literature on smoking cessation and weight change, we chose a weight change (i.e., gain or loss) cut-point of 35 pounds because gains of 25 to 30 pounds are at the high end of what would be considered feasible after three months of quitting smoking (H. Lee Moffitt Cancer Center & Research Institute, 2000). However, weight loss is also possible, especially if other unhealthy behaviours (e.g., drinking alcohol, eating unhealthy foods) that previously accompanied smoking are also discontinued (Aubin et al., 2012). An additional 5 pounds were then added to this cut-point value to account for any potential recall error that may have occurred when estimating weight. In addition to the 31 participants who were excluded from the analyses due to implausible weight change (i.e., a self-reported loss or gain of 35 pounds or more over the 12-week study period), 2 of the sleep outlier participants were also excluded from the analytical sample (the other 2 participants identified as sleep outliers in the primary objective analyses were also classified as weight change outliers, and were therefore already excluded). Therefore, the final analytical sample for our secondary study objective was 96 participants.

Separate multiple linear regression models for each continuously-measured sleep variable (i.e., sleep quantity on work/school nights, sleep quantity on non-work/non-school nights, sleep quantity variability, sleep quality score, and sleep hygiene score) were used to test potential cross-sectional and longitudinal associations between sleep measures and adiposity. In addition, to examine whether there were differences in adiposity levels between short sleepers and
adequate sleepers, we first ran a t-test comparing baseline adiposity levels among the two categories of sleepers. Another t-test was then conducted to compare follow-up adiposity levels between the two groups of sleepers. In the literature, several researchers (e.g., Taheri et al., 2004) have found a U-shaped association between sleep duration and adiposity, suggesting it is not unusual to find a nonlinear association between these two variables.

To determine whether multicollinearity was an issue in the cross-sectional and longitudinal models, relationships between potential confounding variables (i.e., baseline physical activity in the cross-sectional models and change in physical activity in the longitudinal models, number of cigarettes smoked per day at baseline in the cross-sectional models and follow-up smoking status in the longitudinal models, sex, educational attainment/current post-secondary enrollment, race, and intervention status in the longitudinal models) were examined through bivariate correlations, t-tests, and Chi-squared tests of association. The only significant association (in both the cross-sectional and longitudinal models) occurred between sex and educational attainment/current post-secondary enrollment ($\chi^2 (1) = 4.42, p = 0.04$). To test whether this significant association produced substantial changes in the regression coefficient estimates for the key explanatory variables, we ran separate models including both sex and educational attainment/current post-secondary enrollment, only sex, and only educational attainment/current post-secondary enrollment and compared the regression coefficient estimates. Inclusion of both covariates together in the model did not appear to meaningfully change the regression coefficient estimates; therefore, both sex and educational attainment/current post-secondary enrollment were included in all models. Variance inflation factor values for the covariates of interest were also examined and ranged from 1.01 to 1.08 in the cross-sectional
models and 1.00 to 1.10 in the longitudinal models, indicating that our data did not appear to violate assumptions of independent explanatory variables.

In all five sleep models, sex was also examined as a potential effect modifier (i.e., included in the cross-sectional models as a “sex x baseline sleep” interaction term and in the longitudinal models as a “sex x change in sleep” interaction term), due to evidence in the literature suggesting that associations between sleep quantity/quality and BMI differ when stratified by gender (Knutson, 2005; Meyer et al., 2012; Mezick et al., 2014).

After examining cross-sectional and longitudinal associations between the various sleep measures and BMI, we then used logistic regression to determine whether young adults’ self-reported sleep significantly contributed to their odds of being overweight or obese. Normal weight participants (i.e., those with a BMI between 18.5 and 24.9 kg/m²) were used as the reference group, while those participants with a BMI of 25.0 kg/m² or greater comprised the overweight/obese category. At baseline, there were 3 individuals who were classified as underweight based on BMI (i.e., BMI of 18.5 kg/m² or less), who were included in the normal weight group.

5.5 Summary of Methods

In summary, quantitative baseline and 12-week follow-up self-reported questionnaire data from 125 young adults participating in the SMS USA study were used to (a) determine the extent to which participants who received text messages aimed at improving sleep and physical activity habits (compared with individuals receiving a smoking cessation texting intervention) improved their sleep habits, and (b) to explore potential cross-sectional and longitudinal associations between sleep and BMI/weight status (n = 96). In our primary study objective,
multiple linear regression was used to assess the effect of the intervention on self-reported sleep measures. In our secondary study objective, multiple linear regression was used to examine potential cross-sectional and longitudinal associations between sleep and BMI, and logistic regression was used to examine potential cross-sectional and longitudinal associations between sleep and weight status.

6.0 Results

6.1 Primary Research Objective

The primary objective of this study was to determine the extent to which participants who received text messages aimed at improving sleep and physical activity habits (compared with individuals receiving text messages aimed at smoking cessation) improved their sleep quantity, sleep quantity variability, and sleep quality (assessed via self-report). We hypothesized that greater improvements in sleep quantity, sleep quantity variability, and sleep quality would be observed among those participants in the intervention group receiving text messages aimed at improving sleep habits, and also among those participants with a shorter self-reported sleep duration (i.e., less than 6 hours) on work/school nights at baseline.

6.1.1 Study Sample

Demographic and baseline characteristics for participants in the analytical sample are presented in Table 6.1. Of the 129 participants who completed 12-week follow-up measures, 125 were included in the present analyses (four participants were considered to be sleep outliers and were therefore excluded from the analytical sample). Examining the 49 participants who were randomized to receive the sleep/physical activity intervention, 24 (49.0%) were male and 25 (51.0%) were female. The majority of the sleep/physical activity group participants (67.3%)
were white or Caucasian, with the remaining 32.7% being classified as “other” (which included participants identifying as black or African American, Asian, Native Hawaiian or other Pacific Islander, Native American or Alaskan Native, mixed racial background, and other). At the time of the study, the majority of participants in the sleep/physical activity intervention group (75.5%) were either currently enrolled in some form of post-secondary education or had graduated from a post-secondary program. The remaining 24.5% of participants either had a high school education or less, or were previously enrolled in post-secondary education but did not complete the program. The median number of text messages sent on an average day among sleep/physical activity group participants was 50 (25%, 75% quartiles = 19, 125), and participants reported getting, on average, 9.3 hours of physical activity per week.

Demographic and baseline characteristics for the 76 participants randomized to the smoking cessation group were similar, with no significant between-groups differences being found for any of the demographic/baseline characteristics. 56.6% of the smoking cessation group was comprised of male participants, while the remaining 43.4% was comprised of female participants. The majority of participants in the smoking cessation group (65.8%) were white or Caucasian, with the remaining 34.2% being classified as “other”. At the time of the study, the majority of participants in the smoking cessation group (81.6%) were either currently enrolled in some form of post-secondary education or had graduated from a post-secondary program. The remaining 18.4% of participants either had a high school education or less, or were previously enrolled in post-secondary education but did not complete the program. The median number of text messages sent on an average day among smoking cessation group participants was 50 (25%, 75% quartiles = 20, 100), and participants reported getting, on average, 9.9 hours of physical activity per week.
Although we observed intervention effects on all sleep outcomes in the desired direction among participants in the sleep/physical activity intervention group, results from the linear regression models indicated that there were no significant differences between the intervention groups on any of the follow-up sleep measures. This was observed in both the unadjusted models and after adjusting for several covariates, including change in physical activity, smoking status at follow-up, daily text messaging usage, sex, educational attainment/current post-secondary enrollment, and race. Refer to Table 6.2 for results from the linear regression models.

Next, we examined sex and baseline sleep category (i.e., short sleepers versus adequate sleepers) as potential effect modifiers, in order to determine whether the intervention had differential effects for males versus females and short sleepers versus adequate sleepers. In all
five of the sleep outcome models, no significant interactions between sex and the intervention were found (results not shown).

Results from the models for short sleepers \( (n = 36) \) and adequate sleepers \( (n = 89) \) can be found in Table 6.3 and Table 6.4, respectively. Among short sleepers, we found that individuals in the sleep/physical activity group reported getting significantly more sleep on work/school nights, compared with those in the smoking cessation group \( (\hat{\beta} = 1.080, 95\% \text{ CI (0.008, 2.152)}) \). This significant association remained robust after adjusting for several covariates, including change in physical activity, smoking status at follow-up, daily text messaging usage, sex, educational attainment/current post-secondary enrollment, and race \( (\hat{\beta} = 1.102, 95\% \text{ CI (0.038, 2.167)}) \). Although intervention effects on the other four sleep outcomes were observed in the desired direction among short sleepers in the sleep/physical activity group, results from the linear regression models indicated that there were no significant differences between short sleepers in both groups on these sleep measures at follow-up, in both the unadjusted and adjusted models.

Regression coefficient estimates from both the unadjusted and adjusted linear regression models for adequate sleepers in Table 6.4 indicate that, although intervention effects on most of the sleep outcome variables were observed in the desired direction among adequate sleepers in the sleep/physical activity group, none reached statistical significance.
Table 6.2. Change in Sleep Measures from Baseline to 12-Week Follow-Up by Intervention Assignment

<table>
<thead>
<tr>
<th>Sleep Measure</th>
<th>Baseline Mean (SD)</th>
<th>12-Week Follow-Up Mean (SD)</th>
<th>Change</th>
<th>Unadjusted Difference β (95% CI)</th>
<th>P-value</th>
<th>Adjusted Difference β (95% CI)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sleep quantity on work/school nights (hours)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sleep/physical activity group</td>
<td>5.86 (1.43)</td>
<td>6.43 (1.41)</td>
<td>0.57 (1.51)</td>
<td>0.287 (-0.192, 0.766)</td>
<td>0.24</td>
<td>0.305 (-0.179, 0.788)</td>
<td>0.22</td>
</tr>
<tr>
<td>Smoking cessation group</td>
<td>6.42 (1.43)</td>
<td>6.49 (1.65)</td>
<td>0.07 (1.33)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sleep quantity on non-work/non-school nights (hours)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sleep/physical activity group</td>
<td>7.69 (2.30)</td>
<td>8.04 (2.19)</td>
<td>0.35 (2.21)</td>
<td>-0.090 (-0.842, 0.662)</td>
<td>0.81</td>
<td>-0.115 (-0.862, 0.632)</td>
<td>0.76</td>
</tr>
<tr>
<td>Smoking cessation group</td>
<td>8.30 (2.01)</td>
<td>8.37 (2.22)</td>
<td>0.07 (2.55)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sleep quantity variability (hours)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sleep/physical activity group</td>
<td>1.84 (2.14)</td>
<td>1.61 (2.08)</td>
<td>-0.22 (2.56)</td>
<td>-0.260 (-0.981, 0.461)</td>
<td>0.48</td>
<td>-0.269 (-0.990, 0.452)</td>
<td>0.46</td>
</tr>
<tr>
<td>Smoking cessation group</td>
<td>1.88 (2.12)</td>
<td>1.88 (1.99)</td>
<td>0.00 (2.63)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sleep quality score b</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sleep/physical activity group</td>
<td>17.63 (5.06)</td>
<td>16.14 (5.02)</td>
<td>-1.49 (5.12)</td>
<td>0.291 (-1.246, 1.829)</td>
<td>0.71</td>
<td>0.330 (-1.214, 1.875)</td>
<td>0.67</td>
</tr>
<tr>
<td>Smoking cessation group</td>
<td>16.86 (5.54)</td>
<td>15.51 (4.68)</td>
<td>-1.34 (5.23)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sleep hygiene score c</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sleep/physical activity group</td>
<td>22.92 (5.95)</td>
<td>21.71 (6.30)</td>
<td>-1.20 (8.05)</td>
<td>0.827 (-1.278, 2.932)</td>
<td>0.44</td>
<td>0.504 (-1.579, 2.586)</td>
<td>0.63</td>
</tr>
<tr>
<td>Smoking cessation group</td>
<td>23.49 (6.90)</td>
<td>21.13 (6.50)</td>
<td>-2.36 (6.01)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Abbreviations: SD, standard deviation; CI, confidence interval

*Adjusted for baseline sleep, change in physical activity level, smoking status at 12-week follow-up, daily text messaging usage, sex, educational attainment/current post-secondary enrollment, and race

b Sleep quality was assessed using 8 self-report items adapted from the PSQI; scores were the sum of participants’ quantified responses for each item, with higher scores being indicative of poorer sleep quality (possible scores ranged from 8 to 32)

* Sleep hygiene was assessed using 9 self-report items adapted from the SHI; scores were the sum of participants’ quantified responses for each item, with higher scores being indicative of poorer sleep hygiene (possible scores ranged from 9 to 36)
Table 6.3. Change in Sleep Measures from Baseline to 12-Week Follow-Up by Intervention Assignment for Short Sleepers (< 6 hours/night)

<table>
<thead>
<tr>
<th>Sleep Measure</th>
<th>Baseline Mean (SD)</th>
<th>12-Week Follow-Up Mean (SD)</th>
<th>Change Mean (SD)</th>
<th>Unadjusted Difference β (95% CI)</th>
<th>P-value</th>
<th>Adjusted Difference β (95% CI)a</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sleep quantity on work/school nights (hours)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sleep/physical activity group</td>
<td>4.25 (0.68)</td>
<td>5.88 (1.93)</td>
<td>1.63 (1.71)</td>
<td>1.080 (0.008, 2.152)*</td>
<td>0.05**</td>
<td>1.102 (0.038, 2.167)*</td>
<td>0.04**</td>
</tr>
<tr>
<td>Smoking cessation group</td>
<td>4.55 (0.83)</td>
<td>5.05 (1.40)</td>
<td>0.50 (1.36)</td>
<td>0.465 (-1.054, 1.984)</td>
<td>0.54</td>
<td>0.133 (-1.522, 1.788)</td>
<td>0.87</td>
</tr>
<tr>
<td><strong>Sleep quantity on non-work/non-school nights (hours)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sleep/physical activity group</td>
<td>6.38 (2.96)</td>
<td>7.25 (2.32)</td>
<td>0.88 (2.63)</td>
<td>0.612 (-2.172, 0.948)</td>
<td>0.43</td>
<td>-0.871 (-2.628, 0.887)</td>
<td>0.32</td>
</tr>
<tr>
<td>Smoking cessation group</td>
<td>7.70 (2.47)</td>
<td>7.20 (2.26)</td>
<td>-0.50 (2.66)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Sleep quantity variability (hours)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sleep/physical activity group</td>
<td>2.13 (2.70)</td>
<td>1.38 (2.28)</td>
<td>-0.75 (2.93)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Smoking cessation group</td>
<td>3.15 (2.25)</td>
<td>2.15 (2.21)</td>
<td>-1.00 (3.09)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Sleep quality score</strong>b</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sleep/physical activity group</td>
<td>19.81 (4.94)</td>
<td>18.06 (5.85)</td>
<td>-1.75 (6.35)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Smoking cessation group</td>
<td>18.45 (5.38)</td>
<td>18.45 (4.72)</td>
<td>0.00 (3.54)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Sleep hygiene score</strong>c</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sleep/physical activity group</td>
<td>23.38 (6.53)</td>
<td>22.13 (7.06)</td>
<td>-1.25 (9.57)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Smoking cessation group</td>
<td>25.05 (7.02)</td>
<td>24.25 (7.14)</td>
<td>-0.80 (4.56)</td>
<td>-1.317 (-5.713, 3.080)</td>
<td>0.55</td>
<td>-1.643 (-6.165, 2.879)</td>
<td>0.46</td>
</tr>
</tbody>
</table>

Abbreviations: SD, standard deviation; CI, confidence interval

a Adjusted for baseline sleep, change in physical activity level, smoking status at 12-week follow-up, daily text messaging usage, sex, educational attainment/current post-secondary enrollment, and race

b Sleep quality was assessed using 8 self-report items adapted from the PSQI; scores were the sum of participants' quantified responses for each item, with higher scores being indicative of poorer sleep quality (possible scores ranged from 8 to 32)

c Sleep hygiene was assessed using 9 self-report items adapted from the SHI; scores were the sum of participants' quantified responses for each item, with higher scores being indicative of poorer sleep hygiene (possible scores ranged from 9 to 36)

*95% CI does not contain 0

**Significant at p ≤ 0.05
Table 6.4. Change in Sleep Measures from Baseline to 12-Week Follow-Up by Intervention Assignment for Adequate Sleepers (> 6 hours/night)

<table>
<thead>
<tr>
<th>Sleep Measure</th>
<th>Baseline Mean (SD)</th>
<th>12-Week Follow-Up Mean (SD)</th>
<th>Change</th>
<th>Unadjusted Difference β (95% CI)</th>
<th>P-value</th>
<th>Adjusted Difference β (95% CI)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sleep quantity on work/school nights (hours)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sleep/physical activity group</td>
<td>6.64 (0.96)</td>
<td>6.70 (1.02)</td>
<td>0.06 (1.12)</td>
<td>-0.044 (-0.572, 0.483)</td>
<td>0.87</td>
<td>-0.012 (-0.560, 0.536)</td>
<td>0.97</td>
</tr>
<tr>
<td>Smoking cessation group</td>
<td>7.09 (0.90)</td>
<td>7.00 (1.41)</td>
<td>-0.09 (1.30)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Sleep quantity on non-work/non-school nights (hours)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sleep/physical activity group</td>
<td>8.33 (1.59)</td>
<td>8.42 (2.05)</td>
<td>0.09 (1.97)</td>
<td>-0.293 (-1.153, 0.568)</td>
<td>0.50</td>
<td>-0.270 (-1.107, 0.566)</td>
<td>0.52</td>
</tr>
<tr>
<td>Smoking cessation group</td>
<td>8.52 (1.80)</td>
<td>8.79 (2.07)</td>
<td>0.27 (2.38)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Sleep quantity variability (hours)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sleep/physical activity group</td>
<td>1.70 (1.85)</td>
<td>1.73 (2.00)</td>
<td>0.03 (2.36)</td>
<td>-0.124 (-0.959, 0.710)</td>
<td>0.77</td>
<td>-0.068 (-0.876, 0.740)</td>
<td>0.87</td>
</tr>
<tr>
<td>Smoking cessation group</td>
<td>1.43 (1.90)</td>
<td>1.79 (1.92)</td>
<td>0.36 (2.37)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Sleep quality score</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sleep/physical activity group</td>
<td>16.58 (4.84)</td>
<td>15.21 (4.36)</td>
<td>-1.36 (4.51)</td>
<td>0.652 (-1.062, 2.366)</td>
<td>0.45</td>
<td>0.634 (-1.115, 2.382)</td>
<td>0.47</td>
</tr>
<tr>
<td>Smoking cessation group</td>
<td>16.29 (5.53)</td>
<td>14.46 (4.23)</td>
<td>-1.82 (5.67)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Sleep hygiene score</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sleep/physical activity group</td>
<td>22.70 (5.74)</td>
<td>21.52 (6.00)</td>
<td>-1.18 (7.37)</td>
<td>1.585 (-0.804, 3.973)</td>
<td>0.19</td>
<td>1.397 (-1.009, 3.803)</td>
<td>0.25</td>
</tr>
<tr>
<td>Smoking cessation group</td>
<td>22.93 (6.83)</td>
<td>20.02 (5.94)</td>
<td>-2.91 (6.39)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Abbreviations: SD, standard deviation; CI, confidence interval

*Adjusted for baseline sleep, change in physical activity level, smoking status at 12-week follow-up, daily text messaging usage, sex, educational attainment/current post-secondary enrollment, and race

*Sleep quality was assessed using 8 self-report items adapted from the PSQI; scores were the sum of participants' quantified responses for each item, with higher scores being indicative of poorer sleep quality (possible scores ranged from 8 to 32)

*Sleep hygiene was assessed using 9 self-report items adapted from the SHI; scores were the sum of participants' quantified responses for each item, with higher scores being indicative of poorer sleep hygiene (possible scores ranged from 9 to 36)
6.2 Secondary Research Objective

The secondary objective of the current study was to explore potential cross-sectional and longitudinal associations between sleep measures (i.e., sleep quantity, sleep quantity variability, and sleep quality; explanatory variables) and BMI (outcome; measured as a continuous variable). In addition, we also explored whether sleep measures (explanatory variables) were cross-sectionally or longitudinally associated with weight status (outcome; measured as a categorical variable). In the cross-sectional analyses, we hypothesized that sleep quantity and quality would be negatively associated with BMI at baseline, sleep quantity variability would be positively associated with BMI at baseline, and poorer sleep habits at baseline (i.e., lower sleep quantity, higher sleep quantity variability, and lower sleep quality) would be associated with higher odds of being overweight/obese at baseline. In the longitudinal analyses, we hypothesized that positive changes in sleep quantity and quality, as well as reductions in sleep quantity variability, would be associated with lower BMI, and that poorer sleep habits at follow-up would be associated with higher odds of being overweight/obese at follow-up.

6.2.1 Study Sample

Demographic and baseline characteristics for participants in the analytical sample are presented in Table 6.5. Of the 129 participants who completed 12-week follow-up measures, 96 were included in the present analyses (31 participants were considered to be weight change outliers and two participants were considered to be sleep outliers, and were therefore excluded from the analytical sample). No significant between-groups differences were found for any of the demographic/baseline characteristics.
Examining the 38 participants who were randomized to the sleep/physical activity group, 18 (47.4%) were male and 20 (52.6%) were female. The majority of participants in the sleep/physical activity group (63.2%) were white or Caucasian, with the remaining 36.8% being classified as “other” (which included participants identifying as black or African American, Asian, Native Hawaiian or other Pacific Islander, Native American or Alaskan Native, mixed racial background, and other). At the time of the study, the majority of sleep/physical activity group participants (76.3%) were either currently enrolled in some form of post-secondary education or had graduated from a post-secondary program. The remaining 23.7% of participants either had a high school education or less, or were previously enrolled in post-secondary education but did not complete the program. The mean amount of physical activity that sleep/physical activity group participants reported getting per week was 10.7 hours, and the mean number of cigarettes smoked per day by participants in this group at baseline was 11.3.

Examining weight-related baseline characteristics among the sleep/physical activity group participants in our sample, mean BMI was 26.0 kg/m\(^2\), and half of participants (50.0%) were categorized as normal weight (i.e., BMI in the range of 18.5 to 24.9 kg/m\(^2\)).

Examining demographic and baseline characteristics for the 58 participants who were randomized to the smoking cessation group, 58.6% of the group was comprised of male participants and the remaining 41.4% of the group was comprised of female participants. The majority of participants in the smoking cessation group (69.0%) were white or Caucasian, with the remaining 31.0% being classified as “other” (which included participants identifying as black or African American, Asian, Native Hawaiian or other Pacific Islander, Native American or Alaskan Native, mixed racial background, and other). At the time of the study, the majority of smoking cessation group participants (81.0%) were either currently enrolled in some form of
post-secondary education or had graduated from a post-secondary program. The remaining 19.0% of participants either had a high school education or less, or were previously enrolled in post-secondary education but did not complete the program. The mean amount of physical activity that smoking cessation group participants reported getting per week was 9.3 hours, and the mean number of cigarettes smoked per day by participants in this group at baseline was 11.8. Examining weight-related baseline characteristics among the smoking cessation group participants in our sample, mean BMI was 25.1 kg/m², and 39.7% of participants were categorized as normal weight (i.e., BMI in the range of 18.5 to 24.9 kg/m²).

Table 6.5. Demographic/Baseline Characteristics of Participants in the SMS USA Study (Overall and by Intervention Assignment)

<table>
<thead>
<tr>
<th>Demographic/Baseline Characteristic</th>
<th>Overall (n=96)</th>
<th>Smoking Cessation Group (n=58)</th>
<th>Sleep/Physical Activity Group (n=38)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>52 (54.2)</td>
<td>34 (58.6)</td>
<td>18 (47.4)</td>
</tr>
<tr>
<td>Female</td>
<td>44 (45.8)</td>
<td>24 (41.4)</td>
<td>20 (52.6)</td>
</tr>
<tr>
<td>Race</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>White or Caucasian</td>
<td>64 (66.7)</td>
<td>40 (69.0)</td>
<td>24 (63.2)</td>
</tr>
<tr>
<td>Other</td>
<td>32 (33.3)</td>
<td>18 (31.0)</td>
<td>14 (36.8)</td>
</tr>
<tr>
<td>Educational attainment/Current post-secondary enrollment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High school or less/Post-secondary non-completer</td>
<td>20 (20.8)</td>
<td>11 (19.0)</td>
<td>9 (23.7)</td>
</tr>
<tr>
<td>Currently enrolled in post-secondary education/Post-secondary completer</td>
<td>76 (79.2)</td>
<td>47 (81.0)</td>
<td>29 (76.3)</td>
</tr>
<tr>
<td>BMI categorization</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal weight</td>
<td>54 (56.3)</td>
<td>23 (39.7)</td>
<td>19 (50.0)</td>
</tr>
<tr>
<td>Overweight/obese</td>
<td>42 (43.8)</td>
<td>35 (60.3)</td>
<td>19 (50.0)</td>
</tr>
<tr>
<td>Physical activity level (hours/week)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean (SD)</td>
<td>9.9 (14.8)</td>
<td>9.3 (13.2)</td>
<td>10.7 (17.0)</td>
</tr>
<tr>
<td>Number of cigarettes smoked per day</td>
<td>11.6 (5.7)</td>
<td>11.8 (5.8)</td>
<td>11.3 (5.6)</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>25.4 (5.4)</td>
<td>25.1 (5.6)</td>
<td>26.0 (4.9)</td>
</tr>
</tbody>
</table>

Abbreviations: BMI, body mass index (calculated as weight in kilograms divided by height in metres squared)
6.2.2 Linear Regression Results

Results from the cross-sectional and longitudinal models can be found in Table 6.6 and Table 6.7, respectively. When examining results for the cross-sectional models, we found a statistically significant association between sleep quantity on non-work/non-school nights and BMI ($\hat{\beta} = -0.495, 95\% \text{ CI (-0.999, 0.009})$) in the expected direction, indicating that getting more sleep on non-work/non-school nights was associated with a lower BMI. This association, however, was no longer significant in the adjusted model ($\hat{\beta} = -0.398, 95\% \text{ CI (-0.914, 0.118})$). No other significant associations were found between any of the other baseline sleep measures and baseline BMI. When examining results for the longitudinal models, we found an association between change in sleep quantity on work/school nights and BMI that approached statistical significance in both the unadjusted ($\hat{\beta} = 0.249, 95\% \text{ CI (-0.025, 0.523})$) and adjusted ($\hat{\beta} = 0.251, 95\% \text{ CI (-0.019, 0.522})$) models. Significant associations were not found between changes in any of the other sleep measures and follow-up BMI.

Table 6.6. Results of Cross-Sectional Linear Regression Analyses of Sleep Measures with Body Mass Index

<table>
<thead>
<tr>
<th>Sleep Measure</th>
<th>Unadjusted Difference $\beta$ (95% CI)</th>
<th>P-value</th>
<th>Adjusted Difference $\beta$ (95% CI)$^a$</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sleep quantity on work/school nights (hours)</td>
<td>-0.458 (-1.274, 0.357)</td>
<td>0.27</td>
<td>-0.307 (-1.144, 0.531)</td>
<td>0.47</td>
</tr>
<tr>
<td>Sleep quantity on non-work/non-school nights (hours)</td>
<td><strong>-0.495 (-0.999, 0.009)</strong> $^a$</td>
<td><strong>0.05</strong></td>
<td><strong>-0.398 (-0.914, 0.118)</strong> $^a$</td>
<td>0.13</td>
</tr>
<tr>
<td>Sleep quantity variability (hours)</td>
<td>-0.268 (-0.739, 0.202)</td>
<td>0.26</td>
<td>-0.230 (-0.701, 0.242)</td>
<td>0.34</td>
</tr>
<tr>
<td>Sleep quality score$^b$</td>
<td>-0.021 (-0.219, 0.177)</td>
<td>0.83</td>
<td>-0.067 (-0.267, 0.133)</td>
<td>0.51</td>
</tr>
<tr>
<td>Sleep hygiene score$^c$</td>
<td>-0.059 (-0.231, 0.113)</td>
<td>0.50</td>
<td>-0.078 (-0.252, 0.095)</td>
<td>0.37</td>
</tr>
</tbody>
</table>

Abbreviations: CI, confidence interval  
$^a$Adjusted for baseline physical activity level, number of cigarettes smoked per day at baseline, sex, educational attainment/current post-secondary enrollment, and race  
$^b$Sleep quality was assessed using 8 self-report items adapted from the PSQI; scores were the sum of participants’ quantified responses for each item, with higher scores being indicative of poorer sleep quality (possible scores ranged from 8 to 32)  
$^c$Sleep hygiene was assessed using 9 self-report items adapted from the SHI; scores were the sum of participants’ quantified responses for each item, with higher scores being indicative of poorer sleep hygiene (possible scores ranged from 9 to 36)  
$^a$Significant at $p \leq 0.05$
Independent sample t-tests were used to compare adiposity levels (i.e., BMI) among short sleepers and adequate sleepers at baseline, and again at 12-week follow-up. There was no significant difference in baseline adiposity levels among short sleepers ($\bar{X} = 26.8 \text{ kg/m}^2$, $SD = 6.2 \text{ kg/m}^2$) and adequate sleepers ($\bar{X} = 24.9 \text{ kg/m}^2$, $SD = 5.0 \text{ kg/m}^2$; $t (94) = 1.522, p = 0.13$), which suggests that a cross-sectional linear association does not exist between sleep quantity on work/school nights and BMI. There was also no significant difference in follow-up adiposity levels among short sleepers ($\bar{X} = 27.2 \text{ kg/m}^2$, $SD = 6.2 \text{ kg/m}^2$) and adequate sleepers ($\bar{X} = 25.1 \text{ kg/m}^2$, $SD = 4.6 \text{ kg/m}^2$; $t (94) = 1.791, p = 0.08$) which, similarly, suggests that a longitudinal linear association does not exist between sleep quantity on work/school nights and BMI. When examining sex as a potential effect modifier to determine whether there were gender differences in potential cross-sectional and longitudinal associations between sleep measures and BMI, no significant interactions were found between sex and baseline sleep measures (cross-sectional models) or changes in sleep measures (longitudinal models).

<table>
<thead>
<tr>
<th>Sleep Measure</th>
<th>Unadjusted Difference $\beta$ (95% CI)</th>
<th>P-value</th>
<th>Adjusted Difference $\beta$ (95% CI)$^a$</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Change in sleep quantity on work/school nights (hours)</td>
<td>0.249 (-0.025, 0.523)</td>
<td>0.07</td>
<td>0.251 (-0.019, 0.522)</td>
<td>0.07</td>
</tr>
<tr>
<td>Change in sleep quantity on non-work/non-school nights (hours)</td>
<td>0.008 (-0.146, 0.163)</td>
<td>0.91</td>
<td>0.027 (-0.126, 0.180)</td>
<td>0.73</td>
</tr>
<tr>
<td>Change in sleep quantity variability (hours)</td>
<td>-0.059 (-0.203, 0.084)</td>
<td>0.42</td>
<td>-0.044 (-0.185, 0.098)</td>
<td>0.54</td>
</tr>
<tr>
<td>Change in sleep quality score$^b$</td>
<td>-0.006 (-0.087, 0.074)</td>
<td>0.87</td>
<td>-0.007 (-0.086, 0.071)</td>
<td>0.85</td>
</tr>
<tr>
<td>Change in sleep hygiene score$^c$</td>
<td>0.016 (-0.045, 0.077)</td>
<td>0.60</td>
<td>0.007 (-0.054, 0.068)</td>
<td>0.81</td>
</tr>
</tbody>
</table>

Abbreviations: CI, confidence interval
$^a$ Adjusted for baseline BMI, intervention status, change in physical activity level, smoking status at 12-week follow-up, sex, educational attainment/current post-secondary enrollment, and race
$^b$ Sleep quality was assessed using 8 self-report items adapted from the PSQI; scores were the sum of participants’ quantified responses for each item, with higher scores being indicative of poorer sleep quality (possible scores ranged from 8 to 32)
$^c$ Sleep hygiene was assessed using 9 self-report items adapted from the SHI; scores were the sum of participants’ quantified responses for each item, with higher scores being indicative of poorer sleep hygiene (possible scores ranged from 9 to 36)
6.2.3 Logistic Regression Results

Results from the cross-sectional and longitudinal models can be found in Table 6.8 and Table 6.9, respectively. Logistic regression results from both the unadjusted (OR = 0.780, 95% CI (0.633, 0.962)) and adjusted (OR = 0.797, 95% CI (0.643, 0.988)) cross-sectional models in Table 6.8 indicate that greater sleep quantity on non-school/non-work nights at baseline was associated with lower odds of being overweight/obese. None of the other baseline sleep measures (i.e., sleep quantity on work/school nights, sleep quantity variability, sleep quality score, and sleep hygiene score) were found to be associated with weight status at baseline. When examining logistic regression results from the longitudinal models, we did not find changes in any of the sleep measures to be associated with weight status at follow-up, after controlling for baseline BMI category (i.e., normal weight versus overweight/obese). Results did not change without the inclusion of the 3 participants classified as underweight based on BMI (i.e., BMI of 18.5 kg/m² or less).
### Table 6.8. Results of Cross-Sectional Logistic Regression Analyses of Weight Status with Sleep Measures

<table>
<thead>
<tr>
<th>Weight Status</th>
<th>Sleep Quantity on Work/School Nights (hours)</th>
<th>Sleep Quantity on Non-Work/Non-School Nights (hours)</th>
<th>Sleep Quantity Variability (hours)</th>
<th>Sleep Quality Score&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Sleep Hygiene Score&lt;sup&gt;c&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal Weight (Reference)</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Overweight/obese</td>
<td>0.854 (0.627, 1.163)</td>
<td><strong>0.780 (0.633, 0.962)</strong>&lt;sup&gt;*&lt;/sup&gt;</td>
<td>0.858 (0.711, 1.035)</td>
<td>1.007 (0.936, 1.083)</td>
<td>0.986 (0.925, 1.050)</td>
</tr>
<tr>
<td>Unadjusted</td>
<td>0.901 (0.652, 1.245)</td>
<td><strong>0.797 (0.643, 0.988)</strong>&lt;sup&gt;*&lt;/sup&gt;</td>
<td>0.860 (0.709, 1.042)</td>
<td>0.993 (0.920, 1.072)</td>
<td>0.973 (0.909, 1.041)</td>
</tr>
<tr>
<td>Adjusted&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Abbreviations: CI, confidence interval; OR, odds ratio

Values presented are ORs (95% CI)

<sup>a</sup>Adjusted for baseline physical activity level, number of cigarettes smoked per day at baseline, sex, educational attainment/current post-secondary enrollment, and race

<sup>b</sup>Sleep quality was assessed using 8 self-report items adapted from the PSQI; scores were the sum of participants' quantified responses for each item, with higher scores being indicative of poorer sleep quality (possible scores ranged from 8 to 32)

<sup>c</sup>Sleep hygiene was assessed using 9 self-report items adapted from the SHI; scores were the sum of participants' quantified responses for each item, with higher scores being indicative of poorer sleep hygiene (possible scores ranged from 9 to 36)

*95% CI does not contain 1
Table 6.9. Results of Longitudinal Logistic Regression Analyses of Weight Status with Sleep Measures

<table>
<thead>
<tr>
<th>Weight Status</th>
<th>Change in Sleep Quantity on Work/School Nights (hours)</th>
<th>Change in Sleep Quantity on Non-Work/Non-School Nights (hours)</th>
<th>Change in Sleep Quantity Variability (hours)</th>
<th>Change in Sleep Quality Score&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Change in Sleep Hygiene Score&lt;sup&gt;c&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal Weight</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>(Reference)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overweight/obese</td>
<td>1.604 (0.995, 2.586)</td>
<td>1.179 (0.904, 1.538)</td>
<td>1.015 (0.806, 1.277)</td>
<td>0.955 (0.838, 1.089)</td>
<td>1.084 (0.984, 1.194)</td>
</tr>
<tr>
<td>Unadjusted</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adjusted&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.591 (0.961, 2.632)</td>
<td>1.160 (0.882, 1.526)</td>
<td>0.995 (0.784, 1.264)</td>
<td>0.971 (0.855, 1.101)</td>
<td>1.082 (0.977, 1.198)</td>
</tr>
</tbody>
</table>

Abbreviations: CI, confidence interval; OR, odds ratio

Values presented are ORs (95% CI)

<sup>a</sup> Adjusted for baseline weight status, intervention status, change in physical activity level, smoking status at 12-week follow-up, sex, educational attainment/current post-secondary enrollment, and race

<sup>b</sup> Sleep quality was assessed using 8 self-report items adapted from the PSQI; scores were the sum of participants’ quantified responses for each item, with higher scores being indicative of poorer sleep quality (possible scores ranged from 8 to 32)

<sup>c</sup> Sleep hygiene was assessed using 9 self-report items adapted from the SHI; scores were the sum of participants’ quantified responses for each item, with higher scores being indicative of poorer sleep hygiene (possible scores ranged from 9 to 36)
7.0 Discussion

Within the last decade, there has been a profusion of research identifying sleep as one of several modifiable risk factors for obesity across different geographic populations and age groups, with young adults being no exception (e.g., Hasler et al., 2004). Among the young adult age group, inadequate sleep is a prevalent issue, with over 20% of young adults getting less than 7 hours of sleep on most nights (Steptoe et al., 2006). Emerging evidence on interventions aimed at improving sleep habits among young adults has shown mixed results, with such interventions being evaluated exclusively using participants enrolled in post-secondary education. Thus, it remains unknown whether such interventions can meaningfully improve sleep habits among the broader population of young adults. In addition, although text message-based interventions have recently been applied to several health behaviours with varying success, a text message-based intervention aimed specifically at improving sleep habits does not yet exist. Therefore, the primary objective of our study was to address this gap in the existing literature by examining the effectiveness of a text message-based intervention on improving sleep habits among a U.S. national sample of young adults. For our secondary objective, we were also interested in exploring whether sleep measures were cross-sectionally and longitudinally associated with measures of adiposity (i.e., BMI and weight status), in an effort to gain insight into whether baseline levels of sleep and changes in sleep were associated with weight outcomes among a national sample of young adults, including those not enrolled in post-secondary education. Previous research examining potential associations between sleep and adiposity has not differentiated between sleep quantity on work/school nights and non-work/non-school nights, nor has it differentiated between sleep quality and sleep hygiene. Our study aimed to address these research gaps through providing additional insight into whether there are differential
associations between sleep and adiposity when examining different components of sleep quantity and quality.

Our main finding was that there were no statistically significant differences between intervention groups with respect to sleep measures at follow-up, although participants in the sleep/physical activity group demonstrated what could be argued as a clinically significant change in sleep quantity on work/school nights (i.e., sleep quantity on work/school nights increased by a mean of 34 minutes in the sleep/physical activity group, compared to the 4 minute mean increase observed in the smoking cessation group). No statistically or clinically significant changes were observed for any of the remaining sleep outcomes, although small changes on all of the remaining outcomes were observed in the desired direction among participants receiving the sleep/physical activity intervention. When we examined whether intervention effects were moderated by baseline sleep level, we found that among short sleepers (i.e., getting < 6 hours of sleep on work/school nights at baseline), those in the sleep/physical activity intervention arm reported getting significantly more sleep on work/school nights at follow-up as compared to those in the smoking cessation intervention.

Examining results from our secondary study objective, we did not find any statistically significant cross-sectional or longitudinal associations between sleep measures (i.e., sleep quantity, sleep quantity variability, and sleep quality measures) and BMI, after adjusting for covariates. When examining whether young adults’ self-reported sleep habits significantly contributed to their odds of being overweight or obese, however, we found a significant cross-sectional association between sleep quantity on non-work/non-school nights and weight status. Specifically, greater sleep quantity on non-school/non-work nights at baseline was associated with lower odds of being overweight/obese at baseline, even after adjusting for covariates.
7.1 Comparison of Primary Objective Findings to the Literature

Within the last two decades, research on the use of educational/motivational interventions to improve sleep habits among young adults has begun to emerge in the literature. More recently, with the advancement of mobile phone technology, text message-based programs have been studied as a mode of intervention delivery to improve a multitude of health behaviours (for a review see Wei, Hollin, & Kachnowski, 2011). To our knowledge, however, a text message-based intervention has not yet been used to improve sleep habits among the young adult population. Below we compare our results to previous interventions designed to improve sleep habits among young adults.

7.1.1 Effectiveness of Interventions to Improve Sleep Habits among Young Adults

Our review of the literature identified 9 studies that have examined the effect of educational sleep interventions on the sleep habits of young adults (Arora et al., 2007; Ball & Bax, 2002; Brown et al., 2006; Clark, 2010; Farias, 2012; Lamberti, 2012; Prestwich et al., 2007; Trockel et al., 2011; Tsai & Li, 2004a). These studies have yielded mixed conclusions, with the slight majority of studies finding statistically significant effects (Ball & Bax, 2002; Brown et al., 2006; Clark, 2010; Prestwich et al., 2007; Trockel et al., 2011), and other studies finding no effects (Lamberti, 2012) or small, non-significant effects (Arora et al., 2007; Farias, 2012; Tsai & Li, 2004a). In the current study, we found that a text message-based intervention aimed at improving sleep and physical activity habits was generally not effective in improving measures of sleep quantity, sleep quantity variability, or sleep quality among our sample of young adult smokers, when compared to a text message-based intervention aimed at smoking cessation. When examining baseline sleep category (i.e., short sleepers versus adequate sleepers) as an
effect modifier, however, we found that among short sleepers (i.e., sleeping less than 6 hours per night on work/school nights at baseline), those in the sleep/physical activity group reported getting significantly more sleep on work/school nights at follow-up than participants in the smoking cessation group. Specifically, short sleepers receiving the sleep/physical activity intervention reported sleeping 66 minutes longer on work/school nights at follow-up, compared to their counterparts receiving the smoking cessation intervention. Although short sleepers receiving the sleep/physical activity intervention still fell well below the national sleep recommendations of 7 to 9 hours per night at follow-up (mean follow-up sleep quantity on work/school nights in this group was 5.88 hours), an increase in sleep quantity exceeding one hour can still be considered clinically significant.

Comparing our results to other sleep interventions in the literature, our findings are similar to those of Trockel et al. (2011), who found significant intervention effects on sleep quality only among poor sleepers in their sample (although we examined sleep quantity as an effect modifier instead of sleep quality). These findings are intuitive, given that individuals with poorer sleep quality or shorter sleep quantity at baseline have more room to improve, compared with their better-rested counterparts. It is possible that we may have found significant improvements in sleep quality had we run separate models for poor quality sleepers and good quality sleepers in our sample; however, the fact that we did not use the full PSQI to measure sleep quality precluded the possibility of using established criteria to differentiate good quality sleepers from poor quality sleepers. Similarly, had we used the full SHI to measure sleep hygiene, we would have been able to used established criteria to differentiate individuals with good sleep hygiene from those with moderate or poor sleep hygiene, and examine whether the
intervention had differential effects on sleep hygiene habits according to participants’ baseline sleep hygiene category.

Assessing the magnitude of intervention effects across studies reporting statistically significant effects on sleep habits, our intervention was among the more successful interventions when examining sleep quantity results (on work/school nights) for short sleepers in our sample. Although results were not significant when including both categories of sleepers in the analysis, mean change in sleep quantity on work/school nights among all participants in the sleep/physical activity group was 34 minutes, which was remarkably higher than the mean change of 4 minutes observed among participants in the smoking cessation group. Similar to our findings for short sleepers, Prestwich et al. (2007) found that receiving a combination of sleep health education and keeping sleep logs resulted in a mean improvement of approximately 54 minutes of sleep per night among participants in their sample. In addition, Ball and Bax (2002) found that receiving a self-care intervention focused on improving sleep hygiene habits was associated with a significantly lower reduction in sleep quantity among first year medical school students (mean reduction = 10 minutes per night, compared to a 46-minute reduction observed among participants receiving a self-awareness intervention where students received feedback on their Epworth Sleepiness Scale scores). Taking into consideration that, like our study, all of the sleep measures in the above studies were based on self-reported data, these findings should be interpreted with caution and indicate the need for more research using objective measures of sleep.

Studies examining the effect of a sleep education presentation (Brown et al., 2006; Clark, 2010) and a web-based sleep intervention (Trockel et al., 2011) on sleep quality exhibited few clinically significant findings, with PSQI scores decreasing by 1.1 units in Brown et al.’s (2006)
study and 2.4 units in Trockel et al.’s (2011) study among participants in the treatment group (PSQI scores can range from 0 to 21, where scores of 0 to 5 indicate good sleep quality and scores of 5 or greater indicate poor sleep quality). Mean PSQI scores could not be accessed for Clark’s (2010) study since it was a dissertation preview. These findings are similar to the modest changes in sleep quality observed in our study, although we did not use the full measure (mean change in sleep quality score among participants in the sleep/physical activity group was -1.49 units, compared with a mean change of -1.34 units among smoking cessation group participants).

Despite the relatively minor improvements in PSQI scores reported in studies by Brown et al. (2006) and Trockel et al. (2011), in both cases, mean scores at follow-up were on the cusp of being classified as good sleep quality (i.e., mean follow-up PSQI scores were 5.50 in Brown et al.’s (2006) study and 5.26 in Trockel et al.’s (2011) study).

Examining factors related to successful sleep interventions, the five sleep interventions reporting significant improvements in sleep quantity or quality measures all had an in-person component, even if it was just at the initial study encounter. For example, the sleep intervention in Ball and Bax’s (2002) study included an in-person lecture/group discussion component, and interventions in studies by Brown et al. (2006), Clark (2010), and Prestwich et al. (2007) involved an in-person sleep education component. Although Trockel et al.’s (2011) sleep intervention was online, the researchers presented the study at the first residence meeting and gave students the opportunity to ask any questions they had about the study. In our intervention, there was no face-to-face correspondence with the research staff or other participants; rather, all communication was via text message (and online for baseline and follow-up surveys). Therefore, it is possible that incorporating an in-person or face-to-face component into our text message-based intervention may have increased participant interest/engagement and led to more
pronounced changes in sleep measures. In Trockel et al.’s (2011) study, the intervention was tailored to participants’ PSQI responses at baseline, where those who were classified as good sleepers at baseline received a condensed version of the online program. In our study, text messages were not tailored to participants’ baseline sleep habits, which may have led participants to perceive text messages as not being individualized or personally relevant to their current habits/practices. Another component of Trockel et al.’s (2011) intervention that may have contributed to its success was encouraging participants to apply the sleep education strategies taught in the intervention through activities such as keeping sleep logs, which was also done in Prestwich et al.’s (2007) intervention. Referring to Table 1, one of the sample text messages for the sleep/physical activity group (i.e., Day 2 Pre-Quit) encouraged participants to keep a sleep log to track their sleep habits, which may have led participants (especially those classified as short sleepers or poor sleepers) in our study, Prestwich et al.’s (2007) study, and Trockel et al.’s (2011) study to become more aware of their sleep habits and, in turn, motivated to improve such habits. It should be noted, however, that researchers in our study and Trockel et al.’s (2011) study did not assess or monitor whether participants kept a sleep log. Interestingly, duration of the intervention did not appear to contribute to the effectiveness of the intervention on producing behaviour change. For example, some of the interventions that demonstrated significant changes in sleep quantity and/or quality were as brief as a 30-minute oral presentation (Brown et al., 2006; Clark, 2010), while the longest intervention took place over an 8-week period (Trockel et al., 2011). Therefore, it does not appear that our 6-week intervention was too short to observe significant improvements in sleep measures.

Comparing our results to the four studies that were not found to be effective in improving sleep measures, there are some key factors that may explain why significant results were not
observed. First, when participants in Lamberti’s (2012) study reported how often they read the educational sleep program emails, only 64% of participants indicated that they consistently read the emails (another 32% indicated that they read the emails sometimes). This finding suggests that it is possible that behaviour change did not occur because a sizeable proportion of the sample was not receiving the full dose of the intervention. In our study, there was no way of knowing whether participants opened the texts that were sent to their mobile phones; however, process data reported in Ybarra et al’s (2013) manuscript indicated that 20% of sleep/physical activity participants reported somewhat agreeing or strongly agreeing when asked if they stopped reading the text messages by the end of the program. Therefore, had more participants read all of the text messages in our study, we may have observed more meaningful changes in sleep measures. Second, Lamberti (2012) also pointed out that missing sleep quality data greatly reduced the number of surveys available for analysis in her study which, in turn, reduced the amount of statistical power available to detect significant treatment effects. Similarly, in our study, 35 participants did not complete follow-up surveys and were subsequently excluded from the analysis (in addition to 4 individuals who were classified as sleep outliers, based on unrealistic responses to sleep quantity items), which would have reduced the amount of statistical power in our study. Considering the lack of meaningful changes observed from baseline to follow-up among the sleep measures examined in our study, however, statistical power was likely not a primary concern. Third, in Tsai and Li’s (2004a) study, large standard deviations for some of the sleep variables indicated a high amount of variability in the data, which may have reduced the amount of statistical power available to detect significant treatment effects (Mullineaux, 2008). Similarly, we observed large variability in sleep quality and sleep hygiene scores at both baseline and 12-week follow-up. This may partially explain why our sleep quality
findings were not significant, especially considering that levels of variability in our data and Tsai
and Li’s (2004a) appeared to be higher when compared to the other sleep intervention studies.
Having a larger sample size or better measures of sleep quality and sleep hygiene would have
helped to reduce this variability.

Some additional explanations for our findings may relate to challenges of changing sleep
habits among adults in this life stage, our measures, and our intervention delivery. First, it is
likely easier for young adults to modify their sleep quantity on work/school nights, since non-
work/non-school nights typically coincide with the weekend. For many young adults, especially
those attending college or university, weekends are a time to go out and engage in other social
activities, which tend to take precedence over getting sufficient sleep. Second, unless meaningful
improvements in sleep quantity on non-work/non-school nights occur in tandem with
improvements in sleep quantity on work/school nights, sleep quantity variability will not
meaningfully change. Therefore, it is not surprising that we did not observe any significant
improvements on sleep quantity variability, given our intervention did not appear to
meaningfully change sleep quantity on non-work/non-school nights. Third, although we used
items from valid and reliable scales to measure sleep quality and sleep hygiene in our study, the
fact that we did not use the full measures (i.e., the PSQI for sleep quality and the SHI for sleep
hygiene) and calculated scores for these sleep variables in a different manner may also explain
why we were unable to replicate results from studies that found significant improvements in
sleep quality. For example, we did not include PSQI items assessing subjective ratings of overall
sleep quality, how often participants relied on sleep medications to get to sleep, daytime
sleepiness, enthusiasm to complete daily tasks, and usual bedtime/wake time (which is compared
to actual sleep time to calculate sleep latency and sleep efficiency). When examining sleep
hygiene, we did not include items assessing frequency of exercising in close proximity to bedtime, frequency of staying in bed longer than usual at least a couple times per week, frequency of sleeping on an uncomfortable bed, and frequency of taking daytime naps lasting at least two hours. Lastly, the intervention content delivered via text message in our study was very brief in comparison to the other sleep interventions, which limited the amount of information that could be delivered at once (i.e., text messages primarily consisted of simple tips). Furthermore, not all of the text messages sent to participants in the sleep/physical activity group targeted sleep habits (i.e., some messages focused on improving physical activity habits). Thus, it is possible that participants did not receive an adequate amount of education regarding sleep and its benefits to motivate behaviour change.

7.1.2 Effectiveness of Text Message-Based Health Behaviour Change Interventions

To the extent of our knowledge, 13 studies have examined the effect of text message-based interventions on improving health behaviours as a means of preventive healthcare (Armstrong et al., 2009; Free et al., 2011; Haapala et al., 2009; Haug et al., 2009; Hurling et al., 2007; Joo & Kim, 2007; Khokar, 2009; Newton et al., 2009; Obermayer et al., 2004; Patrick et al., 2009; Rodgers et al., 2005; Shapiro et al., 2008; Stockwell et al., 2012). Overall, the literature suggests that text message-based interventions are effective in producing statistically significant improvements in a multitude of health behaviours, including smoking (Free et al., 2011; Obermayer et al., 2004; Rodgers et al., 2005), diet (Haapala et al., 2009), screen time (Shapiro et al., 2008), physical activity (Haapala et al., 2009; Hurling et al., 2007), sunscreen use (Armstrong et al., 2009), BSE (Khokar, 2009), and vaccination against disease (Stockwell et al., 2012). Studies by Joo and Kim (2007) and Patrick et al. (2009) targeting dietary and physical activity habits were successful in effecting weight loss among participants, however, changes in
dietary and physical activity habits were not measured in the studies. Only two intervention studies (Haug et al., 2009; Newton et al., 2009) were not found to be effective in significantly improving the targeted health behaviour(s), however, both studies were underpowered and may not have been able to detect statistically significant between-groups treatment effects. In the current study, a text message-based intervention aimed at improving sleep and physical activity habits was not found to be effective in improving sleep measures when analyzing the sample as a whole; however, when assessing intervention effects separately for short sleepers and adequate sleepers, we found that receiving text messages aimed at improving sleep and physical activity habits was associated with statistically significant improvements in sleep quantity on work/school nights among short sleepers. This finding suggests that we may need to focus on targeting short sleepers and address the root causes of their short sleep.

Comparing our intervention to other text message-based health behaviour interventions in the literature, there are multiple factors that may account for differences in findings. First, the number of health behaviours being targeted in text message-based interventions varied across studies, ranging from a single health behaviour in most studies (Armstrong et al., 2009; Free et al., 2011; Hurling et al., 2007; Khokar, 2009; Obermayer et al., 2004; Rodgers et al., 2005; Stockwell et al., 2012) to three health behaviours (Shapiro et al., 2008). Those interventions that were not found to be successful in producing meaningful changes in the targeted health behaviours (Haug et al., 2009; Newton et al., 2009) both targeted only one health behaviour. In the current study, our intervention targeted two health behaviours – namely, sleep and physical activity. Although it did not appear that targeting multiple health behaviours simultaneously reduced the efficacy of the intervention in producing behaviour change, it could be argued that (a) focusing more on sleep content in our intervention text messages and (b) reducing the
complexity of the behaviour change messages may have led to greater improvements in sleep habits among our sample.

Second, the frequency with which text messages were delivered to intervention participants varied considerably across studies, ranging from one message per month (Khokar, 2009) to 5 texts per day (Free et al., 2011; Patrick et al., 2009; Rodgers et al., 2005). Among those interventions that were not found to be successful in improving targeted health behaviours, intervention group participants received text messages once per week (Newton et al., 2009) or 1 to 3 times per week (Haug et al., 2009). In some interventions, including most of those focusing on smoking cessation (Free et al., 2011; Obermayer et al., 2004; Rodgers et al., 2005), the frequency of text message delivery fluctuated throughout the program (e.g., the frequency of text messages increased as one approached his/her identified quit date). In other interventions, participants were given the flexibility of choosing how often text messages were delivered to their mobile phones (Haapala et al., 2009; Patrick et al., 2009), the timing of text message delivery (Obermayer et al., 2004; Patrick et al., 2009), and whether they wished to receive additional text message reminders (Hurling et al., 2007). In two of the interventions, text messages were not initiated by the research program but, rather, by the participants themselves, who would then receive an automated text message response (Haapala et al., 2009; Shapiro et al., 2008). Similar to those interventions focused on smoking cessation, the frequency with which text messages were delivered to participants in our study fluctuated throughout the program, with participants receiving up to 9 texts on their quit day and first post-quit day. Since this frequency is much higher than what was reported in other health behaviour interventions, it is possible that receiving so many text messages may have been somewhat of an annoyance or disturbance to participants in our study, reducing the likelihood of participants continuing to read the messages.
for the remainder of the program. As mentioned earlier, approximately 20% of participants in our intervention stated that they stopped reading the text messages by the end of the intervention.

Third, duration of the text messaging interventions differed across studies, ranging from six weeks (Armstrong et al., 2009; Obermayer et al., 2004) to one year (Haapala et al., 2009). Among those interventions that were not found to be successful in improving targeted health behaviours, the text messaging programs were 3 months in duration (Haug et al., 2009; Newton et al., 2009). In Stockwell et al.’s (2012) intervention, participants stopped receiving text messages as soon as the targeted health outcome was achieved (i.e., influenza vaccination). Comparing the intervention period in our study to those in the existing literature, our 6-week intervention period appears to be one of the shorter interventions. Therefore, it is possible that extending the length of the text messaging program in our study could have allowed more time for behaviour change to occur.

Fourth, content of the text messages varied across interventions and also within interventions. For example, all but two of the interventions (Hurling et al., 2007; Khokar, 2009) delivered more than one type of text message to participants, including combinations of educational, motivational/supportive, and reminder messages, in order to facilitate behaviour change. In many cases, content was tailored to each individual, based on responses to baseline measures (Free et al., 2011; Haug et al., 2009; Hurling et al., 2007; Obermayer et al., 2004; Rodgers et al., 2005; Stockwell et al., 2012). In addition to tailoring intervention content to participants’ baseline responses, in Obermayer et al.’s (2004) smoking cessation intervention, timing of text message delivery was also tailored so that participants received messages timed to high-risk situations that were identified at baseline (i.e., if participants typically craved a cigarette upon waking in the morning, a text message would be delivered at the participant’s
usual wake time). Although our study incorporated both educational messages (i.e., in the form of tips and strategies for improving sleep habits) and motivational/supportive messages, we did not tailor content to participants’ baseline sleep habits. It is plausible that some participants, especially those with good sleep habits at baseline, may have found that the content was not relevant or did not apply to them if they were already performing the suggested behaviours. Therefore, tailoring content of the sleep text messages to baseline sleep habits assessed in the baseline survey would have been more efficient and helpful for participants (especially good sleepers) in terms of identifying what sleep habits needed improving. In addition, similar to the tailoring method used in Obermayer et al.’s (2004) intervention, including a question in the baseline survey asking participants to indicate what time they usually went to bed on work/school nights and non-work/non-school nights and tailoring the intervention so that text messages were delivered shortly before each participant’s bedtime may have been more effective in delivering content to participants right when they needed it.

Fifth, similar to tailoring intervention content to participants’ current habits, about half of the intervention studies that we examined provided feedback to participants throughout the intervention program, based on self-reported behaviours or progress toward health behaviour goals (Haapala et al., 2009; Haug et al., 2009; Hurling et al., 2007; Obermayer et al., 2004; Patrick et al., 2009; Stockwell et al., 2012). In our study, participants did not report their sleep habits to the researchers throughout the program, nor did they receive any feedback on their sleep habits or where their sleep habits were in relation to the national sleep recommendations. Therefore, inclusion of a feedback component may have acted as additional motivation for participants to improve their sleep habits and provided participants with more timely estimates of behaviour change.
Lastly, in the majority of studies (Armstrong et al., 2009; Haapala et al., 2009; Hurling et al., 2007; Joo & Kim, 2007; Khokar, 2009; Obermayer et al., 2004; Patrick et al., 2009; Shapiro et al., 2008), text messaging was not the only component of the intervention. Other intervention elements included website or email (Haapala et al., 2009; Hurling et al., 2007; Obermayer et al., 2004), in-person visits or individual/group training on health behaviours (Armstrong et al., 2009; Joo & Kim, 2007; Khokar, 2009; Shapiro et al., 2008), printed materials (Joo & Kim, 2007; Patrick et al., 2009), and phone calls (Patrick et al., 2009). In our study, as well as the two interventions that were not found to be successful in improving targeted health behaviours (Haug et al., 2009; Newton et al., 2009), text messaging was the only component used to deliver intervention content to participants. Therefore, the addition of different information delivery channels may have provided more support for participants to achieve behaviour change in these interventions, which parallels our finding that the addition of an in-person intervention component may be helpful in producing more meaningful changes in behaviour.

7.2 Comparison of Secondary Objective Findings to the Literature

Recent research examining the impact of sleep on weight outcomes in all age groups suggests that a direct association exists between these two variables, pinpointing sleep as a potential modifiable risk factor for the development of obesity (e.g., Hasler et al., 2004). Although a great deal of research has examined potential associations between sleep quantity and BMI/obesity risk (for a recent review, see Patel & Hu, 2008), less work has been done on examining potential associations between sleep quantity variability and BMI/obesity risk, as well as sleep quality and BMI/obesity risk. Given these gaps in the existing literature, we were interested in whether cross-sectional and longitudinal associations between sleep measures (i.e., sleep quantity, sleep quantity variability, and sleep quality) and BMI that have been found in the
literature among samples of children, adolescents, and adults could be replicated when exclusively examining a sample of young adults between the ages of 18 and 25 years who were trying to quit smoking. In order to assess the clinical significance of potential associations between sleep measures and BMI, we were also interested in determining whether sleep measures were associated with weight status. This is particularly important because obesity in young adulthood is associated with many adverse health consequences including reduced psychological well-being (PHAC, 2011; Puhl & Heuer, 2010) and increased risk for the development of chronic disease in later adulthood (PHAC, 2011).

7.2.1 Sleep Quantity

Sleep quantity was assessed using separate self-reported measures of sleep quantity on work/school nights and non-work/non-school nights, in order to gain a complete picture of participants’ usual sleep quantity habits. When examining potential associations between sleep measures and BMI in the linear regression analyses, we hypothesized that greater sleep quantity (on both work/school nights and non-work/non-school nights) at baseline would be associated with lower BMI at baseline (in the cross-sectional models) and that increases in both measures of sleep quantity from baseline to follow-up would be associated with lower BMI at follow-up (in the longitudinal models). When examining potential associations between sleep measures and weight status in the logistic regression analyses, we hypothesized that greater sleep quantity (on both work/school nights and non-work/non-school nights) at baseline would be associated with decreased odds of being overweight/obese at baseline (in the cross-sectional models) and that increases in both measures of sleep quantity from baseline to follow-up would be associated with decreased odds of being overweight/obese at follow-up (in the longitudinal models).
In general, most of the associations between sleep quantity and adiposity measures in our sample were not found to be statistically significant. We did, however, find a significant cross-sectional association between sleep quantity on non-work/non-school nights and BMI at baseline in the linear regression analyses, indicating that greater sleep quantity on non-work/non-school nights at baseline was associated with lower BMI at baseline. This association, however, was no longer significant after adjusting for baseline physical activity level, number of cigarettes smoked per day at baseline, sex, educational attainment/current post-secondary enrollment, and race. When examining results for the logistic regression models, similar to the results from our linear regression analyses, we only found a significant cross-sectional association between sleep quantity on non-work/non-school nights and odds of being overweight/obese at baseline, indicating that greater sleep quantity on non-work/non-school nights at baseline was associated with lower odds of being overweight/obese at baseline. This significant association remained robust after adjusting for baseline physical activity level, number of cigarettes smoked per day at baseline, sex, educational attainment/current post-secondary enrollment, and race.

The literature examining the relationship between sleep quantity and BMI/obesity risk suggests that there is an association between these variables; however, there is less consensus on the nature of this association (Patel & Hu, 2008). In a review by Patel and Hu (2008), results from 20 cross-sectional and 5 prospective cohort studies examining the association between sleep quantity and BMI/obesity risk were analyzed. Of the 20 adult cross-sectional studies included in Patel and Hu’s (2008) review, the majority found a linear relationship between sleep quantity and BMI/obesity risk (Bjorkelund et al., 2005; Cournot et al., 2004; Heslop, Smith, Metcalfe, Macleod, & Hart, 2002; Ko et al., 2007; Kohatsu et al., 2006; Kripke, Garfinkel, Wingard, Klauber, & Marler, 2002; Moreno, Louzada, Teixeira, Borges, & Lorenzi-Filho, 2006;
Ohayon & Vecchierini, 2005; Shigeta et al., 2001; Singh, Drake, Roehrs, Hudgel, & Roth, 2005; Tamakoshi & Ohno, 2004; Vioque, Torres, & Quiles, 2000; Vorona et al., 2005), either indicating that short sleep is inversely associated with BMI/obesity risk, or that total sleep is inversely associated with BMI/obesity risk. More recent research conducted by Moraes et al. (2013) using objective measures of sleep quantity supports these cross-sectional findings. Interestingly, one of the studies reporting a linear association found that short sleep (≤ 4 hours) was associated with lower BMI, although differences in BMI between the shortest and longest sleepers were exceptionally small (i.e., differed by less than 1 kg/m²; Tamakoshi & Ohno, 2004).

Our finding that shorter baseline sleep quantity on non-work/non-school nights was significantly associated with both higher BMI at baseline and increased odds of being overweight/obese at baseline is therefore consistent with what has been reported in the majority of studies on this topic, although no studies to date have examined potential associations between sleep quantity and BMI/obesity risk separately for sleep quantity on work/school nights and non-work/non-school nights. Three studies examined in Patel and Hu’s (2008) review asked respondents to report separate estimates for usual sleep quantity on weekdays and weekend days; however, these responses were combined into a single weighted estimate of sleep quantity instead of being analyzed separately (Gottlieb et al., 2006; Singh et al., 2005; Vorona et al., 2005). Therefore, it is possible that sleep obtained on non-work/non-school nights or weekend nights may account more for the association observed between sleep quantity and BMI/obesity risk in those studies that did not differentiate between the two measures of sleep quantity, which would have been impossible to determine when a single measure of sleep quantity was used.

A smaller number of studies in Patel and Hu’s (2008) review reported no association between total or short sleep quantity and BMI/obesity risk (Amagai et al., 2004; Gortmaker et
al., 1990; Lauderdale et al., 2006; Ohayon, 2004; Ohayon & Vecchierini, 2005). Examining these studies that found a null association (with the exception of Gortmaker et al.’s (1990) study, which we were unable to access), there are a few explanations for why our results may have differed from these findings. Although sample sizes appeared to be sufficient in these studies (ranging from 669 subjects in Lauderdale et al.’s (2006) study to 11,325 subjects in Amagai et al.’s (2004) study), most of these studies were conducted in locations outside of North America, including rural Japan (Amagai et al., 2004), seven countries across Europe (Ohayon, 2004), and France (Ohayon & Vecchierini, 2005). Therefore, these findings may not be generalizable from a geographic perspective, considering that our study was conducted in the United States. Second, in terms of participant characteristics in those studies finding no associations, Ohayon (2004) and Ohayon and Vecchierini (2005) only included older adults in their study samples. It has been reported in the literature that the association between sleep quantity and BMI tends to wane with age, which may account for the null associations observed in these two studies (e.g., Patel & Hu, 2008). Lastly, Lauderdale et al.’s (2006) study was the only study in Patel and Hu’s (2008) review that assessed sleep quantity using objective measures (i.e., actigraphy over a 72-hour period, including two weeknights and one weekend night), which has been found to be more accurate than self-reported measures. Thus, it is possible that differences in the measurement of sleep quantity (i.e., objective versus subjective) may account for the differences in findings.

In addition to finding a linear association or no association between sleep quantity and BMI, some studies in Patel and Hu’s (2008) review have reported a U-shaped association between sleep quantity and BMI/obesity risk (Chaput et al., 2007; Gottlieb et al., 2006; Kripke et al., 2002; Taheri et al., 2004). In our study, we were not able to divide our sample into more than two groups based on sleep quantity category at baseline (i.e., short sleepers, normal sleepers, and
long sleepers) due to our small study sample, which precluded our ability to examine whether a U-shaped association existed between sleep quantity and adiposity measures. Therefore, additional studies comparing adiposity measures between short, normal, and long sleepers are needed to obtain more insight into the nature of the association between sleep quantity and BMI/obesity risk among young adults.

Interestingly, three of the cross-sectional studies examined in Patel and Hu’s (2008) review found gender differences in the association between sleep quantity and BMI/obesity risk, with one study finding an inverse linear association between short sleep and BMI in men, but not women (Heslop et al., 2002), one finding an inverse linear association between short sleep and BMI in men, but a U-shaped association in women (Kripke et al., 2002), and another study finding an inverse linear association between short sleep and BMI in women, but not in men (Cournot et al., 2004). In addition, recent research by Meyer et al. (2012) found similar results to Heslop et al. (2002), where sleep quantity was shown to be inversely associated with BMI among males, but not females. In our study, however, no gender differences were found in the association between sleep quantity and BMI, which may have happened for a few reasons. First, in contrast to the relatively equal proportion of males and females in our study sample, Heslop et al.’s (2002) study sample included almost six times the amount of males compared to females (i.e., 6,022 males versus 1,006 females). Therefore, statistically significant results may have been observed among males merely as a consequence of the large number of males in Heslop et al.’s (2002) sample. When examining mean BMI values across sleep categories among males, Heslop et al.’s (2002) finding that males who slept less than 7 hours per night, 7 to 8 hours per night, and more than 8 hours per night had mean BMIs of 25.4 kg/m², 25.1 kg/m², and 25.1 kg/m², respectively, demonstrates that this statistically significant association may not be clinically
significant. Second, both Cournot et al. (2004) and Heslop et al. (2002) recruited participants from the workplace in select European regions. Therefore, because cultural and geographic differences likely exist between Europeans and North Americans, it is possible that these findings may not generalize to our sample of American young adults. For example, it is customary for individuals in many European regions to eat dinner very late in the evening which may, in turn, delay bedtime and decrease habitual sleep duration. In addition, geographic differences in the prevalence of overweight and obesity (i.e., when comparing rates reported in the United States to those reported in Europe) may account for observed differences in findings when examining the association between sleep quantity and adiposity (e.g., the prevalence of directly measured overweight and obesity was 42% in Cournot et al.’s (2004) study on European adults, compared with the 62% estimate for American adults that was based on directly measured BMI data from the 2009-2010 NHANES; Flegal et al., 2012). Third, in Kripke et al.’s (2002) study where an inverse association was found between sleep quantity and BMI among men and a U-shaped association was found among women, the remarkably large confidence interval observed for women sleeping at least 10 hours per night (who comprised the right-most side of the U-shaped distribution) indicated large variability in BMI among the longest female sleepers. Therefore, if the true value of BMI fell at the low end of the confidence interval, the association would appear more linear in nature. Lastly, with respect to Meyer et al.’s (2012) finding that sleep quantity and BMI were inversely associated among males, but not females, the authors acknowledged that males and females in their sample appeared to have different covariate distributions, where it was found that adjusting for a variety of covariates generally attenuated effect estimates among women, but not men (Meyer et al., 2012).
Examining the 5 prospective cohort studies conducted among samples of adults in Patel and Hu’s (2008) systematic review, results were unanimous in that short sleep duration was found to be associated with increased risk for overweight/obesity, when both self-reported and objective measures of BMI were used (Agras, Hammer, McNicholas, & Kraemer, 2004; Gangwisch et al., 2005; Hasler et al., 2004; Patel et al., 2006; Reilly et al., 2005). More recent studies, however, have yielded mixed results, with some demonstrating an inverse association (Kobayashi et al., 2012; Patel et al., 2006), some demonstrating a U-shaped association (Chaput et al., 2008; Watanabe et al., 2010), and others demonstrating no longitudinal association between sleep duration and BMI or weight gain over time (Gangwisch et al., 2005; Lauderdale et al., 2009; Stranges et al., 2007). Comparing results from our study to these longitudinal findings, it is highly plausible that we did not observe any statistically significant longitudinal associations between sleep quantity and BMI or weight status simply because our follow-up period (i.e., 12 weeks) was not long enough to observe meaningful changes in both sleep quantity and adiposity. For example, follow-up periods in the literature ranged from one year (Watanabe et al., 2010) to 16 years (Patel et al., 2006), which would have allowed for the observation of longer term changes in these measures. When examining the three studies that did not find a significant longitudinal association between sleep quantity and weight gain over time, it is possible that the objective sleep measures used in Lauderdale et al.’s (2006) study and the older (in terms of mean age) samples used in Gangwich et al.’s (2006) and Stranges et al.’s (2007) studies may have accounted for differences in findings.

7.2.2 Sleep Quantity Variability

Sleep quantity variability was assessed by subtracting self-reported sleep quantity on work/school nights from sleep quantity on non-work/non-school nights. When examining
potential associations between sleep measures and BMI in the linear regression analyses, we hypothesized that lower sleep quantity variability at baseline would be associated with lower BMI at baseline (in the cross-sectional models) and that reductions in sleep quantity variability from baseline to follow-up would be associated with lower BMI at follow-up (in the longitudinal models). When examining potential associations between sleep measures and weight status in the logistic regression analyses, we hypothesized that lower sleep quantity variability at baseline would be associated with decreased odds of being overweight/obese at baseline (in the cross-sectional models) and that reductions in sleep quantity variability from baseline to follow-up would be associated with decreased odds of being overweight/obese at follow-up (in the longitudinal models).

Contrary to our hypotheses, we did not find any statistically significant cross-sectional or longitudinal associations between sleep quantity variability and BMI, or sleep quantity variability and weight status in our study. The literature examining the relationship between sleep quantity variability and BMI/obesity risk unanimously suggests that there is a positive association between these two variables, when examined both cross-sectionally (Kjeldsen et al., 2014; Patel et al., 2014; Spruyt et al., 2011) and longitudinally (Kobayashi et al., 2013) across different population groups ranging from children (Kjeldsen et al., 2014; Spruyt et al., 2011) to older adults (Patel et al., 2014). In three of the four examined studies (Kjeldsen et al., 2014; Kobayashi et al., 2013; Patel et al., 2014), the association between sleep quantity variability and BMI/obesity risk was found to be independent of sleep duration, suggesting that variability in sleep quantity is a risk factor for obesity in and of itself. It is possible that we did not observe any significant associations between sleep quantity variability and BMI or weight status for a few reasons. First, the sample size relating to the secondary objective in our study (n = 96) was
considerably smaller than that of other studies in the literature, which ranged from 308 participants in Spruyt et al.’s (2011) study to 12,900 participants in Kobayashi et al.’s (2013) study. Therefore, it is plausible that we did not observe significant results because we may have had less statistical power to detect significant effects, in comparison to the other studies. Second, three of the four studies examining the association between sleep quantity variability and BMI/obesity risk used objective measures of sleep quantity variability, derived from actigraphy (Patel et al., 2014; Spruyt et al., 2011) or a combination of actigraphy and sleep logs (Kjeldsen et al., 2014). Since sleep data in our study was self-reported and participants were asked to report their sleep quantity on work/school nights and non-work/non-school nights over the past month, potential recall error or social desirability bias among participants in our sample may have affected our findings. For example, some participants may have over-reported sleep quantity to portray themselves as more healthy/socially desirable to the researchers, but it is also possible that some participants may have underreported sleep quantity if they perceived it was the norm to get little sleep. Third, none of the above studies included young adults (i.e., individuals between the ages of 18 and 25 years) in their study samples. Therefore, it is possible that the association between sleep quantity variability and BMI/obesity risk varies with age, and is more pronounced among children and middle-aged/older adults, similar to how the association between sleep quantity and BMI has been found to be stronger in children (e.g., Patel & Hu, 2008). Lastly, when examining results from longitudinal analyses, the extent to which changes in sleep quantity variability and weight outcome measures occurred among participants would have impacted the results. Although changes in these variables were not reported in the one longitudinal study conducted by Kobayashi et al. (2013), the mean change for sleep quantity variability from baseline to follow-up in our sample was 0, and the mean change in BMI within
our sample was also very small (i.e., 0.26 kg/m$^2$). Therefore, it is not surprising that we did not observe significant longitudinal associations between sleep quantity variability and adiposity measures in our study, which may have, in part, been due to the short follow-up period in our study.

### 7.2.3 Sleep Quality

In the current study, sleep quality was separated into “sleep quality” and “sleep hygiene”. Sleep quality was assessed using 8 items adapted from the PSQI and was then quantified into a sleep quality score by coding the response options with numbers and summing participants’ responses to the items. Sleep hygiene was assessed using 9 items adapted from the SHI and was then quantified into a sleep hygiene score by coding the response options with numbers and summing participants’ responses to the items. When examining potential associations between sleep measures and BMI in the linear regression analyses, we hypothesized that better sleep quality (i.e., lower sleep quality scores) at baseline would be associated with lower BMI at baseline (in the cross-sectional models) and that improvements in sleep quality (i.e., decreases in sleep quality scores) from baseline to follow-up would be associated with lower BMI at follow-up (in the longitudinal models). When examining potential associations between sleep measures and weight status in the logistic regression analyses, we hypothesized that better sleep hygiene (i.e., lower sleep hygiene scores) at baseline would be associated with decreased odds of being overweight/obese at baseline (in the cross-sectional models) and that improvements in sleep hygiene (i.e., decreases in sleep hygiene scores) from baseline to follow-up would be associated with decreased odds of being overweight/obese at follow-up (in the longitudinal models).
Contrary to our hypotheses, we did not find any statistically significant cross-sectional or longitudinal associations between sleep quality/sleep hygiene and BMI, or sleep quality/sleep hygiene and weight status in our study. Cross-sectionally, our findings are in contrast to what has been found in the majority of studies examining the cross-sectional association between sleep quality and BMI/obesity risk, which collectively suggest that an inverse association exists between these two variables (Chen et al., 2013; Meyer et al. 2012; Pearson et al., 2006; Resta et al., 2003; Tworoger et al., 2005; Yeh & Brown, 2014). Conversely, our results were consistent with a study by Mota and Vale (2010), who did not find a significant association between sleep quality and BMI among adolescent girls. It can be argued, however, that the single self-reported measure of sleep quality (i.e., “In general, how is your sleeping time”) used by Mota and Vale (2010) did not provide an accurate picture of one’s sleep quality in comparison to the more detailed measures used in other studies, and the fact that Mota and Vale’s (2010) study sample was only comprised of female adolescents further limits the generalizability of these findings.

It is possible that we did not observe any significant cross-sectional associations between sleep quality/sleep hygiene and adiposity measures for a couple of reasons. First, definitions of sleep quality varied widely across studies, with some researchers using very general, single measures of sleep quality (i.e., “In general, how is your sleeping time” in Mota and Vale’s (2010) study) and other researchers using full valid and reliable indices assessing several domains of sleep quality (i.e., the PSQI in Yeh and Brown’s (2014) study). Although Yeh and Brown (2014) used the same index that was used to assess sleep quality in our study, we only used some of the items from the PSQI, which may account for differences in findings. Therefore, the lack of consistency in defining sleep quality in the literature hinders our ability to accurately compare findings across studies. Second, variability in sleep quality within each study sample
may have impacted the observed results. Although Yeh and Brown (2014) found significant results when using continuous PSQI scores in their analyses, the standard deviations observed for baseline sleep quality and sleep hygiene scores in our study were noticeably larger, compared to sleep quality scores in Yeh and Brown’s (2014) study.

The two studies that have explored potential longitudinal associations between sleep quality and obesity/weight gain over time have yielded mixed results, with one study showing no significant association (Hasler et al., 2004), similar to what was found in the current study, and another showing an inverse association, but only among females (Lyytikainen et al., 2011). Comparing our findings to those of Lyytikainen et al. (2011), it is possible that we did not find a significant longitudinal association between sleep quality and adiposity measures for a few reasons. First, participants in Lyytikainen et al.’s (2011) study were recruited from a single city in Finland, which may not be generalizable to our nationally representative American sample of young adults. Second, similar to Heslop et al.’s (2002) study, there were large differences in the proportion of males and females in Lyytikainen et al.’s (2011) study (i.e., 5,723 females versus 1,299 males). Therefore, statistically significant results may have been observed among females merely as a consequence of the larger number of females in Lyytikainen et al.’s (2011) sample, which is possible considering that differences in the prevalence of excessive weight gain (i.e., gain of 5 lbs or more) between sexes appeared to be modest. Lastly, similar to the other sleep measures, it is highly plausible that we did not observe any statistically significant longitudinal associations between sleep quality/sleep hygiene and BMI or weight status simply because our follow-up period (i.e., 12 weeks) was not long enough to observe meaningful changes in these variables, compared to the 5- to 7-year follow-up period in Lyytikainen et al.’s (2011) study.
7.3 Contribution to the Literature

Although findings from the literature on sleep interventions demonstrate evidence of behaviour change, even when receiving as little as 30 minutes of sleep education (Brown et al., 2006; Clark, 2010), all studies to date have been conducted exclusively using samples of post-secondary students. Therefore, these studies neglect to provide insight into whether findings can be generalized to the broader population of young adults, including those not enrolled in post-secondary education. In addition, none of the studies in the literature on text message-based interventions have targeted sleep as a health behaviour, nor have any of the studies on sleep interventions examined potential intervention effects on weight outcomes. Given the heavy usage of mobility phone technology among young adults and the well-established body of literature identifying sleep as one of several modifiable risk factors for obesity, using a text message-based intervention aimed at improving sleep quantity and quality may be a promising approach for improving sleep habits among this population and, in turn, a novel approach for obesity prevention.

The current study builds on the growing body of literature on sleep, obesity, and health behaviour change interventions by providing preliminary evidence that a text message-based sleep intervention may be a promising approach for improving sleep habits among the broader population of young adults, especially those who are short sleepers. Our lack of significant findings among those individuals classified as adequate sleepers at baseline suggests that future sleep interventions may want to tailor the content of text messages based on responses to baseline sleep survey questions, in order to ensure that the content being delivered to individuals is personally relevant. In addition, our finding that sleep quantity on non-work/non-school nights (but not sleep quantity on work/school nights) was cross-sectionally associated with weight
status in our sample suggests that future obesity prevention and treatment interventions may want to tailor sleep intervention content separately for work/school nights and non-work/non-school nights to maximize the impact of such interventions on reducing obesity rates.

7.4 Limitations

There are several limitations that should be kept in mind when interpreting results from our study. First, our study was a secondary data analysis that used data from a text message-based smoking cessation intervention conducted in the United States. As such, assessment of the variables of interest (i.e., sleep and adiposity) was not optimal. For example, although the survey items used to measure sleep quality and sleep hygiene were adapted from valid and reliable indices (i.e., the PSQI for sleep quality and the SHI for sleep hygiene), the full indices were not used. Therefore, it is unknown whether the adapted indices in the current study are valid and reliable measures of sleep quality and sleep hygiene. Furthermore, the items from the full indices that were dropped in the adapted versions would have provided additional information regarding sleep habits and would also have allowed us to classify participants into good sleepers and poor sleepers (sleep quality; PSQI) and having good, moderate, or poor sleep hygiene (sleep hygiene; SHI) based on established cut-points. Similar to the analyses we ran for short sleepers and adequate sleepers, using the full PSQI and SHI would have allowed us to examine baseline sleep quality category and baseline sleep hygiene category as potential effect modifiers to determine whether the intervention had differential effects according to individuals’ baseline sleep habits.

Second, all of the data in the current study were self-reported, which raises the question of whether such data are valid (Barker, Pistrang, & Elliott, 2002). For example, when completing the survey questions assessing sleep quantity and quality, participants were asked to think about
their sleep habits over the past month. Therefore, the accuracy of participants’ responses may have been affected by recall error when having to estimate how they slept, on average, over the past 30 nights. Furthermore, arriving at an accurate estimate of habitual sleep quantity would have been especially difficult for those individuals with high night-to-night variability in sleep quantity (Lauderdale, Knutson, Yan, Liu, & Rathouz, 2008). This is illustrated in a study by Lauderdale et al. (2008), who examined the extent to which self-reported measures of sleep quantity correlated with sleep quantity assessed using wrist actigraphy. These researchers found self-reported and objectively measured sleep quantity to be only moderately correlated ($r = 0.45$) within their sample, indicating a rather large discrepancy between the two methods of measurement (Lauderdale et al., 2008). In addition to recall error, social desirability bias may have also affected participants’ responses to the sleep items. As mentioned earlier, some participants may have over-reported sleep quantity/quality to portray themselves as more healthy/socially desirable to the researchers, but it is also possible that some participants may have underreported sleep habits if they perceived it was the norm to get little or poor quality sleep. Judging by the low mean sleep quantity reported by participants in our sample for work/school nights at baseline (i.e., 6 hours and 12 minutes), however, over-reporting did not appear to be an issue in our study. What did appear to be a major issue in our study, however, were responses to the item assessing participants’ weight. When comparing each participant’s self-reported weight at baseline to self-reported weight at 12-week follow-up, we found that a large proportion of the sample reported a substantial change in weight (i.e., gain or loss) over the 12-week study period, with one participant reporting a loss of 276 pounds. Evidently, this degree of weight change is not feasible given the short time frame and that the original study was in no way focused on weight loss, so we decided on a cut-point to identify those participants who were
outliers based on weight change. After examining the literature on smoking cessation and feasible weight change, we chose a weight change (i.e., gain or loss) cut-point of 35 pounds, which included a 5-pound buffer to account for any potential recall error that may have occurred when estimating weight. After applying this cut-point to the data in the analyses for our secondary study objective, 31 participants (i.e., 24% of the sample) were identified as weight change outliers and subsequently excluded from the analyses.

It is unclear why drastic changes in self-reported weight were observed among such a sizable proportion of our study participants. There is the possibility that input error may have occurred in some instances when participants completed the questionnaires online, and that differences in how participants weighed themselves at both time-points (e.g., the amount of clothing worn, whether weighing was done preprandially or postprandially) may have accounted for some of the variation, yet these factors would theoretically have a minimal impact on weight measurements. Therefore, a major limitation of the current study is that we cannot be sure how valid the weight data are within our sample which, in turn, puts into question the validity of participants’ BMI measures used in our secondary objective analyses. In the literature, one study conducted by Shields, Connor Gorber, and Tremblay (2008) attempted to quantify the bias emerging from self-reported height and weight measures (i.e., when compared to objectively measured height and weight) using a sample of 4,567 participants who took part in the 2005 CCHS. Although the discrepancies between self-reported and objective anthropometric measures did not appear to be substantial (i.e., on average, height was over-reported by 1 cm among males and 0.5 cm among females, and weight was under-reported by 1.8 kg among males and 2.5 kg among females), when calculating the prevalence of obesity within the sample using BMI derived from both sets of measurements, it was found that obesity prevalence estimates were 9
percentage points higher among males when using objectively measured BMI (compared with self-reported BMI), and 6 percentage points higher among females (Shields et al., 2008). These findings therefore illustrate the inaccuracies that can arise when using self-reported data. Because of the concern for bias arising from the use of self-reported measures, future studies should rely on more objective measures of sleep and weight-related parameters, in an effort to maximize the accuracy of study data and subsequent conclusions being drawn from the data.

Third, even when more precise objective measures are used to calculate BMI, this proxy measure for adiposity is not without its limitations. The most notable of these limitations is that BMI is a measure of excess body weight, not excess body fatness (Prentice & Jebb, 2001). As a result, individuals with a high proportion of lean body mass will be incorrectly classified as overweight or obese since this measure cannot differentiate between fat mass and fat-free mass. To illustrate the limitations of BMI in predicting body fatness, results from a study by Meeuwsen, Horgan, and Elia (2010) examining the relationship between BMI and body fatness (as measured by bioelectrical impedance) found that the association between these two variables was not strong. Specifically, Meeuwsen et al. (2010) found that, after adjusting for age, BMI explained 44% of the variation in body fat among males, and 58% of the variation in body fat among females. Furthermore, the association between BMI and body fatness appeared to be stronger at higher BMIs, with a relatively weak correlation being observed among the normal BMI group ($r = 0.21$; Meeuwsen et al., 2010). Given that mean baseline BMI in our sample was 26.0 kg/m$^2$ (i.e., only slightly above the normal range of 18.5 to 24.9 kg/m$^2$), it is quite possible that a noticeable proportion of individuals may have been incorrectly classified as overweight or obese based on BMI when, in fact, they were not. Although BMI offers a quick estimate of adiposity, future researchers may want to supplement such measurements with more direct
measures of body fatness, in order to increase the accuracy with which individuals are classified based on weight status.

A fourth limitation of our research was the high risk for residual confounding when examining physical activity. In the primary objective analyses, we controlled for physical activity to address concerns that intervention effects on sleep variables may, in part, be explained by changes in physical activity that occurred over the study period (as a result of also receiving text messages aimed at improving physical activity habits). In the analyses for our secondary objective, we also controlled for physical activity (i.e., baseline levels in the cross-sectional models and change in physical activity in the longitudinal models) to ensure that physical activity did not explain potential associations observed between sleep measures and adiposity, since it has been well documented in the literature that an inverse association exists between physical activity and adiposity (for a review see Rauner, Mess, & Woll, 2013). Although we adjusted for this variable, our assessment of usual physical activity habits was far from optimal. Specifically, we relied on participant reports of physical activity over the past month, which were separated according to type of physical activity (i.e., vigorous, light to moderate, strengthening/calisthenics). For the sake of simplicity, we chose to combine the three estimates of physical activity into a single physical activity item, measured in hours per week. Therefore, not only are these estimates of physical activity subject to potential recall error and social desirability bias, but it may also be possible that different types of physical activity have different effects on the relationship between sleep and adiposity, which would not have discernable in our study. This is illustrated in a study on 6- to 10-year old children by Ekstedt et al. (2013), who found that engaging in physical activity (specifically, MVPA) increased objectively measured sleep efficiency the following night.
Aside from concerns for residual confounding, there were a few variables that we did not measure in the current study that may have potentially confounded our results. First, participants in the study were permitted to use pharmacotherapy to aid in their smoking cessation attempt, some of which have been found in the literature to attenuate post-cessation weight gain (Parsons, Shraim, Inglis, Aveyard, & Hajek, 2013). Therefore, because we did not control for pharmacotherapy use in the current study, it is possible that this variable may have, to an extent, accounted for the observed relationships between some of the sleep measures and adiposity. Second, we did not have any data on dietary intake to allow us to control for this variable. In the literature, there is a growing body of evidence suggesting that short sleep duration/poor sleep quality is associated with increases in energy intake and decreases in dietary quality, both of which favour weight gain and put one at risk for becoming obese (Chaput, in press). This is the most widely accepted mechanism to date that explains how sleep and adiposity are related, so it is highly plausible that participants’ dietary intake may have explained adiposity levels at baseline and/or follow-up, independent of sleep habits. Despite this possibility, in Patel and Hu’s (2008) review of the literature on short sleep duration and weight gain, the authors found that controlling for caloric intake and/or dietary quality did not appear to attenuate observed relationships between sleep duration and BMI, which suggests that failing to control for this variable in the present study may not have meaningfully affected our results. Third, we did not have a clear measure of depression (either undiagnosed or clinical depression) in the current study, which precluded our ability to adjust for this variable. Specifically, items from the depression module of the Patient Health Questionnaire (PHQ-9; Spitzer, Kroenke, & Williams, 1999) were included in the baseline and follow-up surveys; however, wording of the PHQ-9 items was adapted from another measure, the Center for Epidemiologic Studies Depression Scale.
Revised (CESD-R; Eaton, Muntaner, Smith, Tien, & Ybarra, 2004). As a result, we were unable to use the scoring criteria from the PHQ-9 to classify participants’ degree of depression, since the wording of some items was altered. In the literature, there is a wealth of evidence to support that depression is associated with sleep quality/disturbances (for a review, see Thase, Murck, & Post, 2010), with up to 70% of individuals with depression suffering from insomnia or other sleep quality problems, and a far lesser proportion of depressed individuals experiencing hypersomnia (i.e., sleeping too much; Thase et al., 2010). The literature also suggests that when compared to non-depressed individuals, those individuals suffering from depression are at significantly higher risk for obesity (for a review, see Blaine, 2008). Therefore, it is possible that a high prevalence of depression within our sample may have influenced both the effect of the intervention on sleep measures, as well as the observed associations between sleep measures and BMI/risk of overweight/obesity in the current study.

Fifth, the length of follow-up in our study was relatively short (i.e., 12 weeks). Thus, our study period may have been temporally inadequate to observe meaningful changes in adiposity. Therefore, future studies should focus on using longer follow-up periods – perhaps examining changes over a 1-year period – to determine whether more meaningful changes in adiposity (i.e., increases or decreases) occur after the intervention concludes.

Sixth, the large number of individuals who did not complete follow-up data (n = 35) and who were excluded from the secondary objective analyses after being classified as a weight change outlier (n = 31) drastically reduced our analytical sample in the current study (i.e., n = 129 in the primary objective analyses and n = 96 in the secondary objective analyses). Although it is more plausible that we did not observe significant results in the majority of our analyses due to small changes in the measures of interest over the 12-week study period, it is possible that our
lack of significant results may, in part, be due to low statistical power to detect treatment effects. Furthermore, due to the low number of cases in each group when we attempted to categorize our sample into short, normal, and long sleepers based on baseline BMI, we were not able to examine potential U-shaped associations between sleep measures and BMI or weight status. Therefore, future research should focus on recruiting larger samples to obtain more accurate insight into the nature of the association between sleep measures and BMI/risk of overweight/obesity.

Seventh, we were unable to assess the effect of the dose of the intervention on sleep and weight-related outcomes. In our study, there was no way of knowing whether participants opened the text messages that were sent to their mobile phone; however, process data reported in Ybarra et al.’s (2013) manuscript indicated that 20% of sleep/physical activity participants reported somewhat agreeing or strongly agreeing when asked if they stopped reading the text messages by the end of the program. Therefore, it remains unclear whether the intervention was more successful among those participants who received the full dose of the intervention, compared to those who did not.

A final limitation to our study concerns the degree to which our findings are generalizable to the broader population of young adults. For example, although we used a national sample of young adults (including those not enrolled in post-secondary education), our entire sample was comprised of smokers. According to recent reports from the Substance Abuse and Mental Health Services Administration (2011) in the United States, it is estimated that approximately 34% of American young adults between the ages of 18 and 25 years smoke cigarettes. Therefore, our sample does not capture the larger proportion of young adults who do not smoke cigarettes. Since these individuals are inherently different from the general population
and cigarette smoking has been identified as a confounding variable in the relationship between sleep and BMI, future research should be conducted on samples including non-smokers to determine whether the same results are observed. Furthermore, when examining baseline levels of the outcome variables in our study, the combined prevalence of overweight/obesity in our sample (44%) appeared to be drastically lower than the most recent estimates from the NHANES (62%; Flegal et al., 2012), yet were relatively similar to Canadian rates reported in the 2009-2011 CHMS (47%; Statistics Canada, 2013). Therefore, these results may not be generalizable to the American population from which our participants were recruited. It is important to note, however, that height and weight were objectively measured in the NHANES and CHMS studies but were self-reported in our study, which may, in part, account for the observed discrepancies. Despite the lower combined prevalence of overweight and obesity in our sample when compared to the general population, baseline levels of self-reported sleep quantity on work/school nights and non-work/non-school nights in our sample were relatively similar to those reported by the National Sleep Foundation (2011b) in a recent study of over 1,500 young adults (including those not enrolled in post-secondary education). Therefore, we can be hopeful that baseline sleep characteristics (for sleep quantity, at least) are consistent with those observed among the general population of young adults, and that the observed intervention effects on sleep measures in our study would be feasible among the general population of young adults.

7.5 Strengths

Despite the many limitations of our research, the current study has some key strengths that add to the growing body of literature on sleep, obesity, and health behaviour change interventions. First, our study used a national sample of young adults. All of the studies to date that have examined the effectiveness of sleep interventions on sleep habits among young adults
have used samples of students enrolled in college or university. Therefore, it remains unknown whether results from these studies can be generalized to the broader population of young adults, including those not enrolled in post-secondary education.

Second, to our knowledge, our study was the first to examine the effectiveness of a text message-based intervention on improving sleep habits. Previous text message-based interventions in the preventive healthcare literature have targeted a myriad of health behaviours, including smoking (Free et al., 2011; Obermayer et al., 2004; Rodgers et al., 2005), diet (Haapala et al., 2009; Joo & Kim, 2007; Patrick et al., 2009), screen time (Shapiro et al., 2008), physical activity (Haapala et al., 2009; Hurling et al., 2007; Joo & Kim, 2007; Patrick et al., 2009), sunscreen use (Armstrong et al., 2009), BSE (Khokar, 2009), and vaccination against disease (Stockwell et al., 2012), with the vast majority of these interventions producing statistically significant changes in the targeted health behaviour(s). Therefore, preliminary evidence from the current study supports the argument that this type of intervention platform may be effective in improving sleep quantity habits on work/school nights among young adult short sleepers. More research is needed, however, to confirm whether a text message-based intervention targeting sleep habits can produce meaningful changes in other measures of sleep, including sleep quantity variability and sleep quality. Findings from our study, in addition to those from successful text message-based interventions targeting other health behaviours, can be used to improve upon the current text message-based intervention aimed at improving sleep habits, in order to enhance the effectiveness of future interventions.

Third, our study assessed potential intervention effects on multiple measures of sleep, including sleep quantity variability, which has only recently emerged in the literature as an independent risk factor for obesity (Kjeldsen et al., 2014; Kobayashi et al., 2013; Patel et al.,
Among those studies in the literature that have examined the effectiveness of sleep interventions on improving sleep habits (Arora et al., 2007; Ball & Bax, 2002; Brown et al., 2006; Clark, 2010; Farias, 2012; Lamberti, 2012; Prestwich et al., 2007; Trockel et al., 2011; Tsai & Li, 2004a), only measures of sleep quantity and quality were examined. Therefore, examining sleep quantity variability as an outcome variable was a novel component of our research and added to the comprehensiveness of the sleep measures examined in our study. Future research, however, should rely on more objective measures of sleep quantity variability (as well as sleep quantity and quality) to increase the accuracy of the conclusions drawn from intervention studies.

Fourth, within our assessment of sleep quantity and sleep quality, we differentiated between sleep quantity on work/school nights and non-work/non-school nights, and also between sleep quality and sleep hygiene. Differentiating components of sleep quantity proved to be beneficial in the current study, based on our finding in the primary objective analyses that short sleepers in the sleep/physical activity group reported getting significantly more sleep on work/school nights (but not on non-work/non-school nights) than those in the smoking cessation group, as well as our finding in the secondary objective analyses that sleep quantity on non-work/non-school nights (but not sleep quantity on work/school nights) was cross-sectionally associated with both BMI and risk of being overweight/obese. These findings provide us with more detailed insight into which components of sleep may be more easily influenced in text message-based interventions, and also indicate that obesity researchers conducting future sleep interventions may want to target sleep quantity on work/school nights and non-work/non-school nights separately, since these components appeared to exert different effects on one’s risk for overweight/obesity among young adults in our sample.
Fifth, when examining the associations of interest in our study, we controlled for a wide range of covariates that have been found to be associated with sleep and BMI in the literature, including change in physical activity, smoking status at follow-up, daily text messaging usage, sex, educational attainment/current post-secondary enrollment, and race in the primary objective analyses, and baseline or change in physical activity level, number of cigarettes smoked per day at baseline or smoking status at follow-up, sex, educational attainment/current post-secondary enrollment, and race in the secondary objective analyses. This allowed us to obtain a more realistic idea of the intervention’s effectiveness and association with weight outcomes.

A sixth and final key strength of the current study was the longitudinal design used to examine intervention effects on sleep measures, as well as the effect of changes in sleep measures on BMI and weight status. In previous cross-sectional studies reporting an association between sleep measures and BMI/obesity risk (Bjorkelund et al., 2005; Chaput et al., 2007; Cournot et al., 2004; Gottlieb et al., 2006; Heslop, Smith, Metcalfe, Macleod, & Hart, 2002; Ko et al., 2007; Kohatsu et al., 2006; Kripke, Garfinkel, Wingard, Klauber, & Marler, 2002; Moreno, Louzada, Teixeira, Borges, & Lorenzi-Filho, 2006; Ohayon & Vecchierini, 2005; Shigeta et al., 2001; Singh, Drake, Roehrs, Hudgel, & Roth, 2005; Taheri et al., 2004; Tamakoshi & Ohno, 2004; Vioque, Torres, & Quiles, 2000; Vorona et al., 2005), it was not possible to infer the causal direction of the association, since both sleep and BMI/weight status data were collected simultaneously at one point in time (Monette, Sullivan, & DeJong, 2011). Although no significant longitudinal associations were found between sleep measures and BMI or weight status in our study, had we found significant associations, we would have been able to conclude that changes in sleep preceded changes in BMI or weight status.
7.6 Next Steps

Although the current study addresses some of the gaps in the existing literature, it also serves as a basis upon which future studies can improve. The next logical step for this study would be to recruit a national sample of young adult short sleepers (including non-smokers) to participate in a larger trial of a text message-based intervention aimed specifically at improving sleep measures. Exclusively targeting sleep in the intervention messages will allow researchers to obtain a clearer idea of the effect of receiving sleep messages on sleep habits (i.e., will allow researchers to more clearly link the exposure to the outcome), and eliminate the potential for residual confounding by change in physical activity that arose in our study. As highlighted in the limitations section, future research should also use more objective measures of sleep and adiposity to maximize the accuracy of the data from which researchers are drawing conclusions. Ideally, participants would come to a study centre to have their height and weight measured by trained researchers, and wear a wrist actigraph monitor over an extended period (including both work/school nights and non-work/non-school nights) to get a more comprehensive view of participants’ usual sleep habits. Along with more objective measures, it would be beneficial for researchers to extend the follow-up period, in order to determine whether more meaningful changes in sleep and adiposity ensue after a 12-week period. Perhaps using a follow-up schedule similar to what was used in Haapala et al.’s (2009) text message-based weight loss intervention study (i.e., following up at 3, 6, 9, and 12 months) would allow researchers to study both short-term and long-term changes in the outcome variables. In addition, collecting accurate information on physical activity and dietary intake (i.e., using actigraphy and food records, respectively) in future studies would allow researchers to determine whether intervention effects are confounded by these variables.
Conducting formative research through one-on-one interviews or focus groups with young adults to better understand why our text message-based sleep intervention was not generally successful in producing behaviour change (including an assessment of barriers young adults face when attempting to improve sleep habits) would also be beneficial. These individuals may have some insight into strategies that can be embedded into future text message-based sleep interventions to increase engagement among participants. For example, based on our finding that the intervention had differential effects for short sleepers and adequate sleepers (when examining changes in sleep quantity on work/school nights over the intervention period), it is possible that adequate sleepers did not perceive the intervention content as being personally relevant if they already practiced those behaviours, thereby decreasing their engagement in the program. In several of the successful text message-based health behaviour change intervention studies that have been published in the literature, researchers have tailored intervention content based on participants’ responses to baseline survey measures (Free et al., 2011; Haug et al., 2009; Hurling et al., 2007; Obermayer et al., 2004; Rodgers et al., 2005; Stockwell et al., 2012). This indicates that future researchers may want to tailor text message content to participants’ current habits, in order to ensure that the content being delivered is personally relevant. In addition to tailoring content, future researchers may want to tailor the timing and frequency of text message delivery to participants’ preferences, in order to ensure that participants are getting appropriate levels of support based on personal preference, and that information is delivered when it is actually needed (i.e., not in the middle of the day for a behaviour that should be performed right before going to bed). Other forms of support that have been embedded within successful text message-based interventions, such as providing ongoing feedback to participants (Haapala et al., 2009; Haug et al., 2009; Hurling et al., 2007; Obermayer et al., 2004; Patrick et al., 2009; Stockwell et
al., 2012) and using additional information channels such as website or email (Haapala et al., 2009; Hurling et al., 2007; Obermayer et al., 2004), in-person visits or individual/group training on health behaviours (Armstrong et al., 2009; Joo & Kim, 2007; Khokar, 2009; Shapiro et al., 2008), printed materials (Joo & Kim, 2007; Patrick et al., 2009), and phone calls (Patrick et al., 2009) may be helpful for those individuals wanting additional support around changing their sleep habits. Currently, there are several smart phone applications available that provide users with information on their sleep quantity and quality, which researchers may want to use in future studies to provide additional behaviour change support to participants.

Lastly, our finding that sleep quantity on non-work/non-school nights (but not sleep quantity on work/school nights) was cross-sectionally associated with weight status in our sample suggests that future obesity prevention and treatment interventions may want to tailor sleep intervention content separately for work/school nights and non-work/non-school nights to maximize the impact of such interventions on reducing obesity rates.

8.0 Conclusions

In summary, this thesis examined the effectiveness of a text message-based intervention on improving sleep habits (i.e., sleep quantity, sleep quantity variability, and sleep quality) among a national sample of young adult smokers, and also whether sleep measures were cross-sectionally and longitudinally associated with BMI and risk for overweight/obesity. This was a secondary data analysis using data collected from 129 participants enrolled in a text message-based smoking cessation intervention, SMS USA. Although we observed intervention effects on all sleep measures in the desired direction among participants in the sleep/physical activity intervention group, results indicated that there were no significant differences between the
intervention groups on any of the follow-up sleep measures. Among short sleepers (< 6 hours/night), however, participants in the sleep/physical activity group reported getting significantly more sleep on work/school nights at follow-up than those in the smoking cessation group. When examining potential associations between sleep measures and BMI, sleep quantity on non-work/non-school nights was found be cross-sectionally associated with BMI, however, this association disappeared after adjusting for covariates. When examining potential associations between sleep measures and weight status, greater sleep quantity on non-school/non-work nights at baseline was found to be cross-sectionally associated with lower odds of being overweight/obese in both the unadjusted and adjusted models.

A growing body of research has identified sleep as one of several modifiable risk factors for obesity across different geographic populations and age groups, with young adults being no exception (Hasler et al., 2004). This study provides insight into whether a 6-week text message-based intervention can produce meaningful changes in sleep habits among young adults and, in turn, whether improvements in sleep habits can lead to improvements in weight parameters. The results from this study will not only help inform future obesity prevention interventions targeting sleep as a modifiable risk factor, but will also provide a basis upon which future research examining the link between sleep and obesity can expand.
9.0 References


discrimination, and psychological well-being in the United States. *Journal of Health and
Social Behaviour, 46*(3), 244-259.


Centers for Disease Control and Prevention. (2013). National Health and Nutrition Examination

eating behavior? *Sleep, 33*(9), 1135-1136.

Chaput, J. P. (in press). Sleep patterns, diet quality and energy balance. *Physiology and

associated with reduced leptin levels and increased adiposity: Results from the Québec
Family Study. *Obesity, 15*(1), 253-261.

sleep duration and weight gain in adults: A 6-year prospective study from the Quebec

associates with lower adiposity gain in adult short sleepers. *International Journal of
Obesity, 36*, 752-756.


https://www.sc.edu/healthycarolina/pdf/facstaffstu/tobacco/SmokingAndWeight.pdf.


*Proceedings of the National Academy of Sciences of the United States of America, 4*(12), 370-373.


Luckhaupt, S. E., Tak, S. W., & Calvert, G. M. (2010). The prevalence of short sleep duration by industry and occupation in the National Health Interview Survey. *Sleep, 33*(2), 149-159.


Moraes, W., Poyares, D., Zalcman, I., de Mello, M. T., Bittencourt, L. T., Santos-Silva, R., & Tufik, S. (2013). Association between body mass index and sleep duration assessed by objective methods in a representative sample of the adult population. *Sleep Medicine, 14*, 312-318.


10.0 Appendices

Appendix A: University of Guelph Research Ethics Approval

<table>
<thead>
<tr>
<th>RESEARCH ETHICS BOARD</th>
</tr>
</thead>
<tbody>
<tr>
<td>UNIVERSITY OF GUelpH</td>
</tr>
<tr>
<td>Certification of Ethical Acceptability of Research Involving Human Participants</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>APPROVAL PERIOD:</th>
<th>November 21, 2012 to November 21, 2014</th>
</tr>
</thead>
<tbody>
<tr>
<td>REB NUMBER:</td>
<td>12NV004</td>
</tr>
<tr>
<td>TYPE OF REVIEW:</td>
<td>Delegated Type 2</td>
</tr>
<tr>
<td>RESPONSIBLE FACULTY:</td>
<td>JESS HAINES</td>
</tr>
<tr>
<td>DEPARTMENT:</td>
<td>Family Relations &amp; Applied Nutrition</td>
</tr>
<tr>
<td>SPONSOR:</td>
<td>N/A</td>
</tr>
<tr>
<td>TITLE OF PROJECT:</td>
<td>Smoking Cessation via Text Messaging: Feasibility Testing of SMS USA</td>
</tr>
</tbody>
</table>

The members of the University of Guelph Research Ethics Board have examined the protocol which describes the participation of the human subjects in the above-named research project and considers the procedures, as described by the applicant, to conform to the University's ethical standards and the Tri-Council Policy Statement.

The REB requires that you adhere to the protocol as last reviewed and approved by the REB. The REB must approve any modifications before they can be implemented. If you wish to modify your research project, please complete the Change Request Form. If there is a change in your source of funding, or a previously unfunded project receives funding, you must report this as a change to the protocol.
Adverse or unexpected events must be reported to the REB as soon as possible with an indication of how these events affect, in the view of the Responsible Faculty, the safety of the participants, and the continuation of the protocol.

If research participants are in the care of a health facility, at a school, or other institution or community organization, it is the responsibility of the Principal Investigator to ensure that the ethical guidelines and approvals of those facilities or institutions are obtained and filed with the REB prior to the initiation of any research protocols.

The Tri-council Policy Statement requires that ongoing research be monitored by, at a minimum, a final report and, if the approval period is longer than one year, annual reports. Continued approval is contingent on timely submission of reports.

Membership of the Research Ethics Board: B. Beresford, Ext.; F. Caldwell, Physician; C. Carstairs, COA; S. Chuang, FRAN (alt); K. Cooley, Alt. Health Care; J. Clark, PoliSci (alt); J. Devlin, OAC; J. Dwyer, FRAN; M. Dwyer, Legal; D. Dyck, CBS; D. Emslie, Physician (alt); B. Ferguson, CME (alt); H. Gilmour, Legal (alt); J. Goertz, CME; B. Gottlieb, Psychology; B. Giguere, Psychology (alt); S. Henson, OAC (alt); G. Holloway, CBS; L. Kuczynski, Chair; S. McEwen, OVC (alt); J. Minogue, EHS; A. Papadopoulos, OVC; B. Power, Ext.; V. Shalla, SOAN (alt); J. Srbely, CBS (alt); R. Stansfield, SOAN; K. Wendling, Ethics.

Approved: ______________________

Date: ______________________

per

Chair, Research Ethics Board
Appendix B: Other MSc Contributions

Publications


Presentations

