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Association of Sleep Behavior to Physical Activity and BMI in 9th and 10th Grade Students

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Thesis Summary:

Many studies have shown a correlation between low levels of physical activity in adolescents and higher risk for obesity and cardiovascular disease[1]. In addition, a 2003-2004 National Health and Nutrition Examination Survey found that 42% of children ages 6-11 meet the recommendation for 60 minutes of daily moderate-to-vigorous physical activity, only 8% of adolescents do so, suggesting a decline in activity with age[2].

Identification of the moderators and mediators affecting changes in physical activity behavior has become a necessary task for interventions aimed at increasing physical activity levels[3]. Unfortunately, many of the assumed factors, including those of family and the built environment, have only been weakly associated with changes[4]. And literature that examines the reasons for physical activity decline during youth is limited. The Transitions and Activity Changes in Kids (TRACK) Study was designed in 2008 to identify factors related to physical activity changes in children transitioning from elementary to middle school. The TRACK I study used technologically advanced, objective measurement of physical activity and multi-level modeling strategies to examine and identify the factors. Over 1100 5th grade students from York and Sumter county schools were recruited and measured in 2010, and measurements were made again in their 6th and 7th grade years in order to better track behavioral changes.

Because of the TRACK I study's success in gathering accurate and abundant data used for two publications, it was expanded into the TRACK II study in 2012. TRACK II uses the same top-level methods of measurement to identify contributing factors in 9th grade students as they move towards young adulthood.

My research within the project specifically examined sleep as a factor influencing physical activity levels and BMI. Many studies have examined the relationship between regularly adequate sleep patterns and physical wellbeing in adult males and females, but research on this relationship in youth is limited[5-7]. For example, one recent study found a decline in physical activity levels with short-term sleep deprivation, but the study exclusively involved adult males[8]. In addition, a great deal of research has aimed to link regular exercise with normal, healthy sleep cycles, but less research has looked at sleep's effects on fitness levels.

Through compilation and examination of results from a number of studies published in scientific literature and by contribution to and analysis of results of the TRACK II research survey project conducted by USC's Children's Physical Activity Research Group, my thesis examined the influence of sleep on physical activity levels and BMI in various levels of youth and adolescence.

The primary purpose of the TRACK II study was to identify and examine the relationship between PA, BMI, and self-reported sleep in adolescents. A key element of the study was to objectively measure minutes spent in sedentary behavior, light PA, and MVPA for comparison with self-reported sleep and demographic variables.

Abstract

Despite the topic's popularity in research, the relationship between sleep duration and physical activity (PA) remains unclear. Measurement protocol differences, highly specific samples, and incomplete data contribute to varying results suggesting that additional research is needed. The purpose of the TRACK II study was to examine the relationship between PA, BMI, and self-reported sleep in adolescents. 369 9th and 10th grade students from 2 diverse school districts participated in the study. Participants completed a self-reported sleep questionnaire and had their height and weight measured. Demographic variables were also reported by participants. Actigraph accelerometers were used to objectively measure physical activity. Participants wore the accelerometers for 1 week and data was collected in 60-second epochs. Minutes of sedentary behavior, light PA, and moderate-to-vigorous PA (MVPA) were determined using age-specific cutpoints. Spearman correlations were used to examine relationships among sleep, physical activity and BMI for the total sample, and by gender and race. Complete data were available for 276 participants (40.2% male). Average self-reported sleep was 7.2 (SD=1.71) hours per weeknight and 8.07 (SD=2.47) hours per weekend night. Average minutes of MVPA was 14.15 minutes/day (SD=14.08). Average BMI was 24.55 kg/m^2 (SD=6.37). No significant correlations between sleep and MVPA or BMI were found for the total group, by gender, or by race. For this small sample of high school students, self-reported sleep was not associated with objectively measured physical activity or BMI. Additional studies using objectively measured sleep are needed before any conclusions can be made.

Introduction

Selection of this topic was motivated by two primary problems within the US: progressive decline in physical activity levels with age and consistent increases in childhood obesity and average BMI. Initial observation of decreased physical activity is most evident as children transition into adolescence. Multiple longitudinal studies, which will be discussed in this thesis, have tracked changes in physical activity in order to examine and quantify this decline at its earliest stages. The role that physical activity levels play in healthy weight and BMI maintenance supports the need for intervention at younger ages.

Rising Childhood Obesity Levels within the US

Physical inactivity is one behavioral factor that may contribute to caloric imbalance, or too few calories expended for the amount of calories consumed. Continual and consistent caloric imbalances cause overweight and obesity, which can be defined by Body Mass Index (BMI). The same method and variables are used to calculate BMI at all ages, but unlike with adults, BMI weight status categories for children and teenagers account for weight and height changes still occurring with age. The CDC has determined these categories through percentile calculations that express BMI levels in youth relative to other children of the same age and gender. According to the CDC's BMI-for-age Growth Charts, obesity is defined as a BMI at or above 95%, and overweight is a BMI from 85% to less than 95%.

In the past 30 years, obesity levels in America have more than doubled in children and quadrupled in adolescents. In 2012, over one third of US children and adolescents were reportedly overweight or obese (Ogden et al., 2014). The high number of health risks and health consequences associated with childhood obesity provide cause for alarm. In the Bogalusa Heart Study, 70% of obese youth (ages 5-17 years) had either high blood pressure or high cholesterol, and 39% had both or more risk factors for cardiovascular disease (Freedman et al., 2007). Increased risk for impaired glucose tolerance, insulin resistance, and type 2 diabetes are also highly associated (Whitlock et al., 2005). Psychological factors, including lower self-esteem, may account for self-reported lower quality of life by obese children (Morrison et al., 2015). Future health is also a concern, as obese children face a higher risk for obesity presence and more severe obesity during adulthood (Cunningham et al., 2014). Heart disease, diabetes, and certain cancers are all associated with adult obesity (Kelsey et al., 2014).

Declining Physical Activity with Age

As stated previously, many longitudinal studies have been conducted to examine the changes in physical activity levels that occur in youth during transition into adolescence. The changes in behavioral, social, and environmental factors during this transition in age may contribute to physical activity patterns and play an interdependent role with PA to affect energy expenditure, caloric balance, and BMI.

The most common method of attaining accurate measurements for physical activity is accelerometry (Laporte et al., 1985). Accelerometers determine the quantity and intensity of movement as well as frequency, pattern, and duration of activity. The device’s small size and various placement options provide convenience in wear for continuous activity monitoring.

Previous studies have suggested that reliable accelerometry estimates of daily physical activity are achieved with 4-12 measurement days, but specific variance occurs with age group (Gretebeck & Montoye, 1992). One study examining accelerometer use for youth determined that 4-5 days of monitoring was sufficient for achieving a 0.8 correlation reliability level in children, while 8-9 days was needed to reach the same level in adolescence (Trost, 2000).

Accelerometer data is expressed by dimensionless units called counts. The value of a count is specific to each accelerometer brand or model, but units in all models provide information on the frequency and intensity of vertical accelerations and decelerations. The intensity aspect of measurement allows reliable differentiation between separate activities and accurate estimates of energy expenditure.

Researchers can express data as counts, steps, bouts of activity, or estimates of energy expenditure per minute, day, or other duration period. Most studies examining physical activity changes in children and adolescents have measured counts as periods of physical activity performed at light, moderate-to-vigorous, and vigorous intensity (Berlin et al., 2006).

One UK study within the SPEEDY project used accelerometry (ActiGraph GTM1M models) to measure physical activity levels in 769 youth at age 10 and again at age 14. Researchers found that MVPA declined significantly for boys and girls, and that total PA declined the most on weekends, indicating a shift in use of free time (Brooke, 2016). Another longitudinal UK study (based on results of the PEACH project) used the same ActiGraph model to examine changes in sedentary time and physical activity in 363 youth. Accelerometry measurements were taken over a one-week period at age 12 and again at age 15. Paired sample t-tests of data showed that MVPA remained "relatively" stable, and only light PA decreased during school and weekends.

Another shorter-term study within the SPEEDY project took measurements at age 10 and 11, and results showed that girls were more likely to exhibit decreases in physical activity (Corder, 2010). When researchers of the SPEEDY project divided objectively measured PA into three different age intervals (9/10 years, 10/11 years, and 13/14 years) and used mixed effects linear regression models in lieu of paired t-tests, results showed that MVPA declined more steeply in boys than in girls (1.9 min/d/yr difference). In contrast, a Sweden-based, longitudinal study examined changes in accelerometer-tracked PA (ActiGraph 7164) in 167 youth as they transitioned from ages 10 to 12 and used matched pairs statistical analyses to examine data. Results showed that total physical activity declined for both boys and girls, while no change in MVPA was seen in either gender (Dencker et al., 2013). A much larger longitudinal study involved 1-week CSA accelerometer measurements for 1032 youth performed at ages 9, 11, 12, and 15 years. Growth curve models used for data analysis showed that MVPA decreased from 182 min/d at age 9 to 49.2 min/d at age 15 (Corder, 2013).

Identification of the contributing factors to these behavioral changes is necessary for the design of effective interventions aimed towards increasing PA levels and preventing childhood obesity. The causal link between physical inactivity or sedentary behavior and obesity and overweight risk is well established in the public health field, but interrelated factors that may affect activity levels, BMI, or both are less understood.

Identifying Potential Factors of Influence

Several studies have explored associations between assumed factors and age-related declines in physical activity in youth. However, the inability to focus experimental efforts on all potential influences equally provides an obstacle. One factor that has shown relatively consistent and significant influence on activity and BMI is shorter or irregular sleep duration.

While average weight and BMI of adolescents in the US have shown increases since the early 20th century, average sleep per night among US adolescents has shown continued decreases. In 1910, average per-night sleep duration was reported as 9.1 hours (Terman, 1913), while the average was 7.4 hours per night in 1994 (Wolfson, 1998). According to a National Sleep Foundation study that examined results from the CDC's 2007 Youth Risk Behavior Survey, this unhealthy trend is increasing at an alarming rate. Self-reports from 12,154 private and public high school students in grades 9-12 (US) show that 68.9% of students attain insufficient sleep (<8 hours) on the average school night. Of this group, 22.8% reported an average of 6 hours per night, and 30.2% reported 7 hours per night. In addition, data division by gender showed insufficient sleep prevalence was higher in females (71.3%) than in males (66.6%) (Eaton, 2010).

In addition to effects on mood and academic performance, insufficient sleep is associated with unhealthy dietary behavior and higher risk of obesity. Though increases in daily fatigue, chronic sleep deprivation poses potential for physical inactivity and sedentary behavior. In addition, neurohormonal effects may increase appetite and caloric intake. In one adult-based study, results from short-term (2-day), partial sleep deprivation showed decreased levels of the appetite-suppression hormone leptin and increased levels of the appetite-stimulating hormone ghrelin. These effects were seen despite the participants' identical caloric intake and low levels of energy expenditure and were accompanied by self- reported increases in hunger and appetite (Spiegel, 2004). A separate, adult-based study observed reduced glucose tolerance following a 6-day period of 4 hours per night sleep restriction (Spiegel, 1999).

These results all provide insight into the relationships between sleep insufficiency and weight gain and increased BMI. Adolescents and youth, whose bodies remain in a period of growth and development, may be more susceptible to these effects of shorter sleep duration.

Current Youth-Centered Research on BMI, Physical Activity, and Sleep

Current research on the association between sleep pattern, physical activity, and BMI in youth is limited by conflicting results, highly specific samples, and incomplete or differing analyses of data.

Through the follow-up assessment of the Tucson Children's Assessment of Sleep Apnea, researchers examined the association between sleep architecture, diet, BMI, and physical activity in 312 Caucasian and Hispanic adolescents of ages 10-17 years. In the initial phase, the participants' parents completed a sleep habits questionnaire and provided demographic information. A follow up assessment was performed 5 years later and participants were at ages 10-17 years. In the follow up, participants and parents completed the Block Kids Physical Activity Screener to assess physical activity through frequency and duration of activities from the past week. The Rockett Youth/Adolescent Questionnaire was completed to assess dietary habits over the last year. Anthropometric measurements were collected for BMI calculations. Finally, a questionnaire was completed to assess sleep behavior, and a repeat home polysomnogram was used to objectively characterize participants' sleep patterns. Sleep architecture was assessed for duration of rapid eye movement (REM) sleep and slow wave sleep (SWS), which is the third and final stage of non-REM sleep preceding REM sleep. Both stages are significant for the body's tissue repair and regrowth, bone and muscle building, and immune system strengthening. In assessing quality of sleep, researchers in this study defined low sleep quality by higher percentage of stage II sleep and lower SWS and REM percentages. Several previous studies in adults have found that acute exercise leads to increased total sleep time, increased SWS, and decreased REM sleep (Youngstedt, 2005). In addition, increased physical activity levels are associated with reduced risk of sleep disturbances and better sleep quality. In results pertinent to this study, BMI was positively correlated with stage II sleep, which supported the hypothesis that higher BMI is associated with more non-REM, non-SWS sleep, or lower sleep quality. (Awad, 2012).

The Quebec en Forme Project used a cross-sectional study to examine the relationship between short sleep duration and obesity-related variables in youth. Complete data was attained for 422 children (ages 5-10 years) from fourteen primary schools and various local community health and recreation centers in the City of Trois-Rivieres. Measurements were taken for body weight, height, and waist circumference, and a questionnaire was administered to the participants' parents to assess information on sleep duration. Unlike the Tucson study, sleep quality was not assessed. Pearson's correlation coefficients controlling for age were calculated to quantify the associations between sleep duration and anthropometric measures for each gender. Results showed a significant negative association between sleep duration and body weight and BMI in boys. Although longitudinal research is needed to confirm study results, researchers observed an inverse association between sleep duration and risk towards childhood obesity development (Chaput, 2006).

The Heartfelt Study provides further confirmation of this relationship through results of a cross-sectional study that examined effects of both sleep duration and quality on BMI and physical activity. Body fat percentage and anthropometric measurements were taken for 383 Texas youth of ages 11-16 years, and actigraph methodology (Motionlogger Actigraph model) was used to monitor sleep/wake hours and daytime physical activity over one 24-hour period. Calculated odds ratio indicate that each hour of increased sleep time results in an 80% decrease in obesity risk. In addition, every hour of sleep disturbance lead to a 3% decrease in daytime physical activity. Overall, study results indicate that sufficient duration and quality of sleep are significant factors for childhood obesity prevention (Gupta, 2002).

Although lacking in objective measurement of sleep duration, the National Longitudinal Study of Adolescent Health provided a much larger youth data set and period of measurement for examining the association between shorter sleep duration and increased BMI. Surveys were administered to 4,486 students (51% female, 49% male) in grades 7-12 in April 1996 and August 1996, and height and weight measurements for BMI were taken at both survey times. Habitual sleep duration and weekly moderate-to-vigorous physical activity (MVPA) was self-reported. Researchers found significant prediction of BMI z-score and overweight by sleep duration in males, where longer sleep duration was associated with lower BMI and risk for overweight. In both regression models calculated for female adolescents, sleep duration was not a predictor for BMI z-score or risk of overweight, indicating a sex-related difference in association between sleep duration and BMI. Unfortunately, the study lacked objective measurements of sleep and physical activity (Knutson, 2005).

The Cleveland Children's Sleep and Health Study involved a longitudinal, cohort study that examined the relationship between sleep duration and BMI with variances in age and sex in 313 youth from ages 8-19. Objectives were to compare the strength of association between middle childhood, early, and late adolescence; determine whether sleep duration in middle childhood predicts BMI in early or late adolescence; and to examine the consistency of the associations by sex. Measurements for BMI were taken at three different age stages, 4 years apart: ages 8-11, 12-15, and 16-19. During the 2nd exam (ages 12-15), objective measurements were taken for BMI and sleep in 294 selected participants. Due to cooperation problems with continued wear of wrist actigraphy, sleep data information was taken solely by parent-reports for the first two stages and by self-reports for the third stage. Age and sex normative data from the CDC was used to calculate BMI z-score. A negative linear association between sleep duration and BMI z-score was observed for boys but not girls, and the magnitude of association decreased with age. Sleep duration reported at age 8-11 predicted BMI z-score in early (12-15 years) and late (16-19 years) adolescence stages (Storfer-Isser et al., 2012). Study findings support a gender and age dependent association between sleep duration and BMI, where observed association is stronger in males than females and in middle childhood compared to adolescence.

Results from the CDC's Youth Risk Behavior Survey (2009) were examined to determine if sufficient sleep is associated with physical activity and sedentary behaviors in 14,782 US students in grades 9-12. Based on self-reported sleep duration, students were divided into "sufficient" (8+ hours/night) and "insufficient" (>8 hours/night) sleepers. Two questions were asked to assess how many days per week students of both groups performed ≤60 minutes of physical activity and how many days per week they performed ≤20 minutes of vigorous physical activity. Logistic regression models were used to analyze data responses and determine associations between physical activity, sedentary behaviors, and sufficient sleep. Prevalence of sufficient sleep increased with the number of days/week that students had ≤60 minutes of physical activity. In the unadjusted analyses, students who were physically active (≤60 min) on 4 or more days per week had higher odds of sufficient sleep than students who were not physically active on any day. When demographic and risk behavior variables were controlled for, associations were attenuated. Only students who were physically active for 7 days/week had significantly higher odds of sufficient sleep. Results do indicate that an association between regular physical activity and sufficient sleep in adolescents and suggests the importance of controlling for confounding variables in future studies (Foti et al., 2011).

Materials and Methods

Methods for the TRACK II study were aimed towards collecting measurements on 3 variables of interest: physical activity, sleep duration, and BMI. Recruitment for participants was conducted in two demographically diverse school districts in central South Carolina, resulting in participation of 369 9th and 10th grade students from Rock Hill and Sumter counties.

Objective measurements for physical activity were achieved with Actigraph accelerometers, which students wore during waking hours for a 1-week period. Accelerometer counts per minute were classified as minutes spent in sedentary behavior, light PA, and moderate-to-vigorous PA using age-specific cutpoints (Troiano, 2007; Trost, 2002). During the period of data collection used in this study, Actigraph accelerometers were not used to obtain objective measurements of sleep duration.

A self-reported sleep questionnaire was used to collect information on average sleep duration on weeknights and on weekend nights, as well as for information on regular sleep behavior. Specifically, five questions were given regarding sleep duration and behavior, including two that asked the hours and minutes that students "usually sleep on a normal school night," and "usually sleep on a night when [there is not] school the next day." Students were asked to not include time spent "awake in bed."

Three questions were used to assess sleep behavior and students' perception of behavior, Students were asked to report how often they get "enough sleep" and how often they had a "good night's sleep…in the last two weeks?" Both questions gave the following answer options: "always," "usually," "sometimes," "rarely," or "never." The last question asked students when they would choose to get out of bed if allowed, and 6 answer choices were provided, ranging from “before 5 a.m.” to “11 a.m. or later.”

Height and weight were measured using standard procedures and Body Mass Index (BMI) was calculated. Demographic variables, including self-reported race, were also collected for use in comparison and analysis of data. Spearman correlations were used to analyze the existing relationships between sleep, physical activity, and BMI within the total sample, as well as by gender and race. A total of 276 participants had complete data for MVPA and sedentary behavior, average weeknight sleep duration, and BMI (60% female, 40% male; Mean Age = 14.6 yrs).

Results

The final sample of 276 students included 111 males and 165 females with a combined average age of 14.6 years. Within the demographic information that they provided, participants self-identified race as one of the following: black, Hispanic, other/mixed, and white. During statistical analysis, sleep and PA was examined for the total group as well as between genders and between race groups. Data was not classified or examined, however, for gender and race together.

Accelerometry measurements for the total group showed an average daily MVPA of 14 minutes. When data was examined by gender, an approximate 13-minute difference was observed between daily MVPA levels in males (~22 min/day) and females (~9 min/day). Average MVPA minutes per day by race was greatest among Hispanic students (~17 min/day) followed and lowest in the "mixed/other" group (~13 min/day). The white (~15 min/day) and black (~13 min/day) race groups both had daily MVPA values closest to total group average.

Examined as a total group and by differing gender or race, no group met the requirement for daily minutes of MVPA (≥60 min/day).

Daily weeknight sleep duration was reported as ~7 hours per night for the total group. Both genders and all race groups had weeknight averages of ~7 hours/night, but the Hispanic race group (~7.9 hrs/night) reported a noticeably higher per weeknight duration. The black race group reported the lowest weeknight duration. Examined as a total group and by differing gender or race, however, no group met the requirements for sufficient sleep duration on a week night (8 hrs/night).

Compared to weeknights, reports for weekend average sleep duration were higher for both genders and for all race groups. As a total group, however, weekend duration surpassed the 8-hour minimum requirement by only 4 minutes (~8.06 hrs/night). Unlike with weeknight sleep duration, female students reported a higher weekend average (~8.2 hrs/night) than males (~7.9 hrs/night). Comparison of weekend sleep duration by race showed self-reports were again highest among Hispanic students (~8.88 hrs/night), followed closely by white students (~8.5 hrs/night). Averages were lowest among black students (~7.6 hrs/night) and students identifying as “other/mixed” (~8.0 hrs/night).

The average BMI for the total group was 24.5. Between race groups, back students had the highest average (~25.8), and white students had the lowest (~23.1).

No statistically significant associations were found between sleep duration and BMI or sleep duration and minutes of MVPA for gender or race. However, data for females as well as data for “black”, “Hispanic”, and “other/mixed” race groups showed negative correlation values between sleep and BMI. In addition, data for females and data for the white race group showed negative correlation values between sleep duration and minutes spent in sedentary behavior.

Discussion and Analysis

Accelerometry measurements for the total group showed an average daily MVPA of 14 minutes. Examined as a total group and by gender or race, no group met the requirement for daily minutes of MVPA (≥60 min/day). The PA levels reported were slightly lower than levels given in many of the examined studies, but, overall, averages were consistent with national CDC reports.

Average weeknight sleep duration reported for the total group was ~7 hours per night. Examined as a total group and by gender or race, however, no group met the requirements for sufficient sleep duration on a week night (8 hrs/night). These results were consistent with the average durations reported or measured in previous studies.

Based on Spearman Correlations performed, no statistically significant relationships between sleep and BMI or sleep and MVPA were found. In comparison of correlation values across both genders, a notably higher positive value was seen between sleep duration and MVPA in male students. Though all correlations were statistically insignificant, the positive values observed for sleep and BMI and for sleep and sedentary behavior among male students were unexpected. Literature review, including the previous research discussed here, is supportive of a negative association between sleep duration and BMI among adolescents, particularly in males.

In sleep duration and BMI data for female students and three race groups, the negative correlation values do suggest potential for association between these two variables. Although current research examining sleep and BMI in adolescence is limited, an age and gender related association is supported by several studies.

Researchers from the Heartfelt Study found that, among all behavioral and demographic variables examined, obesity was the single most consistent correlate of sleep time and lack of physical activity. The obesity odds ratio associated with sleep time was 0.2, implying that the odds of obesity decreases by 80% for every hour of increased sleep time.

Results from an Australian cohort study performed on children of ages 7.5-16.5 years indicate that the association between sleep duration and BMI is stronger in males than females for all examined age groups. The magnitude of this difference varied with age, where the largest difference between genders was seen at 14-16.5 years (Eisenmann, 2006).

As discussed earlier, results from the US National Longitudinal Study of Adolescent Health supported associations between longer sleep duration and lower BMI and risk of overweight among male adolescents (grades 7-12) only. However, the study's lack of objective measurements for both sleep and PA is a considerable factor (Knutson, 2005). In Canada, the Quebec en Forme Project also found significant negative association between sleep duration and BMI and body weight in males but not females. The study was performed for a slightly younger age group, (5-10 years), and it lacked both longitude and objective measurements of sleep (Chaput, 2006). Surprisingly, findings from a study performed with 13-16 year old adolescents suggest that short sleep duration is associated with increased obesity/overweight risk in males and decreased risk in females (Biggs, 2007).

Results from the TRACK II study differed from gender-dependent associations identified in the described literature. Although no statistically significant relationship was present, negative correlation values were observed between sleep duration and BMI in females only. The TRACK II study did not examine age-related association differences, however, and objective measurements for sleep duration were not performed. Results may give reason to believe that further longitudinal research involving objective measurement of sleep is needed before conclusions can be made that association is stronger among male adolescents.

In regards to physical activity, negative correlation values were observed between sleep duration and minutes of sedentary behavior in female students. Unsurprisingly, these values indicate potential for an association between sleep and physical inactivity. Results from the Heartfelt study, discussed previously, also support an inverse association between sleep disturbance and physical activity. Similarly to TRACK II results, the inverse association was stronger for female participants than males. In both genders, each hour of sleep disturbance resulted in a 3% decrease in daytime physical activity. Researchers noted that, though obesity was not directly related to sleep disturbance in regression analysis, data supports a way that sleep disturbance could affect obesity through reduction in daytime PA levels. Objective measurements of sleep and activity for the 383, 11-16 year old Texan adolescents involved one 24-hr period of wrist actigraphy. Unfortunately, this study also lacked a longitudinal aspect.

The Tucson Children's Assessment and follow-up also examined physical activity and BMI in respect to both sleep quality and sleep duration, and researchers aimed to identify effects of chronic exercise on sleep architecture. A positive correlation was found between stage II sleep and total estimated activity, which supports their hypothesis that chronic exercise may lead to sleep disruption and lighter sleep in non-athlete adolescents of ages 10-17 years. When applied to implications of the Heartfelt Study, findings from the Tucson study contradict the notion that regular exercise reduces risk of obesity by promoting less sleep disturbance and thereby promoting higher daytime physical activity and energy expenditure. The contradiction between studies demonstrates the need for longitudinal research that involves objective measurements of sleep and physical activity.

Limitations of the TRACK II project included use of self-reported sleep duration data rather than or in combination with objective sleep measurement. Following the collection period of data used in this thesis, objective sleep measurement by wrist actigraphy has been performed in 10^{th} grade students from one of the school districts. Future TRACK II studies examining the same or similar associations will incorporate and benefit from this data.

According to previous research on the accuracy of accelerometry use in adolescents, 8-9 days of data collection are needed to achieve a sufficient (0.8) correlation reliability level (Trost et al., 2000). Based on this finding, the one-week duration of actigraph monitoring for MVPA and sedentary behavior may be a factor for consideration in future studies. Increasing the period over which accelerometry measurements are made to multiple weeks and spacing data collection to different times during the school year may affect results. The feasibility and necessary recruitment for multi-week data collection is a concern, however, and cooperation issues with accelerometry wear consistently pose an issue for monitoring youth and adolescents.

Ultimately, comparison of previous research results with data from the TRACK II study gives further indication of the complex relationship between physical activity levels, BMI, and sleep duration. Among future investigations, the need is apparent for research that examines these variables longitudinally and incorporates objectively measured sleep and PA levels with BMI.

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