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Childhood Obesity Prevention: Is it a Hop, Jump, and a Skip Away? An Exploratory Study of the Behavioral Ecological Model and the Influence of Contingencies on Child Body Composition

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Childhood Obesity Prevention: Is it a Hop, Jump, and a Skip Away?

An Exploratory Study of the Behavioral Ecological Model and  
the Influence of Contingencies on Child Body Composition

A dissertation submitted in partial satisfaction of the  
requirements for the degree Doctor of Philosophy

in

Public Health (Health Behavior)

by

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2016

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The dissertation of Kristi Marie Robusto is approved, and it is acceptable  
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2016

## DEDICATION

I dedicate this dissertation to several influential groups of people, who have helped me reach this point. First and foremost, I dedicate this dissertation to the Timberline Animal Hospital in Carson City, Nevada. Dr. Mike Pulver and his staff, Sharron, Ashley, Joshua, Tina, are inspirational, and this dedication will not do the group justice. During the process of saving Riley, they reminded me about what it means to perform work with grace and humility, passion, perseverance, and curiosity. They reminded me what it looks like when people dedicate themselves to their work, see it as a service and a privilege, and genuinely care about what it is they are doing. Beyond being stellar at the work they do, Dr. Pulver and his staff welcome you, support you, and treat you like their own family. So, to the people who saved my Ri-guy and reminded me about what it means to be excellent, I dedicate my dissertation to you.

Additionally, I dedicate this dissertation to my mentors throughout the years who have provided support and guidance; to my husband EJ for being by my side during this process; to my parents for teaching me to always pursue my dreams and for teaching me how to work to make them a reality; to my family, especially my brother Dom, for getting it and helping me stay focused and my sister Michelle for always being supportive; and to my friends—I am so fortunate to have such encouraging, motivating, understanding friends. To everyone who has helped me get here, I dedicate this dissertation to you, as well.

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## LIST OF ABBREVIATIONS

ALM = Appendicular lean mass

ALMI = Appendicular lean mass index

AMZ = age-matched z-score

AP = Anterior-posterior

AVAS = Additivity and variance stabilization

BEM = Behavioral Ecological Model

BIA = Bioelectrical impedance analysis

BMC = Bone mineral content

BMD = Bone mineral density

BMI = Body Mass Index

BP = Blood pressure

CDC = Center for Disease Control and Prevention

cm = Centimeter

DLW = Doubly-labeled water

DXA = Dual energy x-ray absorptiometry

FMI = Fat mass index

F/V = Fruit and Vegetable

g = gram

g = gravitational forces

$g/cm^2$  = grams per centimeters squared

HC = Hip Circumference

HSD = Habitual Sleep Duration

HSV = Habitual Sleep Variability

ISCD = International Society for Clinical Densitometry

kg = kilograms

kg/m<sup>2</sup> = kilograms per meters squared

L1-L4 = Lumbar vertebrae 1 to lumbar vertebrae 4

LMI = Lean mass index

LTPA = Leisure Time Physical Activity

mcg = Microgram

METs = Metabolic Equivalent

mg = Milligram

microSV = micro sievert

MVPA = Moderate to Vigorous Physical Activity

NCI = National Cancer Institute

NDS = Nutrition Data System

NHANES = National Health and Nutrition Examination Survey

NSF = National Sleep Foundation

OR= Odds Ratio

PA = Physical Activity

PBF = Percent Body Fat

PDS = Pubertal Development Scale

pQCT = Peripheral quantitative chromo tomography

PSG = polysomnography

RCT = Randomized Control Trial

SB = Sedentary behavior

SD = Standard Deviation

SDP = Sleep Duration Percent

SES = Socio-economic status

SF = Skinfold

SPSS = Statistical Package for the Social Sciences

SSB = Sugar Sweetened Beverage

TB = Total body

TBLH = Total body less head

US = United States

WC = Waist circumference

WHtR = Waist-to-Height Ratio

zBMI = BMI z-scores

zFM = Fat Mass z-score

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The following three chapters will have co-authors for potential publication:

(1) The Relationship between Body Composition and Bone Mineral Content and Density in Preadolescent Children: Does Mass Type Matter?, (2) Is Healthy Body Composition Just a Hop, Jump, and a Skip Away: Relationships Among Physical Activity, Sedentary Behavior, and Body Composition, and (3) Do Parental Household Rules Influence the Relationships between Sleep Duration and Preadolescent Body Composition? A Systematic Review.

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3. Caparosa S, Nichols J, Marshall S, Cipriani D, Kingsbury T, Lorenz K, **Robusto K**, Nicaise V. (2011). Exergaming: Not just for kids anymore! *ACE Fitness Matters*, March 2011, 1-5. San Diego, CA: American Council on Exercise.
4. Kobus DA, Brown CM, Wu L, **Robusto K**, Bartlett, J. (2010). Cognitive performance and physiological changes under heavy load carriage. (Tech Report No. 10-12). San Diego, CA, Pacific Science & Engineering Group.
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3. Olsen D, Pabutsky A, **Robusto K**, Berger M, Mburia-Mwalili A. Exploring the utilization of tobacco cessation medications among female Medicaid recipients aged 40-64 in Nevada. Break-out Presentation at the Council of State and Territorial Epidemiologists Conference: June 2016; Anchorage, AL.
4. **Robusto K**. How to make exercise as addictive as tobacco: The behavioral ecological model. Presentation at University of California, San Diego CVD/EPI Lecture Series, March 7, 2014; San Diego, CA.
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ABSTRACT OF THE DISSERTATION

Childhood Obesity Prevention: Is it a Hop, Jump, and a Skip Away?

An Exploratory Study of the Behavioral Ecological Model and  
the Influence of Contingencies on Child Body Composition

by

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Doctor of Philosophy in Public Health (Health Behavior)

University of California, San Diego, 2016

San Diego State University, 2016

Professor Melbourne Hovell, Chair

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**Background:** This dissertation explored three hierarchical levels of the Behavioral Ecological Model (BEM) related to childhood obesity by addressing the following aims: (1) explore the relationships between preadolescents' body composition (i.e., fat and lean mass) and bone mass/density; (2) explore the relationships between preadolescents' engagement in physical activity and sedentary behavior with their body composition; and (3) perform a systematic review evaluating the relationships between parental household rules, child/adolescent sleep, other obesity-related behaviors, and weight status/body composition.

**Methods:** For Aims 1 and 2, analysis of the validity baseline data collected between 2009 and 2014 for the Healthy Smiles Trial was performed ( $N = 44$ ). For Aim 3, a systematic review of the literature was performed using PubMed (Medline) and Google Scholar databases. After screening abstracts and articles for inclusion, studies included in the review ( $N = 48$ ) were evaluated and study fidelity was scored.

**Results:** In 8- to 14-year-old boys and girls, DXA-derived body composition was related to bone mass. Bivariate analyses showed lean mass measures were positively associated with total body less head (TBLH) and AP Spine (L1L4) bone mineral content (BMC)/density (BMD); however, after controlling for age, gender, height, weight, and pubertal status, the relationships were insignificant. Partial correlations controlling for age, gender, height, weight, and pubertal status showed fat mass index (FMI) was significantly negatively associated with TBLH BMC and L1L4 BMC ( $p < 0.01$ ), and android fat mass was negatively associated with TBLH BMD ( $p < 0.05$ ). In 8- to 14-year-old boys and girls, after controlling for age, gender, height,

weight, leg length, and pubertal status, partial correlations showed moderate, vigorous, and MVPA were positively associated with DXA-derived lean mass measures and negatively associated with DXA-derived fat mass measures ( $p < 0.05$ ). There were no relationships between DXA-derived body composition and light PA, total PA, or sedentary time. Finally, systematic review results showed: (1) higher fidelity studies demonstrated expected relationships between parental household rules and associated obesity-related behaviors (e.g., TV watching rules associated with decreased TV time); (2) parental household rules demonstrated an inconsistent relationship with child weight status/body composition; (3) sleep duration was consistently inversely associated with child weight status, irrespective of study fidelity; (4) parental household rules may be related to sleep duration, and sleep duration may mediate the relationship between rules/child behaviors and child weight status, but more research is needed. Several limitations in the literature were identified.

**Conclusions:** In summary, body composition is an important physiological component and should be evaluated in addition to BMI, as lean and fat mass may have different yet important relationships with variables pertinent to childhood obesity related research. Both physical activity and sedentary behavior should continue to be concurrently evaluated, as they are not simply opposite ends of the same spectrum. Furthermore, future studies should confirm that intensity of PA may be more important with regard to child body composition and weight status, so more effective evidence based recommendations for preventing and reducing childhood obesity can be established. Finally, parental household rules may influence child obesity-related

behaviors; however, more research is needed to determine their relationship with child weight status/body composition. Systematic review results call for more multi-level, dynamic, robust studies to determine more effectual means for combating childhood obesity.

## INTRODUCTION

This dissertation will examine three separate theoretical hierarchies of the Behavioral Ecological Model (BEM) related to childhood obesity and body composition in a sample of preadolescent boys and girls enrolled in the Healthy Smiles Program. Healthy Smiles was an obesity prevention randomized control trial designed to increase physical activity (PA), reduce sedentary practices, and promote healthy diets among preadolescents who obtained orthodontia care. The three hierarchies include: (1) the physiology by assessment of body composition and bone health, (2) the individual behaviors related to childhood obesity and body composition, such as physical activity and sedentary behavior, and (3) social contingencies in the home potentially related to childhood behaviors that may contribute to obesity and body composition.

A brief review of childhood obesity epidemiology, body composition, bone growth and health, individual level behaviors (e.g., PA and sedentary time), and social contingencies in the home related to childhood obesity, as well as an overview of the BEM, is included below. The review below serves to tie the three dissertation chapters together via the overarching theme of the dissertation: childhood obesity and childhood obesity prevention.

### **Childhood Obesity: Epidemiology**

Childhood obesity is considered a serious health concern (1-4), as evidenced by the numerous public health efforts put in place (e.g., recommendations, interventions, reports) in the United States in the past decade (5-8). According to the White House Task Force Report, one in three children aged 2-19 years old are considered to be overweight or obese (9). While obesity rates appear to be stabilizing at about 17% for 2-19 year olds (5, 10), prevalence of childhood obesity has increased three- to four-fold in the past 30 years (5, 11, 12). Among children between 6-11 years, obesity rates have increased from 6.5% (1975-1980) to 17.7% (2011-2012) (5, 10-12). Among adolescents aged 12-19 years, obesity rates have increased from 5.0% (1975-1980) to 20.5% (2011-2012) (5, 10, 12).

With an increase in childhood obesity, there is an increased risk for certain health consequences. It has been estimated that one in three children born in 2000 will develop diabetes (9). Obese children are at an increased risk for multiple health conditions such as sleep apnea, asthma, liver disease, cardiovascular risk factors such as hypertension and dyslipidemia, bone and joint issues, and psychosocial issues (1, 4, 11, 13). In 2007, Freedman et al. estimated that 70% of overweight children and adolescents (BMI  $\geq$  95th percentile) had at least one additional cardiovascular disease risk factor, and that 39% had two or more additional risk factors (14). Finally, obese children and adolescents are more likely to become obese adults (1, 4, 11). There are a multitude of factors that contribute to the obesity epidemic; however, major culprits



include decreases in physical activity, increases in sedentary behaviors (15), and poor diet (4).

### **Childhood Obesity: Body Composition**

Obesity is defined as “abnormal or excessive fat accumulation that presents a risk to health” (16, para. 1). Body mass index (BMI) is used as an estimate of body fat (17), and while it is considered a reliable indicator of fatness (18), it is an imperfect measure, as it cannot discriminate between fat and fat free mass (1, 19). According to the Center for Disease Control and Prevention (CDC), BMI is used as a screening tool, but is not a diagnostic tool in children and adolescents (18). With the increased prevalence of childhood obesity, as determined by BMI-for-age-percentiles, direct assessment of child body composition (fat, lean, and bone mass) has increased (20, 21). From these data, smoothed body fat percentile curves for US (United States) children and adolescents, stratified by age and gender, were created (21). Regional fat distribution may differ not only by age and gender, but by pubertal stage, as well (20, 22); therefore these factors should be considered in future studies evaluating body composition in children.

### **Body Composition Assessment: DXA**

Dual energy x-ray absorptiometry (DXA) provides an accurate and precise method of measuring body composition, as it can differentiate between fat and fat free mass even in young children (22, 23). Because of its fast, safe, accurate and precise

technology, with minimal radiation doses (0.03-15.2 microSV), DXA is an ideal method for measuring children (24). In 1999, NHANES began collecting DXA total and regional body composition measures of participants ages 8 and older. Total body (TB), total body less head (TBLH), and regional body composition measures taken in cross-sectional series were analyzed, and means and percentiles by age, gender, and race/ethnicity were provided for approximately 2,000 8- to 11-year-old boys and girls, and about 3,400 12- to 15-year-old boys and girls (23).

**Girls.** Girls' mean TBLH percent body fat was 32.7% at 8-11 years, and 33.1% at 12-15 years. Female body fat percent, fat mass, and lean soft tissue mass increased between 8-11 and 12-15 years. Furthermore, total body, TBLH, and trunk percent body fat was highest in Mexican-Americans and lowest among non-Hispanic blacks (23).

**Boys.** Overall, boys' mean TBLH percent body fat was 28.4% at 8-11 years and 25.2% at 12-15 years. In boys, all body fat percent measures decreased, while fat mass and lean soft tissue mass increased between 8-11 and 12-15 years. Furthermore, total body, TBLH, and trunk percent body fat was highest in Mexican-Americans, and lowest among non-Hispanic blacks (23).

**Overall.** Overall, mean total body and TBLH body fat percent, fat mass (kg), and trunk percent body fat were higher in girls compared to boys across all ages and ethnicities, and lean soft tissue (kg) was about the same between boys and girls 8-11 years old, and lower in girls 12-15 years old (23).

### **Childhood Obesity: Bone Health**

Obese children are considered to be at increased risk of bone and joint issues (19). This is evident by the increased risk of slipped capital femoral epiphysis and tibia vara, abnormalities in gait, and greater likelihood of falling in obese children, likely due to excess loading on the bone from excessive fat (20). Irrespective of these increases, the effect of body weight and excess fat mass on bone strength and density in children remains controversial (20, 25, 26).

Children with lower bone mineral density (BMD) are at increased risk for fractures (27). Furthermore, children who experience similar forearm injuries are more likely to fracture if they have lower BMD (24). In the past four decades, there has been an increase in the incidence of distal forearm fractures, the most common childhood fracture (28, 29), paralleling the increase in childhood obesity.

Previous research has shown that children with forearm fractures were more likely to be overweight (30-36). These studies have found BMI and fat mass to be independent predictors of increased fracture risk (26, 31). In a study of 10-year-old girls, Goulding et al. found within a 4-year period that those with increased body weight were at a 1.5-fold increased risk for fracture at any skeletal site and a 1.7-fold increased risk for fracture at the distal forearm (34). In another study, children with recurrent fractures had a higher BMI than those with only one or no fractures (35). Others have suggested that obese children may have lower bone mass for their body size, thus increasing their likelihood to fracture (20, 34). However, not all studies have found body weight to increase fracture risk (26). A two-fold increase in fracture

risk for every one standard deviation (*SD*) decrease in whole body BMD, independent of age and body weight has been demonstrated in children (26).

The mechanism for this increase in fractures is unknown, although it may be due to changes in physical activity patterns, deficits in bone strength (37), impaired bone mass accrual, or a combination of all three (29). Understanding the effect of body composition on bone mass accrual in children and adolescents is imperative given the increase in obesity rates, increase in fracture rates, and that low peak bone mass developed during childhood is the primary risk factor for adult osteoporosis (24, 38, 39).

#### **Mechanostat Theory: Component of Physiological Level of BEM**

Frost's Mechanostat theory postulates that bone tissue continuously adapts to mechanical loads placed on it, by way of a 'mechanostat,' to avoid extreme bone deformation and to maintain its integrity and strength (27, 40-43). Frost hypothesized this adaptation would be controlled by several mechanical thresholds (40, 43). Below a certain mechanical threshold bone considered "excess" by the mechanostat will be resorbed (40, 41, 43). Conversely, above a certain threshold, whereby mechanical usage is greater than typical peak loading, bone formation will occur (40, 41, 43). These threshold levels vary by individual and their habitual behaviors (24). Therefore, mechanostat theory encompasses bone growth, modeling, and remodeling (40). According to mechanostat theory, the magnitude of the mechanical loading (e.g., forces) has a greater effect on bone and bone mass than the frequency of loading (40,

41). Body weight is not considered a major load. Frost defined body weight as the “resistance muscle forces must overcome to move the body’s mass against the pull of earth’s gravity” (40, p. 8). Because the muscles have to work against poor lever arms and gravitational forces, they exert the largest loads on bone, excluding traumas. Muscular forces exerted on bone may be 2-10 times that of body weight alone (40, 41).

Accordingly, changes in mechanical loading of bone, be it via physical activity, muscle loading/contracting, body weight, or other loading, will start the bone adaptation processes (24). The processes are also different at an individual level; threshold levels for bone adaptation in one child may not have the same effect on another child due to individual characteristics and lifestyle factors (24).

### **Bone Growth in Children**

The child’s skeleton is an ever-changing organ in both size and composition. As a child’s skeleton grows, it is continually modeling and remodeling itself to produce a competent mechanical structure optimally designed to provide protection, locomotion, and support. Bone growth occurs both by increasing size and by accruing bone mineral. (44)

Multiple factors including genetics, age, gender, ethnicity, pubertal status, body size, body region, and fat and lean mass influence bone growth and development in children (24). Peak bone mass is typically achieved during adolescence or early adulthood (45, 46). There are site-specific variations in peak mass acquisition, with most acquiring peak hip (femur/neck of) mass by 20 years of age, and peak spine mass during the third decade of life (20). After 18 months of age, boys’ and girls’ bone acquisition differs; however, they tend to accrue bone mass at relatively similar rates

until about 12-14 years (20, 24). Boys may also demonstrate higher porosity rates during this time (24).

In general, prepubertal bone growth occurs in the lower limbs contributing to longitudinal growth, whereas growth during puberty mostly occurs in the spine (20). During puberty there is an exponential increase in the bone accretion rate, and it is a time of both vulnerability and opportunity for bone growth optimization (24). Furthermore, changes in bone structure occur, with increased trabecular bone of the spine and long bones during pubertal stages 3 and 4 (24). Finally, child size is important to consider, as smaller children will have smaller density for age, based purely on size (44).

### **Body Composition and Bone Mass**

Fat and fat free mass (i.e., lean mass) appear to have independent relationships with bone mass in children. Understanding these dynamic relationships and their implications for healthy bone growth and development is critical given the ongoing obesity epidemic and the potential impact it may have on bone health and osteoporosis rates later in life. Childhood obesity, adult obesity and co-morbidities, and osteoporosis gravely impact morbidity and mortality, as well as cause huge economic burdens.

## **Fat Mass**

The relationship between fat mass and bone mass, density, and development is complex. The literature is conflicted regarding the effects fat mass has on bone mass and density, with some studies demonstrating positive effects (20, 34, 45, 47-49) and some noting negative effects (20, 25, 34, 47). Age, pubertal status, body region, and fat type and amount appear to modify some of the relationships shown between fat and bone mass.

Positive associations between fat mass and bone area and mass (total body/less head) have been shown in prepubertal children, even after controlling for height and lean mass (34, 47, 48). Bone area for height also demonstrated to be higher in an obese population of children compared to a normal child population (49). Subcutaneous fat may have a positive relationship with bone (20) as well, but implications of regional fat distribution on bone development need to be explored further. Finally, using peripheral quantitative chromo tomography (pQCT) total body fat mass was positively related to volumetric bone density, cortical, and trabecular bone mass in young girls (45). Overall, moderate levels of adiposity may augment bone development in children.

Conversely, negative effects, or caveats to positive effects, of fat mass on bone mass have been reported. Multiple studies report inverse associations between fat mass and bone mass in children (34). While prepubertal children appear to benefit from increased fat mass, a greater amount of adiposity is detrimental to bone mass accrual in pubertal and immediately post pubertal children (20, 25, 47). Clark et al.

showed that as girls progressed through puberty, the beneficial effects of increased fat mass attenuated or even reversed (47). Increased fat mass limited or eliminated the positive effect of lean mass on bone in children, as well (20, 50). Bone mineral content (BMC) for lean mass was lower in an obese population of children compared to a normal weight child population (49). Recently, the relationship between fat distribution and bone accrual has become of some interest. Several studies demonstrate that abdominal/visceral fat negatively affect bone development (45, 49, 51) and that high levels of abdominal adiposity may lead to sub cortical bone development (i.e., less compact bone development) in young girls (45). Visceral fat may have deleterious effects on bone development by decreasing/hindering bone quality (24). Furthermore, excess adiposity may adversely affect bone development and density via infiltration of the marrow and muscle (24).

### **Lean Mass**

The literature consistently demonstrates that lean mass, commonly thought of as muscle mass, is positively associated with BMC, bone area, and BMD in children and adolescents, as measured by DXA (34, 48, 52, 53). DXA-derived lean mass is different from magnetic resonance imaging (MRI) skeletal mass, as lean mass encompasses an estimate of skeletal muscle mass, organs, and other soft tissue (48). However, in a study comparing DXA-determined lean mass and MRI-determined skeletal muscle mass, and their respective relationships with bone mass, lean mass and skeletal muscle mass produced similar results (48). Therefore, authors concluded that



DXA lean mass could be used as an estimate of skeletal muscle mass to examine relationships with bone (48). While age, gender, and ethnicity may modify the relationship between lean mass and bone mass, it is still considered one of the best predictors of bone mass and density in children. When controlling for age, gender, race/ethnicity, height, and fat mass, children with higher lean mass have more bone mass (48). Lean mass index (LMI), calculated by dividing lean mass by height squared, has also been used in evaluating the relationship between lean mass and bone mass, given that smaller children have smaller bone size. Children with a greater LMI have greater BMC, as well (34).

### **Appendicular Lean Mass**

Appendicular lean mass (ALM) is the lean tissue mass of the arms and legs (54). Seventy-three to 75% of skeletal muscle mass is comprised of ALM (54). While skeletal muscle mass controls locomotion and posture, ALM is considered the primary portion of skeletal muscle mass contributing to locomotion, ambulation, and activity (55).

Previously, ALM and the appendicular lean mass index (ALMI) have been used in older adults to evaluate the relationship between lean mass and BMD, and to assess sarcopenia. In older adults, low values of ALM and ALMI were associated with decreased bone density (52). Researchers started assessing the relationship between ALM, ALMI, and BMC, bone area, and BMD in children; however, this remains an emerging area of investigation from which few studies exist to make definitive

conclusions. In a study of 3- to 5-year-olds (52), Goulding et al. found ALM and ALMI were highly correlated with total body and TBLH BMC in both boys and girls. Additionally, the authors found a stronger relationship between ALM and BMC than between total body lean mass and BMC. It appears that lean mass distribution may impact bone mass accrual, and needs to be explored further.

### **Individual Behavior Impacting Obesity and Body Composition:**

#### **Physical Activity, Sedentary Behavior, Sleep**

##### **Physical Activity**

**Benefits.** Increasing physical activity in children and adolescents has become a common theme in addressing a multitude of public health issues, including childhood obesity and child bone health. The White House Task Force Report asserts that “young children need opportunities to be physically active through play and other activities” (9, p. 19). Engaging in physical activity allows children to develop and improve both fine and gross motor skills, balance, coordination, strength, and flexibility (9).

***Obesity/Cardiometabolic Benefits.*** Beyond its importance for motor learning and development, increased physical activity can increase the effectiveness of obesity reduction/treatment, independently decrease mortality (13), and have positive effects on children’s health (56, 57). Getting more physical activity can decrease risk for chronic diseases and disorders (9) and produce modest positive effects on aerobic

fitness, cardiovascular risk factors such as blood lipid levels, blood glucose levels, and blood pressure levels, and improve psychological health (56).

***Bone Health Benefits.*** High impact or weight-bearing activity initiated during pre-pubertal or early pubertal years seems to be the most beneficial for improving bone mass (27, 59-61). Increases in physical activity have positive effects on the whole body, spine, and hip BMD in growing children (61). Performing high impact weight bearing activity (AKA high/odd impact or bone building activity), such as plyometrics, resistance training, and gymnastics positively impacts osteogenesis at a greater magnitude compared to low intensity weight bearing activity (62, 63).

***Guidelines.*** The CDC recommends that children engage in 60 minutes or more of daily physical activity (58); at least 3 days per week most of the 60 minutes should be aerobic-based moderate to vigorous physical activity (MVPA), and muscle strengthening and bone strengthening exercises should also be performed at least 3 days a week (58).

***Child Physical Activity Epidemiology.*** Despite recommendations and potential health benefits, few children are meeting PA recommendations. In general, older adolescents are less likely to engage in PA than younger children, and boys are more likely than girls to engage in MVPA (9).

***Younger Children (6-11 Years).*** Younger children are more likely to meet PA guidelines compared to older adolescents. Among 6- to 11-year-olds, a greater percentage of 6- to 8-year-olds met PA guidelines compared to 9- to 11-year-olds

(76.1% vs. 64.7%), demonstrating that children become less active with age (65). Furthermore, more boys met PA guidelines than girls (48.9% vs. 34.7%) (64).

**Older Adolescents.** Among 12- to 15-year-olds, a greater percentage of boys met PA guidelines than girls (11.9% vs. 3.4%) (64). There is approximately a 30-35% decrease in the percent of 12- to 15-year-old boys and girls meeting PA guidelines compared to their younger counterparts.

Among high school students, approximately 15% did not engage in 60 minutes of MVPA on at least one day during the past 7 days. Approximately 10% of high school boys did not engage in any MVPA, and nearly 20% of girls did not engage in MVPA during the past 7 days (66, 67). Furthermore, approximately 53% of high school students did not engage in at least 60 minutes of MVPA on 5 or more days during the past 7 days, with approximately 43% of high school boys and 63% of high school girls not engaging in MVPA on 5 of the past 7 days (67).

#### **Physical Activity and Childhood Body Composition and Obesity.**

Understanding the relationship between physical activity, body composition, and childhood obesity is important given the potential immediate and long term health implications. The data reflecting body composition and immediate and long term health implications are inconclusive (68, 69).

Results from observational, cross-sectional, and longitudinal studies are conflicted across and within study designs, with some showing inverse relationships between PA and BMI and/or body fat (70-74) and others demonstrating no relationship between PA and BMI (69, 74, 75). A number of studies divided PA levels into

quartiles and compared PA quartiles to body composition. Those noting inverse relationships between PA and body composition often found that participants in the highest PA quartile engaged in significantly more activity than those in the lowest quartile, and had a lower BMI (70, 73, 76). A few studies noted that the intensity of activity may be more important for body composition than total PA (70, 71, 73, 74). Respondents who engaged in vigorous activity were more likely to have lower obesity rates and lower body fat (71, 76).

The inconsistencies in the literature are likely due to both the different concepts of PA and widely varying procedures. Physical activity is defined as “any bodily movement produced by skeletal muscles that results in energy expenditure” (77, p. 126), and it can occur as different types (e.g., running) or in different frequencies, intensities, durations, and domains. The definition and varying aspects make evaluating PA complex. Multiple measures of PA have been implemented including self-report, heart rate monitors, pedometers, accelerometers, and doubly-labeled water (DLW), thus, allowing for multiple PA outcomes, such as energy expenditure and time spent in MVPA. Not only are PA measurements and outcomes heterogeneous across studies, but measures of obesity and body composition vary, as well. Most studies incorporate BMI; however, body fat has been determined by bioelectrical impedance analysis (BIA), skinfold measures, circumference measures, and most recently DXA (74). Some researchers have noted that cross-sectional studies do not provide clear temporal order between activity and body composition, and bidirectional mechanisms are plausible (69, 78).

## **Sedentary Behavior**

**Definition and Recommendations.** Sedentary behavior (SB) is a functionally separate class of behavior, not simply the absence of MVPA. Rather, SB includes sitting and lying behaviors while at school, work, commuting, in domestic/home environments, and for leisure (e.g., TV viewing) (79-82). SB has an energy cost of 1.0-1.5 METs (79-82). Because SB is its own response class, both from a behavioral and a physiological determinants perspective (83, 84), it is possible to meet MVPA recommendations and still be considered sedentary. Importantly, light activity (1.6-2.9 METs), such as standing, has previously been misclassified as SB. Frequently, screen time is used as a proxy measure of sedentary time. Current recommendations suggest that children limit their leisure screen time viewing (e.g., TV time, video game play, computer/internet for leisure, etc.) to 2 hours or less per day (65, 85).

### **Sedentary Time Epidemiology.**

**Overall.** The amount of time children engage in sedentary behaviors and the prevalence of children meeting screen time recommendations has been evaluated by a number of studies. In general, North American children/adolescents engage in SB for approximately 6-8 hours per day (9, 86, 87), or about 40-60% of their waking hours (88). Sedentary time and length of sedentary bouts also increase with age (9, 88, 89), with younger children more likely to meet recommendations than older adolescents. Furthermore, less than 4 in 10 children in a national sample met both PA and screen time recommendations concurrently, and obese children were less likely to meet recommendations (65).

**Demographic Trends.** Boys tend to engage in more screen time oriented behaviors, whereas girls spend more time in non-screen time behaviors (89). Race/ethnicity appears to be related with sedentary time, with non-Hispanic blacks spending the most time being sedentary, followed by Hispanics, compared to non-Hispanic whites and Asians (89). Socio-economic status (SES) may influence the type of sedentary behaviors children perform. Low SES children may spend more time in ‘passive’ sedentary activities (e.g., TV viewing), whereas higher SES children may spend more time in ‘involved’ or ‘active’ sedentary activities (e.g., video game play).

In all studies reviewed, children engaged in more sedentary time, and in screen time, on weekend days compared to week days (89). However, one study noted that on week days children spent more time completing homework, whereas on weekend days children watched more television (89). These relationships are limited by cross-sectional designs.

**Younger Children (6-11).** Nearly 51% of 6- to 11-year-olds met screen time recommendations in 2001-2006 NHANES data (90). Similar to PA trends, within 6- to 11-year-olds (65), a greater percentage of 6- to 8-year-olds met screen time recommendations compared to 9- to 11-year-olds (59.1% vs. 47.8%) (65).

**Older Adolescents.** Among 12- to 15-year-olds, 44% met screen time recommendations in 2001-2006 NHANES data (90). This was an 8% decrease in the percent of boys and girls meeting recommendations compared to their younger counterparts.

Among high school students, the percent that report playing video games for 3 or more hours per day increased from 21% in 2005 to 42% in 2013, with a notable increase of 10% occurring between 2011 and 2013 (66, 67). Boys engaged in more game play than girls. Conversely, students watching 3 or more hours of television per day decreased from 42.8% in 1999 to 32.4% in 2011, and stabilized between 2011 and 2013 (66, 67).

### **Sedentary Behavior and Childhood Obesity and Body Composition.**

Independent of PA, sedentary behavior in adults is associated with increased waist circumference (WC) and obesity, increased lipid levels, and increased blood pressure (BP) (83, 84, 91-99). Similar relationships in children have not yet been confirmed.

**Screen Time.** In children, evidence indicating the relationship between increased screen time (e.g., TV time) and increased obesity (87-89) is beginning to accumulate. Spending more than 2 hours per day engaged in SB (usually determined by TV time) was associated with unfavorable body composition in multiple reviews (87-89). As children age, SB increases and light activity decreases (100).

In a meta-analysis conducted by van Grieken et al., they concluded that studies aimed at decreasing SB may help in the prevention of childhood overweight (101). However, only 6 of the 34 studies they reviewed had significant effects on BMI (101). Furthermore, some studies have shown that sedentary time is not independently associated with weight status or other cardiometabolic risk factors, after adjusting for PA in children and adolescents (102).



While a number of studies consistently demonstrate a relationship between self-reported screen time and body composition in children, the relationship with objectively measured total sedentary time is less clear (88, 103). A majority of studies have used screen time or TV time as a proxy for sedentary time. Screen time seems to account for approximately a third of total sedentary time (88, 104). However, these two variables are not highly correlated ( $r = 0.08$ ), thus leading researchers to believe the two variables are not assessing the same construct (88, 104). Screen time and total sedentary time via accelerometry may be functionally separate classes of behavior, thus, demonstrating different relationships with body composition.

## **Sleep**

**Background.** Adequate sleep is important, particularly for children and adolescents, as it influences healthy brain function, physical health, and growth and development (105). School age children (5-12 years) need to get at least 10 hours of sleep a day, and it is recommended that adolescents acquire 9-10 hours of sleep daily (106-108). According to the National Sleep Foundation (NSF), school aged children average 9-10 hours of sleep per day (109).

Sleep time and percent meeting sleep time recommendations by gender and weight status were evaluated in a cross-sectional sample of 7- to 12-year-olds. Normal weight boys and girls averaged 10.1 and 10.3 hours a day, respectively. However, overweight/obese boys and girls averaged 9.7 and 10.1 hours of sleep a day, respectively. Moreover, while 55.4% of boys met the sleep recommendations, only

18.5% of overweight and 6.5% of obese males met the sleep recommendations. Similarly, 69.3% of girls met sleep recommendations, but only 18.7% of overweight and 12.5% of obese females met the recommendations (110).

**Sleep Time and Obesity Risk.** Short sleep duration has been identified as a potential risk factor for obesity in children (110-114). In a 2008 review of cross-sectional studies evaluating sleep duration and obesity in children and adults, Cappuccio et al. found a significant relationship in 7 of 11 studies in children and all adult studies (111). They concluded that there was a consistent pattern of increased odds of obesity by approximately 60-80% in both children and adults who had shorter sleep durations. Results from seven observational longitudinal studies, conducted between 2004 and 2010, consistently demonstrated positive relationships between short sleep duration and weight gain in children (113). Furthermore, boys and girls failing to meet sleep recommendations were at 2.1 and 1.5 increased odds of being obese, respectively (110).

While most studies find inverse relationships between short sleep duration and BMI and fat mass, few studies have evaluated these relationships with DXA. Bornhorst et al. assessed fat mass via sum of skinfold measures and found the relationship between short sleep duration and BMI decreased by approximately 50% when adjusting for fat mass (112). Understanding the relationship between short sleep duration, lean mass, and fat mass may have important health implications, as well.

## **Social Environment Influencing Childhood Obesity**

### **Role of the Parents**

Social contingencies of reinforcement and punishment acting on children and adolescents will influence their behavior (115, 116). Numerous studies have evaluated different aspects of the social environment with the increases in both childhood obesity and the use of ecological models. One particular social environment of interest is the home environment, focusing on parents' influential role in promoting or preventing obesity-related behaviors. Parents can influence obesity promoting or preventing behaviors through modeling (117, 118), participating with the child, transporting the child to various locations to engage in PA, or enforcing contingency management systems (i.e., rules) in the home (114, 119-122).

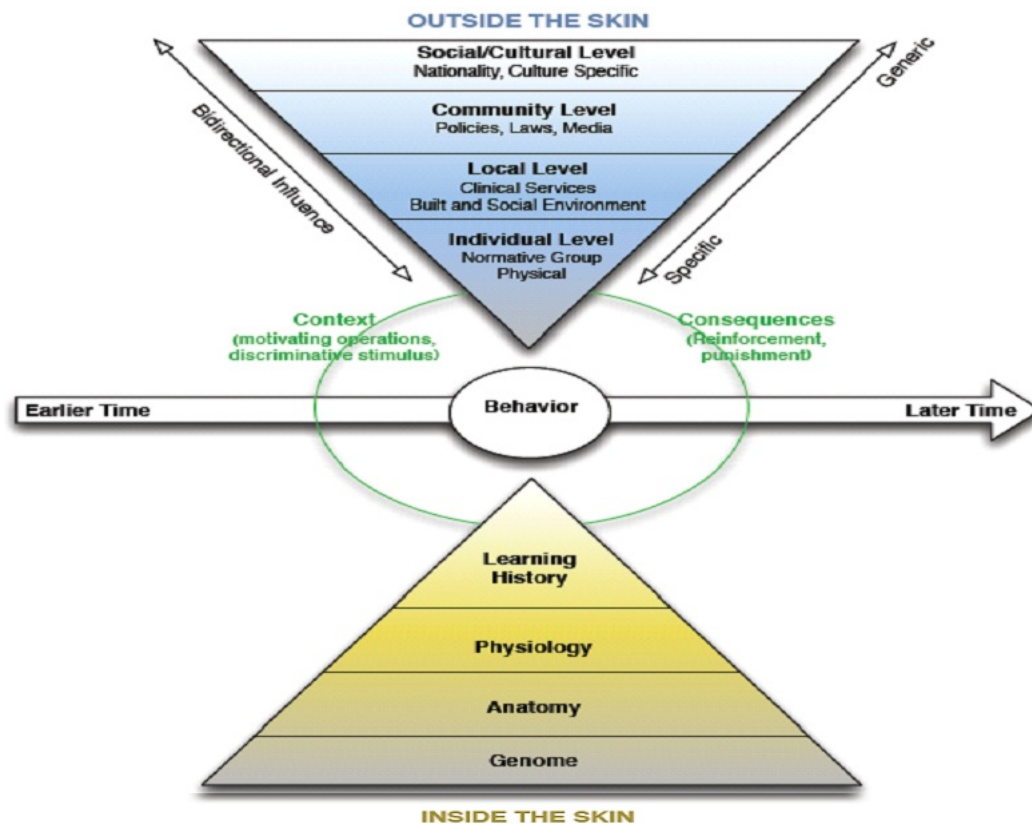
Family household rules offer the opportunity to promote healthy behaviors that could be beneficial for a child's body composition (122). Evidence is accumulating suggesting positive relationships between rules and engagement in PA (114, 120). Studies evaluating family rules commonly incorporate those related to screen/TV time (120,121). Decreases in TV time have been observed with set TV time rules (120). However, consistency of rule enforcement by the parent was of greater importance than simply having a rule in place.

While establishing the relationship between rules and engagement in health promoting behaviors is valuable, the next step is demonstrating these relationships influence body composition. Few studies have explored body composition outcomes. In a preschool aged population, the number of routines (e.g., bedtime, TV time) that

were enforced in the home was inversely related to childhood obesity (119). Further, Hearst et al. observed that overweight parents and children were less likely to have established and consistently enforced rules (121). Jones et al. also explored the impact of family rules on the relationship between sleep and composition in young children (114). Overall, family rules appear to have implications for child behaviors that are related to body composition, and possibly effects on body composition; however, more research is needed to elucidate these relationships.

### **Theoretical Model: The Behavioral Ecological Model (BEM)**

The BEM is a theoretical framework that attempts to explain both individual and population level behavior, and applies these explanations to health related behavior. While founded on both the principles of natural selection and the principles of behavior (e.g., respondent and operant conditioning), the BEM extends these principles beyond the individual level to group processes and population level functions, emphasizing ecological principles in order to explain both individual and population behavior. The BEM asserts that individual and population behavior is selected by cascading and bi-directionally interacting physiological and environmental (physical, social, cultural) contingencies of reinforcement. Multiple additive or synergistic contingencies that continuously counter competing contingencies, are required to sustain behavior (Figure 0.1) (115, 116).



**Figure 0.1:** The Behavioral Ecological Model

### Chapters of the Dissertation

The dissertation will examine three separate theoretical hierarchies of the BEM related to childhood obesity and body composition in a sample of preadolescent boys and girls enrolled in the Healthy Smiles program. Healthy Smiles was an obesity prevention randomized control trial designed to increase physical activity, reduce sedentary practices, and promote healthy diets among preadolescents who obtained orthodontia care. The three hierarchies include: (1) the physiology, by assessment of body composition and bone health, (2) the individual behaviors potentially related to

childhood obesity and body composition, such as physical activity and sedentary practices, and (3) social contingencies in the home potentially related to childhood obesity and body composition. These three hierarchies will comprise the chapters of the dissertation to follow.

The three chapters are designed to be both independent and to build on each other from a theoretical perspective from the first to the third chapter. The first chapter incorporates only the “inside the skin” level of the BEM. Currently, limited research has been done with this level of the model. However, the individual’s biological components and their coordinated movements of these components (e.g., physiology) potentiate the individual’s ability to engage in any given behavior. While the individual’s biology/physiology may act as discriminative stimuli, or reinforcing or punishing stimuli (e.g., pain) for a given behavior, or conversely may be learned as a function of the external environmental contingencies acting on it, the purpose of the first chapter is to initiate the evaluation of this theoretical level in the area of body composition. Exploring the relationships among different components of the individual’s body composition will aid in accomplishing this first step, and add to the current literature regarding the relationships between fat mass, lean mass, and appendicular lean mass and bone mineral content and density in 8- to 14-year-olds.

The purpose of the second chapter is to build on the first chapter by incorporating the child’s behavior (PA/SB), and exploring the influence their physical activity and sedentary behavior has on their body composition. Physical activity and sedentary behavior are considered separate functional response classes, as they

produce different sets of common reinforcing contingencies. Physical activity and sedentary behavior are also considered incompatible, as both cannot be engaged concurrently. Theoretically, they would be considered competing contingencies, and will likely diminish the reinforcing consequences of the other. This chapter will explore the relationship between how much physical activity and sedentary behavior the participants engaged in with body composition outcomes. This will occur under the assumption that those who are highly reinforced by physical activity will engage in it more than those who are not, those who are highly reinforced by sedentary behaviors will engage in them more than those who are not, and that the reinforcing value of sedentary behavior will likely cause a decrease in the engagement of physical activity in certain contexts, and potentially vice-versa, as the Healthy Smiles program did not assess this directly.

The third chapter will build on the first two chapters and incorporate the social component of the BEM. The BEM emphasizes ecological principles by extending the role of contingencies of reinforcement beyond the individual, to address two group/population level contingencies that influence individual, group, and population level behavior: Macrocontingencies and Metacontingencies. The purpose of the third chapter is to explore the social context by evaluating the literature regarding the impact parental rules in the home have on child and preteen behavior and body composition.

The final chapter of the dissertation will tie the three chapters together and provide overarching conclusions from the exploration of the varying hierarchies and their relationships with childhood obesity.



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## CHAPTER 1

### The Relationship between Body Composition and Bone Mineral Content and Density in Preadolescent Children: Does Mass Type Matter?

### Abstract

Child and adolescent body composition and its effects on bone mass need to be understood given the increasing childhood fracture rates mirroring the increased childhood obesity rates. The purpose of this study was to explore the relationships between DXA-derived body composition (e.g., lean mass, fat mass) and bone mineral content/density in a sample of 8- to 14-year-old boys and girls. Participants, recruited via orthodontist offices, were part of the Healthy Smiles trial's baseline validation sample ( $N = 44$ ). During the laboratory session, participants completed a total body and AP Spine DXA scan. Measures evaluated included total body less head (TBLH) lean mass, appendicular lean mass, percent fat, fat mass, android fat mass, their respective indices, bone mineral content (BMC) and density (BMD), and AP spine (L1L4) BMC and BMD. Descriptive statistics, bivariate associations, and partial correlations controlling for covariates were performed. All lean and appendicular lean mass measures were positively associated with all BMC/BMD measures ( $p < 0.01$ ) during bivariate analyses; however, these relationships disappeared during the partial correlations analysis. Partial correlations showed that fat mass index (FMI) was negatively associated with TBLH BMC and L1L4 BMC ( $r = -0.43$ ,  $p < 0.01$ ), and android fat mass (kg) was negatively associated with TBLH BMD ( $r = -0.35$ ,  $p < 0.05$ ). To better understand the relationships between body composition and bone mass accrual, particularly in relationship to childhood obesity, more research is needed to confirm negative implications fat mass may have on bone mass in children and adolescents.

## Introduction

Obesity has been associated with an increased risk for bone and joint issues among children (1). Paralleling the increase in childhood obesity over the past four decades has been an increase in the incidence of distal forearm fractures in children (2, 3). Despite research demonstrating that children with these kinds of forearm fractures are more likely to be overweight (4-10), the mechanism for the increased fracture rate is still unknown. Changes in physical activity patterns, deficits in bone strength (11), impaired bone mass accrual (3), or a combination, may be contributing factors.

Understanding how body composition affects bone mass accrual is critical due to the increase in childhood fracture rates. Peak bone mass developed during childhood is the primary risk factor for adult osteoporosis. However, the relationship between body composition and bone mass, density, and development is complex. The development of bone mass and density in children/adolescents is impacted by a multitude of variables including age, gender, pubertal status, height, fat mass, lean mass (12), and potentially appendicular lean mass. The effects of fat mass on bone mass are conflicted, with many variables modifying the effects of the relationship. (8, 10, 13-16). In contrast, the literature consistently demonstrates that lean mass (primarily muscle mass), as measured by dual energy x-ray absorptiometry (DXA), is positively associated with bone mineral content (BMC) and bone mineral density (BMD) in children and adolescents (8, 15, 17, 18). In addition to lean mass, appendicular lean mass (ALM), the lean mass of the arms and legs, and its index (ALM related to height) has gained increasing interest. While ALM and appendicular

lean mass index (ALMI) have previously been used in older adults to evaluate the relationship between lean mass and BMD to assess sarcopenia and associated frailty, less is known regarding the relationships among ALM and ALMI and bone mineral content, bone area, and bone density in children. In older adults, low values of ALM and ALMI are associated with decreased bone density (17). Similar results were demonstrated in one study of children; Goulding et al. found ALM and ALMI were highly correlated with total body and total body less head (TBLH) BMC in 3- to 5-year-old boys and girls (17). Additionally, a stronger relationship between ALM and BMC than between total body lean mass and BMC was shown (17). Lean mass distribution may impact bone mass accrual; however, this remains an emerging area of investigation and more studies are needed.

The purpose of this study was to explore the relationships among fat mass, android (abdominal) fat mass, lean mass, and ALM, and their respective indices, with BMC and BMD, in a subsample of 8- to 14-year-old boys and girls who participated in the Healthy Smiles Program.

## **Methods**

### **Design**

This study investigated the relationship between body composition (fat and lean mass) and BMC/density (BMD) in a sample of preadolescent boys and girls enrolled in the Healthy Smiles Program. The current analysis used baseline validation data from Healthy Smiles, a multi-component randomized control trial designed to increase

physical activity (PA), reduce sedentary practices, and promote healthy diets among preadolescents obtaining orthodontia care. The study was approved by the San Diego State University Institutional Review Board.

### **Participants**

Private and corporate practice orthodontists in San Diego, Orange, or Riverside, California, and Tijuana, Mexico were recruited to participate in the Healthy Smiles Program. Recruited offices varied in number of clients served, type of practice, and in second language capabilities. Each enrolled office was trained in implementing the intervention for the condition to which they were randomly assigned: (a) experimental condition, obesity prevention; or (b) tobacco control.

Active orthodontic patients aged 8-14 were first notified of the program via a letter from their orthodontist. If patients did not request removal from the recruitment list after 2 weeks, research staff members were given their contact information for screening by phone. To qualify, patients had to be 8- to 14-years-old, have at least one year remaining in active orthodontic treatment, have no plans to move within the next year, be able to care for themselves, and have no physician-prohibitive restrictions on engaging in regular physical activity. Preteens who participated in physical activity three or more times per week for 9 or more months of the year were also excluded. Participants from Mexico had slightly different recruitment processes and had to be 8-16 years old.



Forty-four preteens (18 boys, 26 girls) aged 8-14 years participated in the baseline validity assessments. Participants were a randomly selected (6%) subsample from the larger Healthy Smiles Program.

### **Protocol/Procedures**

During an introductory home visit, the parent and child signed consent and assent forms, and completed self-administered questionnaires. Trained research staff measured child weight and height using study provided scales and stadiometers. All information collected at the home visit, except height and weight, was self-reported. Following the home visit, families randomly selected to be part of the validity sample completed a single laboratory session for fitness testing, and participants were asked to wear an accelerometer for 8 days. During the 8-day period, validity participants ( $N = 44$ ) completed the same three baseline phone interviews the entire baseline sample completed; additionally, validity participants also completed three 24-hour detailed food recall questionnaires. Families who were randomly selected to participate in validation measures received \$20 as incentives after completing all baseline measures.

### **Measures**

**Anthropometrics.** Participant's height (wall mounted stadiometer) and weight (Health-o-meter® digital scale) were measured, without shoes, and recorded to the nearest 0.5cm and 0.1kg, respectively. Leg length was measured on the participant's

left side (to match DXA measures), with feet together, and without shoes.

Measurements were performed from the greater trochanter to the floor and recorded to the nearest 0.1cm. All anthropometric measures were performed by trained staff and repeated to ensure reliability.

**DXA Body Composition and Bone Density.** Each participant had a total body and lumbar spine (anterior-posterior [AP] view) DXA scan performed (Lunar Prodigy densitometer; GE/Lunar Corp., Madison, WI) in order to evaluate body composition and BMC/BMD. Certified technicians performed all scans, and daily quality assurance checks were done using the manufacture's calibration block. Participants wore loose fitting athletic wear and removed any metal and/or hard plastic (e.g., jewelry) prior to scanning. Coefficients of variation for our lab, on 30 adult subjects measured twice, were 1.05% for the spine, 0.85% for the total body BMD, 1.46% for fat mass, and 0.55% for lean tissue mass. Bone-free fat and lean mass were used in analyses (17). Additionally, in accordance with ISCD recommendations for pediatric populations, total body less head (TBLH) measures were used (19), as during childhood, the child's head size remains relatively stable while the rest of the skeleton grows, and the head significantly contributes to the child's bone mass measures; therefore, it is excluded from analyses (20). Body composition variables analyzed included TBLH lean mass (kg), TBLH lean mass index (LMI), appendicular lean mass (ALM; kg), appendicular lean mass index (ALMI), TBLH fat mass (kg), TBLH fat mass index (FMI), and android fat mass (kg). ALM was calculated by summing the lean mass of the arms and legs. All indices were calculated by dividing the variable of

interest by height in meters squared. BMC (g) and BMD (g/cm<sup>2</sup>) for both total body (TBLH) and AP spine (L1L4) were included in analyses.

**Phone Interviews.** Phone interviews were conducted with both the child and the parent on three separate days, during the time period in which the child wore the accelerometer. Families reported information about demographics, parent and child physical activity and sedentary behavior, parent and child diet, tobacco use and exposure, and rules in the home. Each family completed a weekend recall and two weekday recalls when possible. When families were not able to meet this measurement schedule, any 3 days of recalls were accepted.

**Impact Physical Activity.** Prior day physical activity was reported by the child during each of the three phone calls. The recall questions asked about different parts of the child's day. Partitioning of the day depended on what type of day the child recalled: a non-school day or school week day. For each portion of the day, participants were asked if "they engaged in any exercise, activity, or sport." If yes, the participant was asked what they did. Reported types of physical activity were coded as either non-impact or impact activity in an effort to relate them to 'bone-building' activities. Two variables were created from these data: (1) Total Impact Score and (2) Total Impact PA bouts. The total impact score is the sum, an unadjusted frequency count or tally, of the number of impact activities a participant said they performed across all prior day PA recalls (up to 3 days), irrespective of when they engaged in them or what kind of recall day it was. All but one participant completed all 3 prior day PA recalls. The Total Impact PA bouts variable was created by first determining

the number of available blocks/bouts to engage in PA during each prior day recall and summing the total number of available bouts. School day recalls had between five and seven available bouts, depending on the participant's school recess and PE schedule. Non-school days had four available bouts. Then the number of bouts that a participant engaged in impact activity was totaled. Finally, the ratio of number of impact bouts to number of available bouts was computed, in an effort to "adjust" for type of recall days.

**Diet.** In addition to the previous day food frequency recalls, validation families completed three 24-hour dietary phone recalls during the 8 days of accelerometer wear. Trained interviewers obtained dietary recalls from each participant's parent using a computer-based prompting system (Minnesota Nutritional Data System [NDS], Nutrition Coordinating Center, University of Minnesota, Minneapolis, Minnesota, version 4.03, released November 2013). Interviewers also asked about supplement use. Nutrient calculations were derived from NDS for calcium (mg/day) and Vitamin D (mcg/day) by taking the average calcium and vitamin D intake across the three 24-hour dietary recalls. The average calcium and vitamin D intake across the recalls were used for analyses.

**Maturation Status.** The Pubertal Development Scale (PDS) was used to assess pubertal stage of the participant. The PDS is a 5-item questionnaire, by which the parent reported growth spurt, body hair, and skin change for both boys and girls, voice change and facial hair for boys, and breast change and menarche for girls. High concordance has previously been established between the PDS and Tanner staging

(21). PDS was calculated following previously established methods (21, 22). Briefly, each of the 5 items was scored on a 1-4 ordinal scale, with the exception of menarche, which was coded dichotomously as 1 for “no” or “premenarcheal” and 4 for “yes” or “postmenarcheal.” An overall score was calculated by summing the scores of the 5 items and dividing by 5. This preserved the original 1-4 metric (22). To ensure scores were not deflated due to any missing data, the overall PDS score was also calculated by summing the 5 items and taking the average of the scores, where a minimum of 3 items needed to have scores to do so. Because none of our participants were missing any of the 5 items on the questionnaire, both methods produced the same overall PDS score.

### **Statistical Analyses**

Statistical analyses were performed using SPSS (version 21) and R: A Language and Environment for Statistical Computing (version 3.1.2). Data were originally entered and cleaned in SPSS; however, R was employed when more complex analyses needed to be performed that were outside of SPSS capabilities. Frequencies and distributions of all variables were reviewed. Means (*SD*) and medians were calculated for participant’s physical characteristics, body composition, and bone measures (BMC/BMD) for the total sample and by gender.

Bivariate analyses among physical characteristics, body composition, and bone measures included Mann-Whitney U tests and Spearman correlation coefficients.

Mann-Whitney U tests were used to characterize the relationship between gender and

all other variables. Spearman correlation coefficients were used to determine the strength of the relationship between bone measures (TBLH and AP Spine BMC/BMD) and potential covariates: age in days, gender, height, weight, pubertal status, high impact physical activity, and average calcium and vitamin D intake. Spearman correlation coefficients were also used to characterize the relationship between bone measures and key independent variables: TBLH fat percent and mass and index (FMI), android fat percent and mass, TBLH lean mass and lean mass index (LMI), and appendicular lean mass and index (ALMI). Bootstrap hypothesis testing was used to test for differences between certain Spearman correlations.

Additivity and variance stabilization (AVAS) was performed in R to identify transformations, if needed, in the data set. After performing AVAS on the dependent variables for the total sample, it was determined that the AVAS analyses needed to be explored separately by gender. No clear transformation was identified, and, therefore, no transformations were used. In an effort to check multiple assumptions within the data, given its small sample size and the exploratory nature of the paper, very specific hypothesis testing using simple and weighted least squares linear regression was performed. Any oddities in the regression plots or analyses were noted and checked when possible (data not shown).

Given the limited sample size and collinearity among certain variables, partial correlation was used to determine the associations between body composition and bone variables, while holding the effects of covariates constant. First, models were fit to the dependent variable of interest (e.g., TBLH BMC) which included the following

covariates: age in days, height, weight, pubertal status score, gender, and interactions between height and gender, and weight and gender. The same model was then fit to the corresponding independent variable of interest (e.g., TBLH Lean Mass). When models were fit for/with indexed variables (e.g., ALMI), height was excluded, since it was already accounted for during the indexing process. Once the models were fit, the correlations between the residuals from the fitted models were determined.

## Results

### Physical Characteristics

Participants' physical characteristics stratified by gender are provided in Table 1.1. This sample of preadolescent children (18 boys, 26 girls) was 8-14 years old with a mean (*SD*) height of 153 (12) cm, weight of 46 (11.5) kilograms, and BMI of 19.4 (3.4). Twenty-seven (61.4%) participants were Caucasian (one participant who was Middle Eastern was coded as Caucasian for analyses), 13 (29.5%) were Hispanic, and 4 (9.1%) were Asian. All girls TBLH and android fat measures were statistically significantly higher ( $p < 0.05$ ), with girls having about twice as much body fat as boys. Girls TBLH lean mass and LMI were statistically significantly less ( $p < 0.05$ ) than the same measures for boys. Pubertal status, ALM, ALMI, and L1L4 BMD (AP Spine) approached significant differences ( $p < 0.09$ ) between genders, with girls being further into puberty, having less appendicular lean mass, and slightly greater L1L4 BMD than boys. No differences were found for the remaining physical characteristics.

## Bivariate Correlations

Spearman correlation coefficients among covariates (e.g., age) and body composition measures (e.g., TBLH lean mass), with the dependent variable bone measures (e.g., TBLH BMC) for the entire validation sample ( $N = 44$ ) are presented in Table 1.2. Here only large correlation coefficients are highlighted ( $r = 0.5-0.9$ ,  $p < 0.01$ ). Among covariates, age in days, height, weight, BMI, and pubertal status were positively associated with both TBLH and AP Spine bone variables. While not significantly different, correlations tended to be stronger between covariates and TBLH bone measures compared to AP Spine variables, with the exception of pubertal status. TBLH lean mass and ALM measures were strongly positively associated with both TBLH and AP Spine variables, as well. Among fat measures, TBLH fat and android fat mass were moderately positively associated with various bone measures, but these associations were not as strong.

Spearman correlation coefficients among covariates, body composition, and bone measures stratified by gender are presented in Table 1.3. Here only large correlation coefficients are highlighted ( $r = 0.5-1.0$ ,  $p < 0.01$ ). Among boys ( $N = 18$ ) and girls ( $N = 26$ ) age in days, height, weight, and pubertal status were strongly positively associated with all bone variables. Additionally, among girls, BMI was also moderately-strongly positively associated with all bone variables. No significant associations were found between BMI and bone measures in boys. TBLH lean mass and LMI were significantly positively associated with TBLH and AP Spine bone measures for both boys and girls, with lean mass associations being higher than LMI



associations. Similarly, ALM and ALMI were also significantly positively associated with TBLH and AP Spine bone measures for both boys and girls, with ALM associations being higher than ALMI associations. For all lean mass and ALM measures/indices, positive correlations were slightly higher with AP Spine for boys compared to girls, but did not reach significance. Lean mass and ALM associations appeared similar across all bone measures. For TBLH bone measures, ALMI associations were slightly higher than LMI, whereas ALMI associations with AP Spine were only higher in girls. Among girls, all fat measures were moderately-strongly positively associated with TBLH BMC and BMD. Additionally, among girls all fat measures were moderately positively associated with L1L4 BMC and BMD, except TBLH percent fat and L1L4 BMC. In general, girls' data showed stronger relationships among fat and L1L4 BMD measures compared to L1L4 BMC measures. No significant associations were found among any fat and bone measures in boys. Correlations between TBLH fat mass and TBLH BMC and BMD were significantly different by gender ( $p < 0.05$ ), whereas correlations between TBLH fat mass and AP Spine measures approached significant difference by gender ( $p < 0.09$ ). Correlations among TBLH FMI and TBLH BMC, TBLH BMD, and L1L4 BMD were also significantly different by gender ( $p < 0.05$ ), while the correlations between TBLH FMI and L1L4 BMC approach significant differences by gender ( $p < 0.06$ ). All other fat and lean mass associations with bone measures were not significantly different by gender.

## Partial Correlations

**Modeling.** Adjusted  $r$ -squared values for all dependent variables (TBLH BMC, TBLH BMD, L1L4 BMC, L1L4 BMD), when modeled with non-indexed independent variables (TBLH lean mass, TBLH fat mass, ALM, Android fat mass), were moderately high to high (0.73-0.89). Similarly, adjusted  $r$ -squared values for all dependent variables, when modeled with indexed independent variables (TBLH LMI, TBLH FMI, ALMI), were moderately high to high (0.68-0.89). Irrespective of whether DVs were modeled with indexed or non-indexed IVs, TBLH bone variables (0.78-0.89) had greater adjusted  $r$ -squared values than the L1L4 bone variables (0.68-0.73). Adjusted  $r$ -squared values for all non-indexed independent variables were high (0.88-0.93). For indexed independent variables, adjusted  $r$ -squared values were moderately high (0.70-0.79). The fitted models demonstrated that age in days, height (when included), weight, pubertal status, and gender were related to all of the variables, separately (data not shown).

**Correlations.** Partial correlations between the residuals of the fitted models are presented in Table 1.4. After taking all covariates into account, within each of the fitted models, most bone and body composition measures were no longer statistically significantly related to each other. Significant associations with each of the bone measures are discussed here. TBLH BMC and Android fat mass (kg) approached being statistically significantly related ( $r = -0.29, p < 0.06$ ), and TBLH BMC and TBLH FMI were statistically significantly related ( $r = -0.43, p < 0.01$ ). After accounting for all other variables, these fat measures demonstrated weak to moderate

negative associations with TBLH BMC. TBLH BMD and Android fat mass (kg) were statistically significantly related to each other ( $r = -0.35, p < 0.05$ ), demonstrating a weak negative relationship after accounting for all other variables. L1L4 BMC and TBLH FMI were statistically significantly related to each other ( $r = -0.43, p < 0.01$ ), demonstrating a moderately negative relationship after accounting for all other variables. No measures were associated with L1L4 BMD after accounting for all covariates.

### **Discussion**

In an effort to better understand the relationship between body composition and BMC/BMD in pre-adolescents, this study explored the relationships between fat mass, lean mass, and bone mass in a sample of 8- to 14-year-old boys and girls. Through our analytical exploration of the Healthy Smiles DXA data, we reconfirmed that boys and girls are, in fact, different. Gender matters when evaluating the relationship between body composition and bone mass. Further, we reconfirmed that these relationships, while incredibly important to understand, are difficult to dissect given the multitude of important and dynamic variables needing to be considered (e.g., age, gender, height, weight, pubertal status, etc.), and their high correlation amongst one another and amongst the body composition and bone mass measures. Our main findings, however, after controlling for age, gender, height, weight, and pubertal status, indicated that the only body composition variable still associated with BMC or BMD was fat mass. Specifically, both the fat mass index (FMI) and android (abdominal) fat mass

demonstrated weak to moderate negative associations with bone measures (TBLH BMC, TBLH BMD, L1L4 BMC). The results indicate that as the preadolescents FMI (fat mass in kg/height squared) is higher their TBLH and L1L4 BMC is lower, and as android (abdominal) adiposity is higher the preadolescent TBLH BMC and BMD is lower.

Our findings of positive significant bivariate correlations between DXA-derived lean mass and bone mass measures were similar to those reported in previous investigations (17, 23), despite evaluating the associations in different childhood age groups. Our bivariates were somewhat greater than previously reported in 5 year olds (17). Furthermore, our data showed similar bivariate correlate patterns with TB and lumbar BMC and BMD to those demonstrated in a group of 10- to 19-year-old boys and girls (23). However, our lean mass partial correlation outcome was incongruent with the majority of the literature in our population (10, 15, 24, 25), with the exception of one study (18). In general, lean mass is the major determinant/predictor of TB BMC, Regional BMC, and L1L4 BMC, even after adjusting for potential covariates such as age, gender, height, weight, etc. (10, 15, 24, 25). Similar to Baptista et al., after adjusting for covariates, lean mass was no longer significantly related to bone mass/density in our study (18). Interestingly, as far as we are aware, our study is the first to evaluate the relationship between ALM and ALMI with TBLH and L1L4 BMC and BMD in preteens. While Goulding et al. evaluated the bivariate associations among ALM and ALMI, and bone measures, they did not take the analysis any further (17). Additionally, Dorsey et al. explored whether skeletal muscle

mass predicted BMC in 6- to 18-year-olds (15); however, ALM and skeletal muscle mass are slightly different, as ALM is a component of skeletal muscle mass (26).

Additionally, our data produced mixed agreement with the literature when assessing the relationship between fat mass and bone mass. Our bivariate analyses for the entire sample demonstrated a significant positive association between TBLH fat mass (kg) and all of our bone measures. These results aligned with a number of studies to date (13, 16, 23, 24). After controlling for age, gender, pubertal status, height, and weight, TBLH fat mass was not significantly related to any of our bone measures; however, FMI and android fat mass demonstrated some significant weak to moderate negative associations. Similarly, Viljakainen et al. showed that the lowest whole body BMD z-score was observed in the highest fat tertile, demonstrating a negative relationship between high fat and BMD (27). The authors concluded that adequate amounts of fat are required for normal bone development, but that excess fat is likely detrimental. These conclusions may help explain why our associations, while significant, are not high. In a sample of prepubertal (tanner stage 1) overweight children, visceral adipose tissue (VAT) and subcutaneous abdominal adipose tissue (SAAT) determined via MRI were negative predictors of total body BMC after adjusting for gender, race, height, and DXA determined fat-free soft tissue and fat mass (27). It is possible that our measure of android fat mass by DXA approximate visceral and subcutaneous adipose tissue determined by MRI, and may be why our results show similar trends (negative relationships with bone) when compared to studies using highly specified abdominal adiposity measures.

Mechanisms for explaining the negative relationship between abdominal fat and bone mass are not fully understood, especially in children and adolescents. However, recent studies have identified a few potential mechanisms and hypotheses that need further exploration. First, adipose tissue is a component of the endocrine system that secretes hormones, such as estrogens, IGF, growth hormone, and other growth factors affiliated with bone growth and development (27). Second, in studies able to differentiate between visceral adipose tissue (VAT) and subcutaneous abdominal adipose tissue (SAAT), VAT has been shown to be associated with bone and muscle attenuation in adults (28), and in rats (29). VAT may be associated with adverse bone outcomes because it is associated with an adverse inflammatory profile (pro-resorptive), and ectopic adiposity deposits (12, 28, 29, 30). Ormsbee et al. hypothesized that increased adiposity leads to decreased growth hormone, decreased IGF, and increased inflammation, as well as potentially other hormonal disturbances that alter bone processes by increasing reactive oxidative species (ROS) production, increasing osteoclast activity, and decreasing osteoblast activity, as well as creating disturbances in muscle tissue via adipose infiltration and other processes (31). However, this mechanism was related to osteosarcopenic obesity. Interestingly, one additional review postulated that bone and muscle mass are also part of the endocrine system and play a larger role in inter-organ communication than previously thought. Results of the review demonstrated that in mice studies osteocalcin is a bone derived hormone (perhaps secreted by osteoblasts), and osteocalcin deficient mice had increased abdominal adiposity (32). More research is needed to explore these

potential mechanisms, to identify how and why abdominal adiposity may be adversely impacting BMC and BMD.

Overall, there were a number of striking differences among all of the reviewed studies and ours that could contribute to the noted similarities and differences. First, no two studies used the same variables when adjusting for covariates in models or partial correlations. All studies used one or more of the following variables as covariates: age, gender, race, pubertal status/state (or limited it via exclusion criteria), height, weight, BMI, fat mass, fat free mass. Second, a range of bone measures were used in the efforts to determine the relationships between body composition and bone mass. Further, DXA-derived TBLH bone measures were rarely used. Given the effects the bone of the head can have on total body BMC and BMD, this is a significant issue in the literature that deserves further examination. Third, a range of body composition measures were used, as well. For DXA body composition, most studies used total body fat mass and lean or fat-free mass; FMI and android fat mass were reported in only Goulding et al., Guftar Shaikh et al., and Laddu et al., respectively (13, 16, 17). Additionally, even if TBLH bone measures were used, TBLH measures for body composition were not used. The lack of consistency across measures throughout the studies makes the comparisons among them difficult and may partially contribute to the inconsistencies noted between body composition and bone mass/density in children.

There are several study limitations that must be considered. First, this was an exploratory analysis of cross-sectional data. Given the single snapshot of

cross-sectional designs, the lack of temporal order limits the causal inferences that can be made. Second, our exclusion criteria for high levels of formal sports most likely reduced the high-end of the distribution regarding physical activity and its consequential effects on bone in our sample. Additionally, our determination of engagement in bone-building physical activity was relatively crude and based on self-report measures. Both the exclusion criteria and methods used to evaluate bone-building physical activity may have limited the true relationships of both lean mass and bone-building physical activity with bone content and density in our sample. Third, and most important, analyses and exploratory sub-analyses were markedly limited by the small sample size. The small sample, coupled with the relatively large number of covariates needing to be considered, impacted the types of analyses that could be used, possibly truncated the true relationship effects between body composition and bone measures.

Offsetting these limitations were important strengths. First, the study used measures determined by DXA for key dependent and independent variables. Thus, all key variables were measured objectively and by a preferred clinical/validated method currently in the field. Second, the study was innovative due to its inclusion of appendicular lean mass (ALM) and ALMI. Few studies to date have explored the impact lean mass distribution has on bone mass in children and adolescents. Furthermore, the inclusion of android fat mass is a strength given the emerging evidence of its importance with bone health in the pathophysiology research.



Evaluating the relationship between android fat mass and bone mass may be another way of getting at the relationship between childhood obesity and bone health.

### **Conclusion**

In summary, we explored the relationships between body composition and bone mass/density of the total body and lumbar spine in a sample of 8- 14-year-old boys and girls participating in the Healthy Smiles trial. While we did not demonstrate the well-established positive relationship between lean mass and bone mass after adjusting for various confounding variables, we did demonstrate that fat mass index and android fat mass were negatively associated with bone mass. It is possible that due to pubertal status, sample size limitations, exclusion criteria for highly active children, and crude physical activity measures, that we limited our ability to observe relationships between lean tissue and bone, as would be expected based on previous literature (33, 34). However, we may have stumbled onto a theme that is emerging in the literature regarding the relationship between fat mass and bone mass in children. It appears that abdominal adiposity may have negative implications for bone health in children and preadolescents. Given that these specific measures are the variables of interest related to childhood obesity, more research and longitudinal studies are needed to determine if these findings can be replicated in the preteen population.

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A full listing of co-authors is unable to be determined at this time.

**Table 1.1: Healthy Smiles Validation Sample Characteristics (N = 44)**

|   | Girls mean (SD)<br>(n = 26) |          | Girls median | Boys mean (SD)<br>(n = 18) |          | Boys median | Total mean<br>(n = 44) | Total median |
|---|-----------------------------|----------|--------------|----------------------------|----------|-------------|------------------------|--------------|
| Age (yr)                                    | 11.77                       | (1.66)   | 12.0         | 11.89                      | (2.14)   | 12.5        | 11.82 (1.85)           | 12.00        |
| Age (days; hr)                              | 4431.65                     | (548.78) | 4475.50      | 4517.17                    | (758.6)  | 4816.5      | 4466.7 (654.4)         | 423.5        |
|   | 12.14                       |          | 12.26        | 12.38                      |          | 13.2        | 12.24                  | 12.39        |
| Height (cm)                                 | 150.87                      | (10.57)  | 153.2        | 156.02                     | (13.73)  | 160.9       | 152.98 (12.08)         | 154.78       |
| Weight (kg)                                 | 45.87                       | (11.94)  | 48.4         | 46.05                      | (11.19)  | 46.62       | 45.94 (11.51)          | 47.60        |
| Body mass index (kg/m <sup>2</sup> )        | 19.9                        | (3.66)   | 19.7         | 18.7                       | (2.96)   | 18.0        | 19.39 (3.41)           | 19.28        |
| Pubertal Status                             | 2.49                        | (0.68)   | 2.60         | 2.06*                      | (0.75)   | 1.90*       | 2.33 (0.73)            | 2.50         |
| NDS Calcium (mg/day)                        | 872.63**                    | (317.9)  | 829.19**     | 1064.09                    | (442.25) | 1020.94     | 952.78 (382.2)         | 915.48       |
| NDS Vitamin D (mcg/day)                     | 4.87**                      | (2.48)   | 4.35**       | 6.38                       | (4.35)   | 4.89        | 5.5 (3.43)             | 4.49         |
| Total Impact PA Score                       | 3.62                        | (2.95)   | 3.00         | 5.06                       | (3.44)   | 4.00        | 4.20 (3.20)            | 3.50         |
| Impact PA Bouts                             | 0.22                        | (0.16)   | 0.20         | 0.28                       | (0.17)   | 0.25        | 0.25 (0.16)            | 0.21         |
| TBLH Fat %***                               | 31.5                        | (9.1)    | 32.2         | 21.6                       | (11.4)   | 18.1        | 27.4 (11.1)            | 28.4         |
| TBLH Fat Mass (kg)***                       | 13.39                       | (6.65)   | 13.65        | 9.12                       | (6.16)   | 7.52        | 11.64 (6.73)           | 9.9          |
| TBLH Fat Mass Index (kg/m <sup>3</sup> )*** | 5.74                        | (2.65)   | 5.75         | 3.77                       | (2.54)   | 3.19        | 4.93 (2.76)            | 4.16         |
| Appendicular Lean Mass (kg)                 | 13.12                       | (2.97)   | 13.43        | 15.22                      | (4.24)   | 15.66       | 13.98 (3.65)           | 14.01        |
| Appendicular LMI (kg/m <sup>3</sup> )       | 5.68                        | (0.63)   | 5.66         | 6.10                       | (0.85)   | 5.91        | 5.85 (0.75)            | 5.75         |
| Fat Mass Ratio: arms+leg+trnk               | 1.13                        | (0.25)   | 1.10         | 1.15                       | (0.2)    | 1.13        | 1.14 (0.23)            | 1.1          |
| Android Fat %***                            | 35.42                       | (12.27)  | 35.4         | 23.93                      | (14.01)  | 20.4        | 30.72 (14.06)          | 31.5         |
| Android Fat Mas (kg)***                     | 1.11                        | (0.66)   | 1.02         | 0.74                       | (0.59)   | 0.49        | 0.96 (0.65)            | 0.77         |
| TBLH BMC (g)                                | 1371.59                     | (483.70) | 1295.75      | 1379.22                    | (428.08) | 1492.35     | 1374.709<br>(456.600)  | 1368.50      |
| TBLH BMD (g/cm <sup>2</sup> )               | 0.888                       | (0.115)  | 0.885        | 0.878                      | (0.100)  | 0.904       | 0.884 (0.108)          | 0.893        |
| TBLH AMZ                                    | 0.4                         | (0.8)    | 0.3          | 0.3                        | (0.7)    | 0.05        | 0.4 (0.7)              | 0.2          |
| L1-L4 BMC (g)                               | 36.725                      | (13.604) | 34.280       | 36.288                     | (11.56)  | 34.430      | 36.546 (12.67)         | 34.28        |
| L1-L4 BMD (g/cm <sup>2</sup> )              | 0.961                       | (0.237)  | 0.925        | 0.820                      | (0.103)  | 0.804       | 0.940 (0.204)          | 0.836        |
| L1-L4 AMZ                                   | 0.3                         | (1.3)    | -0.1         | -0.1                       | (0.6)    | -0.3        | 0.02 (1.15)            | -0.15        |

*Note.* NDS: Nutritional Data System; mg/day (milligrams/day); mcg/day (micrograms/day); TBLH: total body less head; LMI: lean mass index; BMD: bone mineral density; BMC: bone mineral content; AMZ: age-matched z-score.

\*N of 2 missing; \*\*N=25; \*\*\*Mann Whitney U test: sig difference by gender at  $p < 0.05$ .

**Table 1.2:** Spearman Correlation Coefficients Among Covariate, Body Composition Measures, and Bone Measure for the Healthy Smiles Validation Sample ( $N = 44$ )

|                            | TBLH BMC<br>(g) | TBLH BMD<br>(g/cm <sup>2</sup> ) | L1-L4 BMC<br>(g) | L1-L4 BMD<br>(g/cm <sup>2</sup> ) |
|----------------------------|-----------------|----------------------------------|------------------|-----------------------------------|
| Age (days)                 | 0.84**          | 0.85**                           | 0.76**           | 0.71**                            |
| Height (cm)                | 0.81**          | 0.74**                           | 0.77**           | 0.58**                            |
| Weight (kg)                | 0.89**          | 0.81**                           | 0.74**           | 0.73**                            |
| BMI                        | 0.58**          | 0.52**                           | 0.40**           | 0.53**                            |
| PDS†                       | 0.73**          | 0.72**                           | 0.77**           | 0.82**                            |
| Calcium§                   | 0.19            | 0.18                             | 0.16             | 0.06                              |
| Vitamin D§                 | 0.15            | 0.16                             | 0.06             | 0.05                              |
| Total Impact PA Score      | -0.06           | -0.06                            | -0.03            | -0.15                             |
| Impact PA bouts            | -0.05           | -0.03                            | 0.01             | -0.13                             |
| TBLH Lean Mass (kg)        | 0.87**          | 0.81**                           | 0.80**           | 0.65**                            |
| TBLH Lean Mass Index (LMI) | 0.73**          | 0.69**                           | 0.62**           | 0.57**                            |
| TBLH ALM (kg)              | 0.88**          | 0.83**                           | 0.81**           | 0.67**                            |
| TBLH ALMI                  | 0.80**          | 0.77**                           | 0.71**           | 0.64**                            |
| TBLH Tissue Percent Fat    | 0.22            | 0.17                             | 0.04             | 0.26                              |
| TBLH Fat Mass (kg)         | 0.52**          | 0.44**                           | 0.33*            | 0.47**                            |
| TBLH FMI                   | 0.35*           | 0.29                             | 0.15             | 0.35*                             |
| Android Fat Mass (kg)      | 0.44**          | 0.37**                           | 0.24             | 0.40**                            |

*Note.* TBLH: total body less head; BMC: bone mineral content; BMD: bone mineral density; L1-L4: lumbar vertebrae; 1-4; BMI: body mass index; PDS: pubertal development score; ALM: appendicular lean mass; ALMI: appendicular lean mass index; FMI: fat mass index.

\* $p < 0.05$ ; \*\* $p < 0.01$ ; † $N = 42$ ; § $N = 43$ .

**Table 1.3:** Spearman Correlation Coefficients Among Covariates, Body Composition Measures, and Bone Measures by Gender (Male,  $N = 18$ ; Female,  $N = 26$ )

|                            | TBLH BMC (g) |        | TBLH BMD (g/cm <sup>2</sup> ) |        | L1-L4 BMC (g) |        | L1-L4 BMD (g/cm <sup>2</sup> ) |        |
|----------------------------|--------------|--------|-------------------------------|--------|---------------|--------|--------------------------------|--------|
|                            | M            | F      | M                             | F      | M             | F      | M                              | F      |
| Age (days)                 | 0.74**       | 0.90** | 0.82**                        | 0.85** | 0.79**        | 0.79** | 0.78**                         | 0.83** |
| Height (cm)                | 0.91**       | 0.82** | 0.86**                        | 0.74** | 0.84**        | 0.77** | 0.75**                         | 0.71** |
| Weight (kg)                | 0.84**       | 0.92** | 0.75**                        | 0.85** | 0.70**        | 0.76** | 0.73**                         | 0.82** |
| BMI                        | 0.43         | 0.70** | 0.32                          | 0.65** | 0.27          | 0.50** | 0.43                           | 0.60** |
| PDS†                       | 0.80**       | 0.77** | 0.74**                        | 0.78** | 0.89**        | 0.78** | 0.88**                         | 0.83** |
| Calcium§                   | 0.27         | 0.02   | 0.17                          | 0.11   | 0.23          | 0.02   | 0.26                           | 0.03   |
| Vitamin D§                 | 0.06         | 0.13   | -0.01                         | 0.20   | -0.07         | 0.10   | 0.09                           | 0.10   |
| Total Impact PA Score      | 0.33         | -0.29  | 0.28                          | -0.28  | 0.29          | -0.21  | 0.31                           | -0.34  |
| Impact PA Bouts            | 0.35         | -0.30  | 0.34                          | -0.28  | 0.32          | -0.20  | 0.28                           | -0.34  |
| TBLH Lean Mass (kg)        | 0.93**       | 0.91** | 0.88**                        | 0.84** | 0.93**        | 0.80** | 0.92**                         | 0.80** |
| TBLH Lean Mass Index (LMI) | 0.77**       | 0.75** | 0.74**                        | 0.72** | 0.82**        | 0.54** | 0.90**                         | 0.65** |
| ALM (kg)                   | 0.94**       | 0.92** | 0.90**                        | 0.87** | 0.93**        | 0.83** | 0.93**                         | 0.83** |
| ALMI                       | 0.84**       | 0.82** | 0.81**                        | 0.81** | 0.85**        | 0.66** | 0.91**                         | 0.75** |
| TBLH Tissue Percent Fat    | -0.06        | 0.53** | -0.19                         | 0.48** | -0.31         | 0.36   | -0.20                          | 0.42*  |
| TBLH Fat Mass (kg)         | 0.28         | 0.75** | 0.15                          | 0.68** | 0.06          | 0.56** | 0.17                           | 0.63** |
| TBLH FMI                   | 0.03         | 0.63** | -0.09                         | 0.58** | -0.19         | 0.42*  | -0.09                          | 0.52** |
| Android Fat Mass (kg)      | 0.18         | 0.64** | 0.03                          | 0.58** | -0.03         | 0.43*  | 0.02                           | 0.54** |

*Note.* TBLH: total body less head; BMC: bone mineral content; BMD: bone mineral density; L1-L4: lumbar vertebrae 1-4; BMI: body mass index; PDS: pubertal development score; ALM: appendicular lean mass; ALMI: appendicular lean mass index; FMI: fat mass index.

\* $p < 0.05$ ; \*\* $p < 0.01$ ; † $N = 16$  for Males; § $N = 25$  for Females; italicized correlations indicate significant differences between genders.

**Table 1.4:** Partial Correlations between Body Composition and Bone Measures After Adjusting for Age, Gender, Height, Weight, and Pubertal Status ( $N = 44$ )

|                             | TBLH BMC<br>(g)    | TBLH BMD<br>(g/cm <sup>2</sup> ) | L1-L4 BMC<br>(g) | L1-L4 BMD<br>(g/cm <sup>2</sup> ) |
|-----------------------------|--------------------|----------------------------------|------------------|-----------------------------------|
| TBLH Lean Mass (kg)         | 0.12               | 0.14                             | 0.14             | -0.02                             |
| TBLH Lean Mass Index (LMI)† | 0.05               | 0.10                             | -0.10            | -0.12                             |
| TBLH ALM (kg)               | 0.21               | 0.21                             | 0.14             | 0.07                              |
| TBLH ALMI†                  | 0.04               | 0.18                             | -0.06            | -0.03                             |
| TBLH Fat Mass (kg)          | -0.19              | -0.20                            | -0.24            | -0.07                             |
| TBLH FMI†                   | -0.42**            | -0.19                            | -0.43**          | -0.05                             |
| Android Fat Mass (kg)       | -0.29 <sup>^</sup> | -0.35*                           | -0.22            | -0.11                             |

†Height was excluded from fitted models.

<sup>^</sup> $p < 0.06$ ; \* $p < 0.05$ ; \*\* $p < 0.01$ .

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## CHAPTER 2

Is Healthy Body Composition Just a Hop, Jump, and a Skip Away:  
Relationships Among Physical Activity, Sedentary Behavior,  
and Child Body Composition

### Abstract

Understanding the relationships between physical activity (PA), sedentary behavior, body composition, and childhood obesity is imperative, given the potential health implications. The purpose of this study was to explore the relationships between objectively measured physical activity and sedentary behavior, with DXA-derived body composition in a sample of 8- to 14-year-old boys and girls. Participants were enrolled in the Healthy Smiles trial's baseline validation sample ( $N = 44$ ), and completed a laboratory session where a total body DXA scan was performed. DXA measures included total body less head (TBLH) lean mass, appendicular lean mass, percent fat, fat mass, android fat mass, and their respective indices. Following the laboratory session, participants wore an accelerometer for 8 days to assess minutes of and percent time in total PA, light, moderate, vigorous, and MVPA, as well as sedentary time. Descriptive statistics, bivariate associations, and partial correlations controlling for covariates were performed. Partial correlations showed moderate, vigorous, and MVPA were positively associated with lean mass, lean mass index ( $r = 0.37-0.48, p < 0.05$ ), and appendicular lean mass index ( $r = 0.34, p < 0.05$ ). Additionally, they showed that moderate, vigorous, and MVPA were moderately negatively associated with all fat measures (percent fat, fat mass, fat mass index, and android fat mass) ( $r = -0.32 - -0.52, p < 0.05$ ). No relationships were seen between body composition and total PA, light PA, or sedentary time. Physical activity intensity may be more important than total physical activity and sedentary time with

regard to child body composition and potentially childhood obesity, but more research is needed to confirm these results.

### **Introduction**

Few children meet physical activity recommendations despite the recommendations and potential health benefits. North American youth spend approximately 40-60% of their waking hours (1), about 6-8 hours per day, engaging in sedentary behavior (2-4). Given the health implications, it is important to understand the relationships among physical activity, sedentary behavior, body composition, and childhood obesity.

While numerous studies have evaluated relationships among physical activity, sedentary behavior, and obesity in children, the data are inconclusive (4-6). Several studies of various designs have shown inverse relationships between physical activity and BMI and/or body fat (7-11). Others have demonstrated no relationship between these variables (6, 11, 12). A few studies have indicated that intensity of activity may affect body composition more than total physical activity alone (7, 8-10), with participants engaging in vigorous activity being more likely to have lower obesity rates and lower body fat (8, 13).

Evidence indicates there are relationships between increased screen time (e.g., TV time) and increased obesity (1, 4, 14). Evidence also indicates that as children age, sedentary behavior increases and light activity decreases (15). Tremblay et al. reported that more than 2 hours per day of sedentary behavior was associated with an

unfavorable body composition (4). Many studies have consistently found a relationship in children between self-reported screen time and body composition; however, the relationship is less clear when objectively measured total sedentary time is used (1, 16). Inconsistencies are likely due to the heterogeneous nature of the constructs, study designs, and measures as performed.

Therefore, the purpose of this study was to explore the relationships between accelerometer derived physical activity, sedentary behavior, and DXA body composition in a subsample of 8- to 14-year-old boys and girls who participated in the Healthy Smiles Program.

## **Methods**

### **Design**

The study investigated the cross-sectional relationships between objectively measured physical activity and sedentary behavior with body fat, lean mass, appendicular lean mass (ALM), and android (abdominal) fat mass in a sample of preadolescent boys and girls enrolled in the Healthy Smiles Program. This analysis used the baseline validation data from Healthy Smiles, a multi-component randomized control trial designed to increase physical activity (PA), reduce sedentary practices, and promote healthy diets among preadolescents who obtained orthodontia care. The study was approved by the San Diego State University Institutional Review Board.

## **Participants and Procedures**

A detailed description of participant recruitment and inclusion criteria, as well as overall protocol and procedures are provided in Chapter 1. Briefly, private and public orthodontic offices from Southern California and Tijuana, Mexico were recruited to participate in the Healthy Smiles Program. Patients 8-14 years receiving orthodontia care from participating providers were then recruited into the study. Overall, 44 preteens participated in the baseline validation component of the trial. Validation participants were a randomly selected subsample from the larger Healthy Smiles Program. Participants completed an introductory home visit, where the parent and child signed consent and assent forms, a single laboratory session, wore an accelerometer for 8 days following the laboratory session, and completed three phone interviews during the 8 days.

## **Measures**

Anthropometric, DXA body composition measures, Phone Interviews, and Maturation Status are described in detail in Chapter 1. These measures will be described in brief.

**Anthropometrics.** During the laboratory session, participants' height (wall mounted stadiometer) and weight (Health-o-meter® digital scale) were measured to the nearest 0.5cm and 0.1kg, respectively, with no shoes and minimal clothing. Trained staff performed all measures, and measures were repeated to ensure reliability.

**DXA Body Composition.** To evaluate body composition, each participant had a total body DXA scan performed (Lunar Prodigy densitometer; GE/Lunar Corp., Madison, WI). All scans were performed by certified technicians, and daily quality assurance checks were performed using the manufacturer's calibration block. Participants wore loose fitting athletic wear and removed any metal and/or hard plastic (e.g., jewelry) prior to scanning. Bone-free fat and lean mass measures were used in analyses (17), as were total body less head (TBLH) measures used in analyses in accordance with field standards (17, 18). Body composition variables analyzed included TBLH lean mass (kg), TBLH lean mass index (LMI), appendicular lean mass (ALM; kg), appendicular lean mass index (ALMI), TBLH fat mass (kg), TBLH fat mass index (FMI), and android fat mass (kg). ALM was calculated by summing the lean mass of the arms and legs. All indices were calculated by dividing the variable of interest by height in meters squared.

**Objective Physical Activity and Sedentary Behavior.** Following the laboratory session, validity participants wore an ActiGraph GT3X (ActiGraph, Pensacola, FL) accelerometer for 8 days, including week and weekend days, to objectively assess preadolescent physical activity and sedentary behavior. The GT3X measures and records time varying accelerations in the vertical, medio-lateral, and antero-posterior axes, ranging in magnitude from 0.5 to 2.5g. The monitor was attached to an elastic belt and fastened snugly on the right hip, level with the waist, along the midaxillary line. Participants were instructed to wear the monitor from the time they woke up to the time they went to bed, in order to obtain a minimum of

12 hours of wear time per day, and to take it off for swimming or bathing. Monitors were initialized according to manufacturer's specifications and collected data in 1s epochs. After data collection, accelerometers were downloaded (GT3X firmware version 2.2) for later data reduction and analysis. Data were screened and cleaned using MeterPlus 4.3 software and ActiLife (6.11.15) and were aggregated and analyzed in 15s epochs. Each participant had to wear the device for minimum of 4 days for a minimum of 10 hours per day of wear. Non-wear time was defined as 120 minutes of consecutive zeros. Analysis was performed by applying the Choi algorithm (19) and then data were visually inspected for any wear times <1 hour or >16 hours for possibility of device malfunction or abnormal wear. Sleep filters were applied as needed, on an individual basis. Everson cut points were used to determine activity intensity and sedentary time (20). Percent of time spent in sedentary, light, moderate, vigorous activity, MVPA and total daily PA were assessed.

**Phone Interviews.** Phone interviews were conducted with both child and parent on 3 separate days, while the child wore the accelerometer. Demographics, physical activity, sedentary behavior, diet, tobacco use, and rules in the home were reported on. When possible, families completed a weekend and 2-week day recall; however if families were unable to meet this measurement schedule, any 3 days of recalls were accepted.

**Maturation Status.** The Pubertal Development Scale (PDS) was used to assess pubertal stage of the participant. Methods for calculating participants' PDS score were previously reported (see Chapter 1). Briefly, PDS was calculated following

previously established methods (21, 22), with each item scored on a 1-4 ordinal scale, with the exception of menarche which was coded dichotomously as 1 for “no” or “premenarcheal” and 4 for “yes” or “postmenarcheal.” An overall score was calculated by summing the scores and dividing by 5 (21), since there was no missing data among respondents.

### **Statistical Analyses**

Statistical analyses were performed using SPSS (version 21) and R: A Language and Environment for Statistical Computing (version 3.1.2). Data were originally entered in SPSS; however, *R* was employed for more detailed analyses. Frequencies and distributions of all variables were reviewed. Means (*SD*) and medians were calculated for participant’s physical characteristics, body composition, and physical activity and sedentary behavior for the total sample and by gender.

Bivariate analyses among physical characteristics, body composition, physical activity and sedentary measures included Mann-Whitney U tests and Spearman correlation coefficients. Mann-Whitney U tests were used to characterize the relationship between gender and all other variables. Spearman correlation coefficients were used to determine the strength of the relationship between physical activity and sedentary behavior and potential covariates: age in days, gender, height, weight, BMI, pubertal status, and leg length. Spearman correlation coefficients were also used to characterize the relationship between physical activity/sedentary measures and



dependent variables: TBLH fat percent and mass, android fat mass, TBLH lean mass and lean mass index (LMI), and appendicular lean mass (ALM) and ALMI.

Partial correlation was used to determine the associations between body composition and physical activity/sedentary measures, while holding the effects of covariates constant. First, models were fit to the dependent variable of interest (e.g., TBLH lean mass) which included the following covariates: age in days, gender, height, weight, pubertal status score, leg length. The same model was then fit to the corresponding independent variables of interest (e.g., percent sedentary time). When models were fit for/with indexed variables (e.g., ALMI), height was excluded, since it was already accounted for during the indexing process. Once the models were fit, the correlations between the residuals from the fitted models were determined.

## **Results**

### **Physical Characteristics**

Physical characteristics stratified by gender are presented in Table 2.1. Participants were a sample of boys and girls (18 boys, 26 girls) aged 8-14 years, with a mean weight of 45.9 kg (11.5), height of 153cm (12.1), leg length of 81.2cm (7.0), and mean BMI of 19.4 (3.4). Twenty-seven (61.4%) participants were Caucasian (one participant who was Middle Eastern was coded as Caucasian for analyses), 13 (29.5%) were Hispanic, and 4 (9.1%) were Asian. All fat measures in girls were statistically significantly higher compared to the boys ( $p < 0.05$ ). Girls' TBLH lean mass and LMI were statistically significantly less ( $p < 0.05$ ) than the same measures for boys.

Pubertal status, ALM, and ALMI approached significant differences ( $p < 0.09$ ) between genders, with girls being further into puberty, and having less appendicular lean mass than boys. No differences were found for the remaining physical characteristics.

Physical activity and sedentary behavior measures stratified by gender are presented in Table 2.2. Four female participants were excluded from analyses. One did not wear the accelerometer and three were excluded for not meeting wear time criteria. Overall, participants wore the accelerometer for an average of 5,950 minutes, or approximately 13.5 hours per day, and about 7.5 calendar days. Both boys and girls spent approximately 66% of their time being sedentary, and 28% engaged in light activity. Time spent in moderate (MPA) and vigorous PA (VPA) was significantly different between boys and girls, with boys spending a greater percent of their time in moderate, vigorous, and MVPA. Finally, seven participants (15.9%) met physical activity guidelines.

### **Bivariate Correlations**

Spearman correlation coefficients among covariates (e.g., age) and PA/Sedentary measures (e.g., percent sedentary time) with the dependent body composition measures (e.g., TBLH lean mass) for the entire validation sample ( $N = 40$ ) are presented in Table 2.3. Here only large correlation coefficients are highlighted ( $r = 0.4-0.9$ ,  $p < 0.01$ ). Among covariates all (age, height, weight, BMI, pubertal status, leg length) were significantly positively associated with the percent

time spent being sedentary. The significant relationships between covariates and percent time engaged in the various PA levels were all negative, with the exception of BMI and percent time engaged in vigorous activity. All covariates were significantly negatively associated with the percent time engaged in light and total PA. Further, weight, BMI, and pubertal status were negatively associated with percent time in MPA and MVPA; however, only weight was significantly associated with percent time in VPA. Bivariate relationships between independent and dependent variables followed the same trend. Percent time spent being sedentary was significantly positively associated with all body composition variables except TBLH TPF and FMI. The significant relationships between body composition variables and percent time engaged in various PA levels were all negative. Percent time in light PA was negatively associated with all fat measures. Percent time being physically active (total PA) was negatively associated with all body composition variables, except TBLH TPF and FMI.

Spearman correlation coefficients among covariates (e.g., age) and PA/sedentary measures (e.g., percent sedentary time) with the dependent variable body composition measures stratified by gender (18 males, 22 females) are presented in Table 2.4. Here only larger correlation coefficients are highlighted ( $r = 0.4-0.9$ ,  $p < 0.01$ ). Among boys and girls, age in days was moderately-strongly positively associated with percent sedentary time, and moderately-negatively associated with percent time in light PA (LPA). Among girls, while all covariates were positively associated with percent in sedentary time, weight and pubertal status were the only

variables that were moderately-strongly positively associated with percent in sedentary time. Additionally, among girls, weight, BMI, and PDS were all moderately-strongly negatively associated with percent time in MPA, VPA, MVPA, and total PA; weight and BMI were also moderately-strongly negatively associated with percent time in light PA. Among boys, pubertal status was moderately-strongly negatively associated with percent time in light PA, and height was moderately negatively associated with percent time in total PA.

Bivariate relationships between independent and dependent variables followed similar trends. Among boys and girls, TBLH LM, LMI, ALM, and ALMI were positively moderately-strongly associated with percent time being sedentary, and negatively moderately to moderately-strongly associated with percent time in light and total PA. Among girls, TBLH TPF, FM, FMI, and android fat mass were positively moderately-strongly associated with percent time being sedentary, and were negatively moderately-strongly associated with percent time in light, moderate, vigorous, MVPA, and total PA. LMI was also negatively moderately-strongly associated with percent time in MVPA. No fat variables were associated with percent time in sedentary or any PA levels in boys.

### **Partial Correlations**

**Modeling.** Adjusted  $r$ -squared values for non-indexed dependent variables (TBLH LM, ALM, TBLH TPF, TBLH FM, Android FM), when modeled with independent variables (percent sedentary time, percent in light, moderate, vigorous

PA, MVPA, and total PA), were moderately-high to high (0.79-0.93). Similarly, adjusted  $r$ -squared values for indexed dependent variables (i.e., LMI, ALMI, FMI), when modeled with independent variables, were moderately-high to high (0.70-0.89). Adjusted  $r$ -squared values for independent variables modeled with non-indexed dependent variables were weak to moderate (0.26-0.45), as were adjusted  $r$ -squared values for the independent variables modeled with indexed dependent variables (0.21-0.47). The fitted models demonstrated that age in days, height (when included), weight, pubertal status, gender, and leg length, were significantly related to all key variables of interest, throughout the separate models.

**Correlations.** Partial correlations between the residuals of the fitted models are presented in Table 2.5. After taking all covariates into account, within each of the fitted models, most of the relationships between body composition and percent time being sedentary, and PA levels, either disappeared or were reversed, demonstrating the confounding effect of the covariates. After accounting for covariates, TBLH LM and LMI were moderately positively associated with percent time in MPA, VPA, and MVPA. ALM approached statistical significance with percent time in MPA and MVPA ( $r = 0.31, p < 0.1$ ). ALMI and percent time in MVPA also approached statistical significance ( $r = 0.30, p < 0.1$ ), and ALMI was weakly positively associated with percent time in MPA ( $r = 0.34, p < 0.05$ ). For fat variables, TBLH TPF and TBLH FM were moderately negatively associated with percent time in moderate, vigorous, and MVPA ( $r = -0.42 - -0.52, p < 0.01$ ). TBLH FMI approached statistical significance with percent time in VPA, and was moderately negatively associated with

percent time in MPA and MVPA. Finally, android FM was moderately negatively associated with percent time in moderate, vigorous, and MVPA ( $r = -0.32 - -0.40$ ,  $p < 0.05$ ). There were no significant relationships between any body composition variables and percent time in sedentary, light, or total PA.

### **Discussion**

This study explored objectively measured physical activity, sedentary behavior, and body composition (fat and lean mass), in a sample of 8- to 14-year-old boys and girls. Among the bivariate total sample correlations, the percent of time spent being sedentary was positively associated with all covariates (i.e., other independent variables needing to control for, such as age), as well as all body composition measures. Conversely, in general, the percent of time engaged in any PA level was negatively associated with covariates. When bivariates were explored by gender, these trends were maintained; however, girls demonstrated more significant relationships than boys. Therefore, these trends indicated that older, taller, heavier kids, further into puberty, spent a greater percentage of their time being sedentary and less time being physically active. These trends also indicated potential confounding or moderating effects given that covariates were also positively related to body composition measures (e.g., older children had more lean mass), and that body composition measures, in the bivariate analyses, were positively related to percent time spent being sedentary (i.e., increased sedentary time, increased lean mass) and negatively related to percent time engaged in PA (i.e., increased PA, decreased lean mass). However, in our sample of

preadolescents, after controlling for age in days, gender, height, weight, pubertal status, and leg length, bivariate relationships either disappeared or reversed. Percent time in moderate, vigorous, and MVPA were the only variables still associated with body composition measures. Specifically, percent time in moderate, vigorous, and MVPA were all significantly positively associated with TBLH LM and LMI, indicating that as the preadolescents' percent time engaged in moderate, vigorous, and MVPA was higher, their TBLH LM and LMI was higher, as well. Further, percent time in moderate, vigorous, and MVPA were all significantly negatively associated with all fat measures, indicating that as the preadolescents' percent time engaged in moderate, vigorous, and MVPA was higher, their TBLH body fat percentage, TBLH FM, FMI, and android (abdominal) adiposity was lower.

Our PA and sedentary time trends were similar to those reported in the literature. In general, older adolescents are less likely to engage in PA than younger children, and boys tend to engage in greater amounts of MVPA compared to girls (2). In our sample, age was negatively associated with all PA levels, indicating that older preadolescents were less active. Further, we found significant gender differences for mean moderate, vigorous, and MVPA time. In our sample, boys engaged in about 1.5 more hours of moderate activity, and about 1 hour to 1.5 more hours of vigorous activity than girls. And very few participants met PA recommendations of 60 minutes of MVPA per day (15.9%).

Our finding that after adjustment percent time in MPA, VPA, and MVPA were significantly negatively associated with all DXA body fat measures (TBLH TPF, FM,

FMI, and Android FM) is supported by several themes pervasive in the literature. In general, physical activity determined by accelerometry has been shown to be inversely related to BMI and/or body fat (7-10, 23-26), despite the inconsistent methods used to determine body fat (BMI, WC, BIA, DXA). One prospective study, however, concluded that while there is an inverse relationship, it is a product of increased body fat leading to decreased MVPA, not the other way around (6). Additionally, the literature supports that intensity of PA is more important when evaluating body fat in children and adolescents than total PA time, with most studies noting inverse relationships only between MVPA and body fat (7-9, 13, 23-26), and a few only noting inverse relationships between VPA and body fat (8, 13). Among studies that evaluated sedentary time, most noted no significant relationship between sedentary time and body fat (6, 10, 13, 23-26, 27). There were a few exceptions; Marques et al. found no significant relationship between sedentary time and body fat, with the exception of FMI (25). However, Herman et al. found that adiposity increased across sedentary time tertiles from lowest to highest (28).

Overall, there were some striking differences between our study and those in the literature that may have impacted some of our comparisons. First, no two studies used the same covariates with the exception of age, pubertal status, and gender. Additional covariates ranged from height and weight to mother's weight, child birth weight, SES, various activity components, among others. Additionally, fat mass measures were inconsistent across studies as well, with some combination of BMI and waist circumference, BIA fat mass or FMI, or DXA fat mass, FMI, and trunk fat mass.



Only one other study used DXA android fat mass, all others used trunk fat mass which includes the torso, abdomen, and pelvic region. These differences make it difficult to directly compare our study with prior studies' findings. Interestingly, among reviewed studies none included lean mass and PA or sedentary time. This is of particular interest given the metabolic properties of lean mass, that an individual who meets PA recommendations can also be sedentary and the repercussions of this on body composition may not be fully understood, and that different fitness components have been shown to mediate the relationship between PA and fat mass. Therefore, we were unable to compare our findings with those from the literature, that MVPA was positively associated with lean mass, and there was no significant association between sedentary time and lean mass after adjustments. As the distribution of body composition (fat and lean mass) is emerging as another factor in the relationship between body composition and health indicators, lean mass relationships should be further explored. Finally, PA intensities evaluated were somewhat inconsistent outside of MVPA. A few studies did not include sedentary time, and light PA was rarely evaluated independent of total PA.

Several limitations in this study are important to note. First, the cross-sectional study design limits any causal inferences. Second, excluding preadolescents participating in high levels of formal sports will have limited the effects of the relationship between PA and body composition. It may have also limited our ability to do further exploratory analyses regarding body composition difference between participants meeting and not meeting PA recommendations, with only seven in our

sample meeting recommendations. Third, exploratory analyses and sub-analyses were severely limited by our small sample size. Additionally, it is possible the relationship effects between PA, sedentary behavior, and body composition may have been truncated as a product of the small sample size.

Offsetting these limitations were a few key strengths. First, only objective measures were used for all variables of interest. Accelerometers were used to detect PA and sedentary time, and DXA was used to determine body composition. By using accelerometry we were able to capture all sedentary time, not just screen time, as well as the varying levels of physical activity, instead of solely MVPA. This strengthens the study and study conclusions. Using DXA allowed us to directly compare how PA and sedentary time related to different components of and the distribution of the preadolescents body composition via a well-validated measure. By including lean mass, appendicular lean mass, and android fat mass in our analyses, we were able to contribute some newer areas of body composition exploration to the literature.

### **Conclusion**

In summary, we explored the relationships between objectively measured physical activity, sedentary behavior, and body composition (lean and fat mass) in a sample of 8- to 14-year-old boys and girls participating in the Healthy Smiles trial. Despite our small sample size, we identified inverse relationships between percent time in MPA, VPA, and MVPA, and DXA-derived fat mass, similar to the literature. We found no relationship between percent time being sedentary and any body

composition measures. And we expanded upon the current literature by exploring the relationships between lean mass, appendicular lean mass, android fat mass, and physical activity, demonstrating that lean mass variables were positively associated and android fat mass was negatively associated with percent time in MPA, VPA, and MVPA. Future studies should explore the probable dynamic relationships among physical activity, sedentary time, body composition, and body composition distribution in children and adolescents to better understand how they are related, and which components greatly impact varying health indicators. Ideally, these relationships would be explored between those meeting and not meeting PA and sedentary time recommendations, by BMI categories, fat and lean mass percentages, and fat and lean mass distributions. Additionally, these cross-sectional data call for longitudinal studies with larger sample sizes to be employed to confirm the direction of these relationships. Given our exploratory findings, and the similarities with the literature, it appears that MVPA impacts body composition of 8- to 14-year-olds, and it should continue to be studied and included in the efforts to prevent and reduce childhood obesity.

Acknowledgement: This chapter may be prepared for a potential publication.

A full listing of co-authors is unable to be determined at this time.

**Table 2.1:** Healthy Smiles Validation Sample Physical Characteristics ( $N = 44$ )

|                                      | Girls mean ( <i>SD</i> )<br>( <i>n</i> = 26) |          | Girls median | Boys mean ( <i>SD</i> )<br>( <i>n</i> = 18) |         | Boys median | Total mean<br>( <i>n</i> = 44) | Total median |
|--------------------------------------|--|----------|--------------|---|---------|-------------|--------------------------------|--------------|
| Age (yr)                             | 11.77  | (1.66)   | 12.0         | 11.89                                       | (2.14)  | 12.5        | 11.82 (1.85)                   | 12.00        |
| Age (days; hr)                       | 4431.65                                      | (548.78) | 4475.50      | 4517.17                                     | (758.6) | 4816.5      | 4466.7 (654.4)                 | 423.5        |
|                                      | <i>12.14</i>                                 |          | <i>12.26</i> | <i>12.38</i>                                |         | <i>13.2</i> | <i>12.24</i>                   | <i>12.39</i> |
| Height (cm)                          | 150.87                                       | (10.57)  | 153.2        | 156.02                                      | (13.73) | 160.9       | 152.98 (12.08)                 | 154.78       |
| Weight (kg)                          | 45.87  | (11.94)  | 48.4         | 46.05                                       | (11.19) | 46.62       | 45.94 (11.51)                  | 47.60        |
| Body mass index (kg/m <sup>2</sup> ) | 19.9   | (3.66)   | 19.7         | 18.7  | (2.96)  | 18.0        | 19.39 (3.41)                   | 19.28        |
| Pubertal Status                      | 2.49   | (0.68)   | 2.60         | 2.06*                                       | (0.75)  | 1.90*       | 2.33 (0.73)                    | 2.50         |
| Leg Length (cm) (n=43)               | 80.5   | (5.9)    | 80.0         | 82.2  | (8.4)   | 83.4        | 81.23 (7.02)                   | 81.2         |
| TBLH Fat %***                        | 31.5   | (9.1)    | 33.2         | 21.6  | (11.4)  | 18.1        | 27.4 (11.1)                    | 28.4         |
| TBLH Fat Mass (kg)***                | 13.39  | (6.65)   | 13.65        | 9.12  | (6.16)  | 7.52        | 11.64 (6.73)                   | 9.9          |
| TBLH Fat mass index (kg/m2)***       | 5.74   | (2.65)   | 5.75         | 3.77  | (2.54)  | 3.19        | 4.93 (2.76)                    | 4.16         |
| TBLH Lean mass (kg)***               | 26.81  | (5.67)   | 26.82        | 31.40                                       | (8.34)  | 31.86       | 28.69 (7.17)                   | 28.58        |
| TBLH Lean mass index (kg/m2)***      | 11.63  | (1.2)    | 11.34        | 12.63                                       | (1.6)   | 12.20       | 12.04 (1.44)                   | 11.98        |
| Appendicular Lean mass (kg)          | 13.12  | (2.97)   | 13.43        | 15.22                                       | (4.24)  | 15.66       | 13.98 (3.65)                   | 14.01        |
| Appendicular LMI (kg/m2)             | 5.68   | (0.63)   | 5.66         | 6.10  | (0.85)  | 5.91        | 5.85 (0.75)                    | 5.75         |
| Fat Mass Ratio: arms+leg/trnk        | 1.13   | (0.25)   | 1.10         | 1.15  | (0.2)   | 1.13        | 1.14 (0.23)                    | 1.1          |
| Android Fat %***                     | 35.42  | (12.27)  | 35.4         | 23.93                                       | (14.01) | 20.4        | 30.72 (14.06)                  | 31.5         |
| Android Fat Mass (kg)***             | 1.11   | (0.66)   | 1.02         | 0.74  | (0.59)  | 0.49        | 0.96 (0.65)                    | 0.77         |

*Note.* TBLH: total body less head; LMI: lean mass index,

\**N* of 2 missing; \*\**N* = 25; \*\*\*Mann Whitney U test: sig difference by gender at  $p < 0.05$ .

**Table 2.2:** Healthy Smiles Validation Sample Physical Activity Characteristics ( $N = 40$ )

|                             | Girls mean ( <i>SD</i> )<br>( $n = 22$ ) |          | Girls median | Boys mean ( <i>SD</i> )<br>( $n = 18$ ) |          | Boys median | Total mean<br>( $n = 40$ ) | Total median |
|-----------------------------|--|----------|--------------|---|----------|-------------|----------------------------|--------------|
| Total Wear Time (Min)       | 5906.8                                   | (1175.6) | 5773.5       | 6004.3                                  | (1397.2) | 6366.5      | 5950.6 (1259.1)            | 6194.0       |
| Total Wear Time (Days)      | 7.3                                      | (1.4)    | 7.0          | 7.5                                     | (1.7)    | 8.0         | 7.4 (1.5)                  | 7.5          |
| Sedentary Time (Min)        | 3999.7                                   | (933.39) | 4040.0       | 3877.7                                  | (942.7)  | 4092.4      | 3944.8 (927.5)             | 4092.4       |
| Sedentary Time (%)          | 67.5                                     | (6.5)    | 66.7         | 64.6                                    | (6.5)    | 65.5        | 66.2 (6.6)                 | 65.9         |
| Light PA Time (Min)         | 1647.1                                   | (392.2)  | 1707.1       | 1716.6                                  | (605.5)  | 1744.6      | 1678.4 (493.8)             | 1710.8       |
| Light PA Time (%)           | 28.1                                     | (4.9)    | 28.5         | 28.3                                    | (5.8)    | 28.2        | 28.2 (5.2)                 | 27.9         |
| Moderate PA Time (Min)***   | 184.3                                    | (101.1)  | 161.4        | 269.8                                   | (84.6)   | 269.8       | 222.7 (102.4)              | 217.4        |
| Moderate PA Time (%)***     | 3.1                                      | (1.7)    | 2.7          | 4.6                                     | (1.3)    | 4.4         | 3.8 (1.7)                  | 3.7          |
| Vigorous PA Time (Min)***   | 75.7                                     | (56.5)   | 54.6         | 140.3                                   | (75.2)   | 146.9       | 104.8 (72.4)               | 76.8         |
| Vigorous PA Time (%)***     | 1.3                                      | (0.9)    | 0.92         | 2.5                                     | (1.4)    | 2.1         | 1.8 (1.3)                  | 1.5          |
| MVPA Time (Min)***          | 259.9                                    | (153.8)  | 217.9        | 410.1                                   | (130.3)  | 392.3       | 327.5 (160.8)              | 309.0        |
| MVPA Time (%)***            | 4.4                                      | (2.6)    | 3.5          | 7.1                                     | (2.4)    | 6.5         | 5.6 (2.8)                  | 5.7          |
| Total PA Time (Min)         | 1907.0                                   | (490.0)  | 2017.3       | 2126.7                                  | (670.3)  | 2242.0      | 2005.9 (580.9)             | 2053.1       |
| Total PA Time (%)           | 32.5                                     | (6.5)    | 33.3         | 35.4                                    | (6.5)    | 34.5        | 33.8 (6.6)                 | 34.1         |
| Meeting PA Rec's ( $N/\%$ ) | 3 (13.6%)                                |          |              | 4 (22.2%)                               |          |             | 7 (15.9%)                  |              |

*Note.* Moderate to Vigorous Physical Activity; Rec's: Recommendations

\*\*\*Mann Whitney U test: sig difference by gender at  $p < 0.05$ .

**Table 2.3:** Spearman Correlation Coefficients Among Covariates, Body Composition Measures, and Percent Time Spent Being Physical Activity and Sedentary for the Healthy Smiles Validation Sample ( $N = 40$ )

|                            | Sedentary | Light    | Moderate | Vigorous | MVPA    | Total PA |
|----------------------------|-----------|----------|----------|----------|---------|----------|
| Age (days)                 | 0.65**    | -0.68**  | -0.23    | -0.09    | -0.14   | -0.64**  |
| Height (cm)                | 0.42**    | -0.525** | -0.03    | 0.13     | 0.04    | -0.42**  |
| Weight (kg)                | 0.60**    | -0.51**  | -0.42**  | -0.43**  | -0.49** | -0.60**  |
| BMI                        | 0.50**    | -0.34*   | -0.48**  | 0.63**   | -0.61** | -0.50**  |
| PDS†                       | 0.66**    | -0.55**  | -0.44**  | 0.36*    | -0.46** | -0.66**  |
| Leg Length                 | 0.42**    | -0.48**  | -0.13    | 0.12     | 0.02    | -0.42**  |
| TBLH Lean Mass (kg)        | 0.50**    | -0.59**  | -0.06    | 0.02     | -0.03   | -0.50**  |
| TBLH Lean Mass Index (LMI) | 0.45**    | -0.58**  | -0.02    | -0.04    | -0.04   | -0.45**  |
| TBLH ALM (kg)              | 0.50**    | -0.60**  | -0.07    | 0.01     | -0.04   | -0.50**  |
| TBLH ALMI                  | 0.52**    | -0.62**  | -0.11    | -0.10    | -0.11   | -0.52**  |
| TBLH Tissue Percent Fat    | 0.31      | -0.01    | 0.58**   | -0.71**  | -0.70** | -0.31    |
| TBLH Fat Mass (kg)         | 0.43**    | -0.19    | -0.57**  | -0.68**  | -0.69** | -0.43**  |
| TBLH FMI                   | 0.37*     | -0.10    | -0.57**  | -0.71**  | -0.70** | -0.37*   |
| Android Fat Mass (kg)      | 0.42**    | -0.18    | -0.56**  | -0.69**  | -0.68** | -0.42**  |

*Note.* TBLH: total body less head; BMI: body mass index; PDS: pubertal development score; ALM: appendicular lean mass; ALMI: appendicular lean mass index; FMI: fat mass index.

\* $p < 0.05$ ; \*\* $p < 0.01$ ; † $N = 38$ ; § $N = 39$ .

**Table 2.4:** Spearman Correlation Coefficients Among Covariates, Body Composition Measures, and Percent of Physical Activity and Sedentary Time Measures by Gender (Male,  $N = 18$ ; Female,  $N = 22$ )

|                            | Sedentary |         | Light   |         | Moderate |         | Vigorous |         | MVPA   |         | Total PA |         |
|----------------------------|-----------|---------|---------|---------|----------|---------|----------|---------|--------|---------|----------|---------|
|                            | M         | F       | M       | F       | M        | F       | M        | F       | M      | F       | M        | F       |
| Age (days)                 | 0.70**    | 0.69**  | -0.78** | -0.68** | -0.22    | -0.48*  | 0.15     | -0.47*  | -0.09  | -0.48*  | -0.70**  | -0.69** |
| Height (cm)                | 0.55*     | 0.47*   | -0.60** | -0.55** | -0.18    | -0.22   | 0.15     | -0.12   | -0.05  | -0.33   | -0.55**  | -0.47*  |
| Weight (kg)                | 0.41      | 0.77**  | -0.31   | -0.65** | -0.18    | -0.68** | -0.23    | -0.61** | -0.26  | -0.65** | -0.41    | -0.77** |
| BMI                        | 0.08      | 0.79*   | 0.03    | -0.64** | 0.03     | -0.75** | -0.36    | -0.81** | -0.34  | -0.69** | -0.08    | -0.79** |
| PDS†                       | 0.49      | 0.70**  | -0.67** | -0.48*  | 0.20     | -0.71** | 0.14     | -0.59** | 0.11   | -0.68** | -0.49    | -0.70** |
| Leg Length§                | 0.41      | 0.48*   | -0.51   | -0.51*  | -0.12    | -0.34   | 0.32     | -0.13   | 0.07   | -0.31   | -0.41    | -0.48*  |
| TBLH Lean Mass (kg)        | 0.63**    | 0.60**  | -0.71** | -0.59** | -0.09    | -0.42   | 0.08     | -0.38   | -0.09  | -0.45*  | -0.63**  | -0.6**  |
| TBLH Lean Mass Index (LMI) | 0.55*     | 0.60**  | -0.68** | -0.59** | -0.00    | -0.46*  | 0.06     | -0.51*  | -0.07  | -0.54** | -0.55*   | -0.6**  |
| TBLH ALM (kg)              | 0.65**    | -0.62** | -0.73** | -0.59** | -0.12    | -0.43*  | 0.05     | -0.42   | -0.10  | -0.44*  | -0.65**  | -0.62** |
| TBLH ALMI                  | 0.61**    | -0.64** | -0.68** | -0.57** | -0.13    | -0.51*  | -0.02    | -0.53*  | -0.16  | -0.53*  | -0.61**  | -0.64** |
| TBLH Tissue Percent Fat    | -0.23     | 0.73**  | 0.51*   | -0.57** | -0.13    | -0.75** | -0.52*   | -0.70** | -0.47  | -0.75** | 0.23     | -0.73** |
| TBLH Fat Mass (kg)         | -0.08     | 0.78**  | 0.30    | -0.66** | -0.09    | -0.71** | -0.42    | -0.67** | -0.42  | -0.71** | 0.08     | -0.78** |
| TBLH FMI                   | -0.15     | 0.72**  | 0.41    | -0.58** | -0.15    | -0.71** | -0.50*   | -0.68** | -0.49* | -0.71** | 0.15     | -0.72** |
| Android Fat Mass (kg)      | -0.09     | 0.72**  | 0.32    | -0.60** | -0.09    | -0.68** | -0.45    | -0.64** | -0.42  | 0.68**  | 0.09     | -0.72** |

*Note.* TBLH: total body less head; BMI: body mass index; PDS: pubertal development score; ALM: appendicular lean mass; ALMI: appendicular lean mass index; FMI: fat mass index.

\* $p < 0.05$ ; \*\* $p < 0.01$ ; † $N = 16$  for Male; § $N = 21$  for Females

**Table 2.5:** Partial Correlations between Body Composition and Percent Time Spent in Sedentary and Physical Activity Time After Adjusting for Age, Gender, Height, Weight, Pubertal Status, and Leg Length ( $N = 40$ )

|                             | Sedentary | Light | Moderate | Vigorous | MVPA    | Total PA |
|-----------------------------|-----------|-------|----------|----------|---------|----------|
| TBLH Lean Mass (kg)         | -0.15     | -0.08 | 0.42*    | 0.37*    | 0.43**  | 0.15     |
| TBLH Lean Mass Index (LMI)† | -0.15     | -0.11 | 0.45**   | 0.41*    | 0.48**  | 0.15     |
| TBLH ALM (kg)               | -0.08     | -0.09 | 0.31^    | 0.25     | 0.31^   | 0.08     |
| TBLH ALMI†                  | -0.08     | -0.08 | 0.34*    | 0.17     | 0.30^   | 0.08     |
| TBLH TPF                    | 0.17      | 0.11  | -0.46**  | -0.49**  | -0.52** | -0.17    |
| TBLH Fat Mass (kg)          | 0.18      | 0.09  | -0.45**  | -0.42**  | -0.47** | -0.17    |
| TBLH FMI†                   | 0.18      | 0.03  | -0.45**  | -0.29^   | -0.42** | -0.18    |
| Android Fat Mass (kg)       | 0.26      | -0.07 | -0.40*   | -0.32*   | -0.40*  | -0.26    |

^ $p < 0.10$ , \* $p < 0.05$ , \*\* $p < 0.01$ , †height was excluded from fitted models.



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## CHAPTER 3

# Do Parental Household Rules Influence the Relationship between Sleep Duration and Preadolescent Body Composition?

## A Systematic Review

### Abstract

Childhood obesity is a complex and dynamic issue. The purpose of this study was to perform a systematic review assessing the relationships between parental household rules (social context), child sleep (individual), other obesity-related behaviors (individual), and child and/or adolescent weight status/body composition. A systematic search was performed using PubMed (Medline) and Google Scholar. Searches involving rules had no beginning time limit; however, sleep studies related to weight status were restricted to the past 5 years. No study design limits were employed. Studies needed to evaluate some combination of rules in the home, obesity-related behaviors, sleep, and weight status or body composition in children or adolescents. In studies only evaluating sleep and weight, studies using only preschool aged participants were excluded. Study fidelity was scored using four criteria: (1) study design; (2) recruitment process; (3) measures; and any major biases/flaws. Of 381 studies identified, 48 met inclusion criteria. Studies were divided into five sub-categories given the limited number of studies addressing all variables of interest ( $N = 2$ ). Results indicated that higher fidelity studies consistently demonstrate expected relationships between rules and obesity-related behaviors, excluding sleep; but, rules were inconsistently related to weight status/body composition. Sleep was consistently inversely associated with weight status. Rules may be associated with sleep duration, and sleep duration may mediate the relationship between rules/ behaviors and weight, but more research is needed to confirm these relationships. Several limitations in the literature were identified: (1) too few studies evaluating

these multi-level relationships; (2) too few studies using more robust study designs; and (3) more consistent definitions and measures of key variables are needed.

### **Introduction**

Childhood obesity is a multifaceted public health issue. Both individual behaviors (e.g., sleep duration, physical activity, etc.) and social influence (e.g., parent rules) contribute to the development and/or prevention of childhood obesity. Understanding the relationships among various factors influencing childhood obesity is important so precise and effective prevention programs may be developed and implemented.

At the individual level, behaviors such as physical activity, sedentary time, and diet appear to influence preadolescent weight status and body composition. While these behaviors are often implicated in childhood obesity, sleep restriction/short sleep duration has recently been identified as an emerging individual risk factor for childhood obesity (1). Similar to other individual level behaviors, adequate sleep influences physical health, growth, development, and maturation in children and adolescents (2, 3). Short sleep duration may also alter eating and activity behaviors contributing to its implications on a child's weight status (1, 2, 3). Evidence supporting that short sleep duration is a significant risk factor for childhood obesity is accumulating. In a 2008 review, 7 of 11 studies demonstrated significant relationships between short sleep duration and obesity risk in children (4), and in a

recent meta-analysis short sleep duration was shown to be associated with a 58%-89% increased risk of obesity (1, 2, 5).

The social environment has also been implicated as a factor related to childhood obesity. The home environment, specifically the role of parenting, is of particular interest. Parent modeling (6, 7), playing with the child, providing transportation for the child, or enforcing contingency management systems (i.e., rules) at home (8-12) can influence whether the child engages in obesity-related preventing or promoting behaviors. Family household rules may cause children to engage in healthier behaviors that could be beneficial for body composition (12), as some studies have reported positive relationships between rules and PA engagement (8, 10). While rules related to screen time/TV time and food intake are commonly evaluated (10, 11), evaluation of rules regarding sleep/bedtime are infrequent.

Few studies have explored the relationship between rules in the home and child weight status/body composition. Even fewer studies have explored the relationships among social factors (i.e., rules in the home), individual behaviors (i.e., sleep duration), and child weight status/body composition (8). Jones et al. assessed if parental rules were a confounder for the association between sleep duration and child obesity in a preschool aged population (8). Prompted by the Jones study, our purpose was to perform a systematic literature review evaluating the relationships among parental household rules, sleep, behaviors related to obesity, and child weight status/body composition.

## **Methods**

### **Source and Search Terms**

A systematic literature review was performed using PubMed (Medline) and Google Scholar search databases. Search terms included a combination of terms from two or three of the following categories: (1) Children (e.g., children, child, preteen, preadolescent, adolescent), (2) Rules (e.g., household rules, family rules, rules), (3) Sleep (e.g., sleep, sleep duration, sleep time), and (4) Obesity (e.g., obesity, body composition, body fat). Terminology from the “Children” category was always included. Both “MeSH terms” and the “all fields” search options were used. No beginning time limit was employed for searches involving rules; however, a 5-year limit was used for sleep related searches. All searches were performed through 2016.

### **Selection Criteria**

Several study selection criteria were used. Articles had to be from peer reviewed scientific journals. Book chapters, conference abstracts, and dissertations were excluded. No limits were placed on study design; both observational and experimental studies were included. Articles needed to evaluate either rules in the home and/or the child’s sleep.

### **Data Synthesis**

Study quality of reviewed articles was determined using four criteria. The following criteria (with max score) were used: study design (3), recruitment process



(2), measures used (2), and any major flaws or biases (2). When scoring study designs, qualitative and cross-sectional designs were given a '1,' longitudinal/prospective observational studies were given a '2,' and quasi-experimental and randomized control trials were given a '3.' When scoring the studies recruitment processes, convenience methods were given a '1,' randomized methods were given a '2,' and combinations between convenience and randomized methods, particularly with multilevel/cluster designs, were given a '1.5.' When scoring measures used, a mixed-methods approach was used to account for the study's purpose, criterion measures in the field, validity/reliability of measures, and appropriateness of measures. Scores for measures used were either '1,' '1.5,' or '2,' after accounting for all criteria. Finally, when scoring major flaws or biases, studies with very minimal biases were given a '2,' studies with minor yet notable flaws were given a '1,' and studies with major flaws or biases were given a '0.' Studies were scored out of a total of 9 points.

## **Results**

Two hundred nine articles were initially identified through search databases. One hundred seventy additional articles were included in the screening process from the 'PMC cited' option available for the original articles found in PubMed. Twelve additional articles were identified through other resources for potential inclusion. Ten duplicates were removed, leaving a total of 381 articles initially identified for screening. After the screening process, 59 full text articles were assessed. Eleven studies were excluded due to: not addressing obesity or rules (3); participants being

too young to be included in sleep and weight status only study reviews (2); being reviews/meta-analyses (2); sleep being the outcome variable (1), and other (2). A total of 48 studies were included in the final review. Articles reviewed were further divided into five sub-categories: (1) rules in the home related to child obesity-related behaviors ( $N = 13$ ); (2) rules in the home related to child weight/status and or body composition ( $N = 13$ ); (3) child sleep related to child weight/status and or body composition ( $N = 19$ ); (4) child sleep related to rules in the home and child obesity-related behaviors ( $N = 1$ ); (5) child sleep related to rules in the home, child obesity-related behaviors, and child weight/status and or body composition ( $N = 2$ ).

### **Rules and Child Behavior**

The 13 articles about rules related to child behaviors are outlined in Table 3.1. Articles in this sub-category were published between 2010 and 2016. Of the 13 articles reviewed, 11 used a cross-sectional design, one used a longitudinal observational design, and one used a qualitative approach. No quasi-experimental or RCT designs were employed. Studies were performed in multiple countries ( $N = 7$ ), with most conducted in the United States ( $N = 5$ ). Rules evaluated included screen/media related rules ( $N = 10$ ), food related rules ( $N = 4$ ), and safety/outdoor play rules ( $N = 2$ ), with some studies evaluating more than one rule. Methods used for evaluating each type of rule varied by study. For example, for screen/media related rules, some studies evaluated if there were rules about how much TV a child was allowed to watch, where others created a general screen time rule score. Obesity

related behaviors evaluated included sedentary/screen time ( $N = 11$ ), physical activity ( $N = 3$ ), and eating related behaviors ( $N = 4$ ). Methods for what constituted the behavior of interest, how it was measured (e.g., objectively), and/or who reported it was inconsistent across studies. Finally, a number of covariates were used, and varied by study; however, the most common covariates evaluated included child's age ( $N = 5$ ), child's gender ( $N = 5$ ), and parent's education level ( $N = 6$ ).

All studies that were scored above a 5 (5.5-7.5;  $N = 8$ ) found that rules had the expected relationships with obesity related behaviors of interest. Increased rules about safety/playing outside were positively associated with time spent engaged in sedentary behaviors. Having family rules about TV use, computer use, and total number of screen time rules were negatively associated with time spent in sedentary behavior. Children with screen time rules spent less time watching TV, playing video games, using the computer for entertainment, and were more likely to meet screen time recommendations. Finally, having household rules was negatively associated with sugar sweetened beverage (SSB) intake before controlling for covariates.

Studies scoring 5 or below ( $N = 5$ ) showed inconsistent results regarding the relationship between rules and behaviors of interest. In general, a majority of the study findings showed positive relationships between rules and both screen time and dietary indicators (i.e., fatty food consumption) (16, 19). However, other studies demonstrated either no relationship or negative relationships between rules and behaviors (17, 25).

### **Rules and Child Weight Status/Body Composition**

The 13 articles about rules related to child weight status are outlined in Table 3.2. Articles in this sub-category were published between 2007 and 2016. Of the 13 articles reviewed, eight used a cross-sectional design, two used a longitudinal observational design, one used a qualitative approach, one used a quasi-experimental design, and one RCT was employed. Studies were performed in Australia ( $N = 4$ ), the United States ( $N = 8$ ), and Wales ( $N = 1$ ). Rules evaluated included screen/media related rules ( $N = 10$ ), food related rules ( $N = 5$ ), and safety/outdoor play rules ( $N = 2$ ), with some studies evaluating more than one rule. Similar to the ‘rules and behaviors’ sub-category, methods used for evaluating each type of rule varied by study. Obesity related behaviors evaluated included sedentary/screen time ( $N = 7$ ), physical activity ( $N = 7$ ), eating related behaviors ( $N = 6$ ), and sleep ( $N = 1$ ). Methods for what constituted the behavior of interest, how it was measured (e.g., objectively), and/or who reported it was inconsistent across studies. Finally, a number of covariates were used, and varied by study. The most common covariates evaluated included child’s age ( $N = 5$ ), child’s gender ( $N = 6$ ), unit of recruitment/sampling ( $N = 3$ ), or the covariates were not clearly specified ( $N = 4$ ).

In studies scored above a 5 (5.5-8;  $N = 10$ ), results about the relationship between rules and child weight status were somewhat inconsistent. In general, the studies showed an inverse relationship between sedentary behavior rules and adolescents’ BMI z-scores and unhealthy weight gain (11, 26, 28-30). Additionally, one study showed that overweight/obese parent-child dyads had fewer rules compared

to healthy weight parent-child dyads (11). However, a few studies noted that general family rules, family rules around eating, and limiting TV time were not related to child weight status (27, 33, 35, 37).

In studies scoring 5 or below ( $N = 3$ ), results regarding the relationship between rules and weight status were inconsistent, as well. Food rules in the home increased the likelihood of the child being overweight (31), whereas having TV rules was negatively associated with the child's BMI z-score (32). One study did not find any relationship between rules and weight status in adolescents (34). Additionally, a few studies reviewed also evaluated the relationship between rules and behaviors. In general, rules were associated with healthier behaviors. Family food rules were favorably associated with healthy eating patterns including diet quality index, decreased fast food and soft drink consumption, and increased fruit and vegetable consumption (27, 34). Sedentary behavior rules, such as limiting TV, computer, and video game use were associated with significantly less use, significantly less screen time, and increased VPA (34). Finally, the number of PA rules was positively associated with an increase in MVPA (28).

### **Child Sleep and Weight**

The 19 articles about sleep related to child weight status are outlined in Table 3.3. Articles in this sub-category were published between 2012 and 2016. Of the 19 articles reviewed, 14 used a cross-sectional design, four used a longitudinal observational design, and one RCT was employed. No qualitative or

quasi-experimental designs were used. Studies were performed in a number of countries ( $N = 16$ ), with most conducted in the United States ( $N = 8$ ), and some studies including more than one country. In this sub-category, family rules were not evaluated. A multitude of anthropometric measures were used across the 19 studies, ranging from height and weight to DXA-derived adiposity. Most studies used two or more anthropometric measures. The most frequent measures used were objective height ( $N = 15$ ), objective weight ( $N = 15$ ), calculated BMI ( $N = 15$ ), and BMI z-scores ( $N = 8$ ). Sleep was determined via accelerometry ( $N = 5$ ), polysomnography ( $N = 2$ ; PSG), questionnaires ( $N = 10$ ), diaries ( $N = 3$ ), and some used a combination thereof. Variables used, time frame and days evaluated, who reported the child's sleep, and if sleep was categorized, varied extensively across studies. Obesity related behaviors evaluated in addition to sleep included sedentary/screen time ( $N = 8$ ), physical activity ( $N = 8$ ), and eating related behaviors ( $N = 11$ ). Methods for what constituted the behavior of interest, how it was measured (e.g., objectively), and/or who reported it was inconsistent across studies. Finally, a number of covariates were used, and varied by study; however, the most common covariates evaluated included child's age ( $N = 11$ ), child's gender ( $N = 14$ ), parent's education level ( $N = 5$ ), mother's BMI ( $N = 5$ ), and household income ( $N = 5$ ).

In studies scored above 5 (5.5-8;  $N=13$ ), results consistently showed an inverse relationship between sleep duration and weight status (3, 5, 38, 40, 41, 43, 44, 48, 49, 52, 53), with few exceptions (46, 51). In the sole RCT among the reviewed sleep studies, children weighed less at the end of the weeklong "increased sleep" condition

compared to the weeklong “decreased sleep” condition, with a mean difference in weight of 0.22kg. Using ActiGraph defined sleep periods, there was a mean difference of 141 minutes (or 2 hours and 21 minutes) per night between the increased and decreased conditions (5). Other studies reported longer sleep duration being associated with decreased odds of overweight/obese status, and decreased BMI z-scores, even at 24-months follow up (49). Further, shorter sleep duration was associated with increased BMI, waist circumference, waist-to-height ratio, and skinfold determined percent body fat (3, 43). Not meeting sleep guidelines was also significantly associated with increased odds of being overweight/obese (49), and increased BMI z-scores (53). In one study, girls showed stronger relationships between sleep duration and weight status compared to boys (43). Studies scored below 5 ( $N = 6$ ) produced results similar to those scored 5.5 or greater.

### **Child Sleep, Rules, Behaviors, and Weight**

In Table 3.4, the sole article regarding child sleep related to rules in the home and child behaviors, and the two articles about child sleep related to rules in the home, child behaviors, and child weight/status and or body composition are outlined. Articles in these sub-categories were published between 2013 and 2015. All of the three studies reviewed used a cross-sectional design. Studies were performed in England ( $N = 1$ ), seven European countries ( $N = 1$ ), and the United States ( $N = 1$ ). Rules evaluated included screen/media related rules ( $N = 3$ ), food related rules ( $N = 2$ ), and bedtime ( $N = 2$ ), with some studies evaluating more than one rule. Similar to

other rule related studies reviewed, methods used for evaluating each type of rule varied by study. A range of anthropometric measures were included in the two studies evaluating weight status; however, the most frequent measures used were objective height ( $N = 2$ ), objective weight ( $N = 2$ ), and calculated BMI ( $N = 2$ ). Sleep was determined via accelerometry ( $N = 1$ ), questionnaires ( $N = 1$ ), diaries ( $N = 1$ ), and some used a combination thereof. Variables used, time frame and days evaluated, who reported child's sleep, and if sleep was categorized, varied across studies. Obesity related behaviors evaluated in addition to sleep included sedentary/screen time ( $N = 3$ ), physical activity ( $N = 1$ ), and eating related behaviors ( $N = 2$ ). Methods for what constituted the behavior of interest, how it was measured (e.g., objectively), and/or who reported it were inconsistent across studies. Finally, one study used SES and the others did not specify covariate use.

When evaluating child sleep related to rules in the home and child behaviors, there was only one study (54), and it scored a 5. Rules varied by SES across each country (seven European countries), with higher SES families having more rules than lower SES families. Fruit and vegetable intake was higher, whereas TV viewing and SSB intake was lower in higher SES families (55). There was no difference in sleep duration by SES status. Both studies evaluating children's sleep related to rules in the home, child behaviors, and child weight/status and or body composition scored above a 5 (6.0 - 6.5). Applehans et al. found sleep duration to be the only health behavior associated with weight status in 6-13 year olds, with normal weight children sleeping an average of 33 minutes more than overweight/obese children (55). Additionally,



they found sleep duration to be a mediator between chaos in the home, caregiver screen time monitoring (similar to rules), screen time, bedtime, TV time, and weight status. They suggest sleep duration essentially mediated the relationship between rules/behaviors and weight status. Jones et al. performed three specific analyses. First, they examined the associations among parental sleep, TV, and dietary rules (8). Second, they examined the association between parental rules and child sleep duration and body composition. Finally, they examined the same associations in the second analysis, except those stratified by SES. Body composition did not differ by implementing sleep rules in 3-year-olds; however, BMI, WC, and skinfold measures were significantly greater in children whose parents did not implement a TV rule. Further, subscapular skinfold scores were greater in children whose parents did not use a dietary rule. Finally, for each individual rule, among children whose parents implemented the rule, children had a long sleep duration compared to those whose parents did not implement the rule (8).

### **Discussion**

The purpose of this paper was to review the relationships among parental household rules, sleep, other behaviors related to obesity, and child weight status/body composition. During the review process, it was determined that the literature was limited (only two studies had all of the variables of interest). Therefore, the review was expanded and split into five sub-categories in an effort to account for a combination of the variables of interest. Results from the review showed higher

fidelity studies found parental household rules had the expected relationships with obesity related behaviors. However, when taking the relationships a step further, the literature was inconsistent regarding the relationship between rules and weight status. This relationship may depend on the rule being implemented and why the rule was implemented. An inverse relationship between sleep duration and weight status was consistently demonstrated, irrespective of study fidelity. Further, having rules may impact sleep duration, and sleep duration may mediate the relationship between household rules/obesity related behaviors and weight status, but more research is needed to confirm these relationships. The review also identified specific gaps/issues within the current literature: (1) too few studies evaluating the multi-level dynamic relationships related to child/adolescent weight status, (2) too few longitudinal, quasi-experimental, RCT, or simply more robust study designs being employed, and (3) inconsistent operational definitions and measurement of key variables.

### **Too Few Studies Evaluating the Multi-level Relationships Related to Weight Status**

Childhood obesity is a complex, dynamic, multifaceted public health issue. However, in order to begin to elucidate some of the relationships between parental household rules (social context), sleep and other childhood obesity related behaviors (individual level), and the child's weight status (public health issue) we had to piecemeal different study topics together, as few studies included all components. We found studies clustered into approximately five categories, with slight overlap.

Articles clustered into the following categories: (1) parental household rules related to obesity related behaviors, except sleep; (2) parental household rules related to child weight status/body composition; (3) child sleep related to child weight status/body composition; (4) child sleep related to rules in the home and child obesity-related behaviors; and (5) child sleep related to rules in the home, child obesity-related behaviors, and child weight/status and or body composition. However, the last two categories, the categories most closely related to the reviews' purpose, were comprised of only three articles.

In order to develop efficacious obesity prevention programs, we need studies to begin including multiple levels, and more/consistent aspects from each level, of the ecological model (56, 57, 58), in an effort to capture the potential interacting, mediating, competing, and/or synergistic effects among the various individual and social variables seemingly related to childhood obesity. Understanding the underlying mechanisms would strengthen programmatic efforts for combating childhood obesity.

Current CDC evidence-based practices for early childhood obesity prevention and reduction include focusing on promoting healthy eating, engaging in physical activity and reducing sedentary time, and providing breastfeeding support for age-appropriate populations; however, adequate sleep duration is not included, despite its consistent association with weight status. Further, while social environments are acknowledged as important, specific social level evidence based strategies for childhood obesity prevention and reduction are only minimally addressed. Thus,

enhancing the science and literature to this regard is imperative in discerning these relationship effects.

### **Too Few Robust Study Designs Employed**

Of the 48 studies reviewed, 36 (75%) were cross-sectional, 2 (4.2%) were qualitative, 7 (14.6%) were longitudinal observational, 1 (2.1%) was quasi-experimental, and 2 (4.2%) were RCTs. While cross-sectional studies are beneficial for establishing some relationship patterns and addressing some components of Koch's postulates/Hill's criteria, they cannot establish temporality or specificity, and they cannot rule out any other causes. For example, in some studies reviewed, results indicated that having a parental household rule related to food intake was positively associated with weight status. However, authors suggested it is possible that some parents may have implemented the rules because the child was overweight/obese. In a cross-sectional study design, this potential effect-cause confounding cannot be evaluated. Understanding why and when parents implement rules via more robust longitudinal studies would allow for teasing these sorts of relationships apart to identify true relationship directions.

### **Operational Definition and Measurement Inconsistencies**

Our review reconfirms the need for establishing consistent operational definitions for parental household rules and behaviors related to obesity (e.g., PA, SB, healthy eating, sleep) (12, 47). Additionally, it reiterates the need for establishing

systematic guidelines/field standards for measuring parental household rules, behaviors related to obesity, weight status/body composition, and covariates/confounders. The lack of consistency across studies is so profound, that it clarifies, in part, why the literature produces conflicting results regarding relationships with childhood obesity!

In our review, for example, screen/media related rules were the most commonly incorporated parental household rule. Despite this, what constituted a “screen/media related rule” varied from how much TV a child was allowed to watch to how much time the child was allowed to spend playing video games, using the computer for entertainment, to not being allowed to watch TV during meals, to the creation of general screen based media rule scores that incorporated multiple screen based activities to a dichotomous measure of whether the parent had a screen time/media related rule. Similar inconsistencies were noted for household food related rules. And finally, some studies only evaluated one rule, where others evaluated multiple rules. This array of rule combinations being evaluated makes understanding how parental household rules effect child behavior and/or weight status arduous. To further convolute the issue, the same discrepancies were pervasive across measuring obesity-related behaviors (i.e., sedentary behavior/screen time, physical activity engagement, healthy eating, and sleep duration), as well as anthropometrics evaluated. Sedentary behavior, for example, was measured as usual time (AKA typical/normal time), average time, and total time, during the past day, past week, past month, on week days, on weekend days, or not split by day type, and reported by the child,

parent, or both. Typically, only leisure time sedentary behavior was reported, but some studies did not specify this. Additionally, some studies only focused on screen time, while others asked about other means of sedentary behavior such as reading; some used accelerometers to derive sedentary time, and other studies used a combination of reported and accelerometer derived sedentary time. The variation in measurement demonstrated for sedentary behavior occurs with physical activity, eating behaviors, sleep, covariates/confounders, and, to a lesser extent, anthropometric measures as well. The compounding effect of inconsistent measures across multiple variables implicated in the causal process of such a critical public health issue must be addressed if we collectively want to begin to ameliorate the health, economic, and social effects affiliated with childhood obesity.

### **Limitations and Strengths of the Review**

While we sought to perform a comprehensive systematic review, some limitations should be noted. First, some studies may have been missed due to the nature of the review process and search terms used. Second, when reviewing the literature there is always the risk of publication bias. Third, scoring methods incorporated important fidelity issues; however, the overarching scoring metrics were created using a simple ordinal scale. Offsetting these limitations are key strengths. First, a comprehensive review evaluating components of the literature related to these multi-level relationships was performed. Second, study fidelity was evaluated, and results were reviewed based on study fidelity. Third, the review is innovative in that it

addresses multiple components of ecological models that are imperative to understand regarding childhood obesity.

### **Conclusion**

In summary, this review found few studies have evaluated the relationships among parental household rules, sleep and other obesity related behaviors, and child/adolescent weight status. Additionally, this review found parental household rules are related with obesity related behaviors, such as sedentary behavior, eating habits, and physical activity, but the relationship between parental household rules and child weight status is less distinct. Further, sleep duration should be accounted for as (1) it was consistently related with child weight status as well; (2) it may be affected by parental rules, and/or (3) may serve as a mediator between parental household rules/other obesity related behaviors and child weight status. This review contributes to the literature by being one of the first to systematically review multiple theoretical levels and their influence on obesity related behaviors and child weight status. We recommend that future studies (1) be more inclusive of sleep as an obesity-related behavior, (2) should consistently include more levels of the ecological models, and (3) use more robust study designs to determine causal relationship effects. Furthermore, field standards for measuring these dynamic and complex variables related to childhood obesity should be established, so the various individual and social level variables can be consistently evaluated to determine their true relationship effects with childhood obesity.

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A full listing of co-authors is unable to be determined at this time.



**Table 3.1:** Summary of Studies Evaluating the Relationship between Family Rules and Obesity Related Behaviors ( $N = 13$ )

| First author & publication year | Study design              | Sample size for analysis                                     | Age range (at baseline)     | Country              | Family rules                                      | Obesity related behaviors                              | Weight status/ body comp | Results (related to rules)  | Score |
|---------------------------------|---------------------------|--|-----------------------------|----------------------|---|--|--------------------------|---|-------|
| Atkin 2013                      | Longitudinal (F/U = 1 yr) | 854  | 9-11 years                  | UK                   | Sedentary PA<br>Bedtime                           | Sedentary Time (outcome)                               | N/A                      | Restrictions on playing outside associated with increased SB in girls   | 7.5   |
| Bjelland 2015                   | Cross-sectional           | 3,038  | 10-12 years                 | 5 European Countries | Sedentary   | Screen time  | N/A                      | Rules limiting TV/computer time associated with decreased leisure screen time   | 6     |
| Cillero 2011                    | Cross-sectional           | 247<br>256/262   | 10-11 years;<br>12-13 years | Spain                | Screen Viewing                                    | Screen Time  | N/A                      | Rules' effects on behaviors varied by age and gender.   | 5     |
| Eisenberg 2012                  | Cross-sectional           | 532  | 5-8 years                   | United States        | Household food rules                              | Eating Behaviors/<br>consumption<br>Sedentary time     | N/A                      | Parents who had more rules had children who consumed fatty foods more often.  | 5     |
| Gebremariam 2016                | Cross-sectional           | 440 (39% participation)                                      | ~14 years                   | Norway               | Food Rules (vegetable and soft drink consumption) | Vegetable intake<br>Carbonated sugar soft drink intake | N/A                      | Rules related to vegetable intake did not have a mediation role between parent education and vegetable intake. Rules for carbonated soft drink did significantly mediate the relationship between parent education and soda intake. | 4     |
| Granich 2010                    | Qualitative               | 7 child only;<br>6 parent only;<br>16 family home interviews | 11-12 years                 | Australia            | Electronic Media Use                              | Electronic Media Use, TV viewing                       | N/A                      | Discussed having rules related to TV viewing  | 5.5   |

*(table continues)*

**Table 3.1: Continued**

| First author & publication year | Study design    | Sample size for analysis             | Age range (at baseline) | Country       | Family rules                 | Obesity related behaviors                    | Weight status/ body comp | Results (related to rules)  | Score |
|---------------------------------|-----------------|--------------------------------------|-------------------------|---------------|------------------------------|--|--------------------------|---|-------|
| Kesten 2015                     | Cross-sectional | 735                                  | 6-8 years               | UK            | Sedentary<br>Variable limits | Sedentary<br>Variables                       | N/A                      | Positive associations found between limit setting specific sedentary variables and time spent engaged in those SBs. Varied by gender.   | 5     |
| Lopez 2012                      | Cross-sectional | 539                                  | 5-8 years               | United States | Household<br>Food Rules      | Sugary<br>Beverage<br>Intake (SBB)           | N/A                      | In bivariates, having household food rules was (-) associated with SSB consumption, but it was not significant in the full model.   | 5.5   |
| Pyper 2016                      | Cross-sectional | 3,205                                | 2-17 years              | Canada        | Screen Tune                  | PA Health<br>Eating Screen<br>Time (leisure) | N/A                      | Have a rule odds of child meeting SB recommendations  | 6     |
| Ramirez 2011                    | Cross-sectional | 160 (parent-<br>adolescent<br>pairs) | 12 or older             | United States | Screen Time<br>SBs           | Sedentary<br>Behavior Time                   | N/A                      | Analyses split by adolescent and parent report. In adolescent report, rules for TV, computer use, and total number of screen time rules were significantly (-) associated with time spent engaged in screen based SB. In the parent report only the TV rules were (-) associated with TV viewing. | 5.5   |

*(table continues)*

Table 3.1: Continued

| First author & publication year | Study design    | Sample size for analysis | Age range (at baseline) | Country       | Family rules                           | Obesity related behaviors   | Weight status/ body comp | Results (related to rules)   | Score |
|---------------------------------|-----------------|--------------------------|-------------------------|---------------|--|-----------------------------|--------------------------|--|-------|
| Tandon 2012                     | Cross-sectional | 713 (child-parent pairs) | 6-11 years              | United States | Safety Rules (Outdoor Play), Media Use | Screen Time<br>Sedentary PA | N/A                      | Safety rules (Outdoor play) and media use rules did not mediate the relationship between family SES and PA/SB.   | 7     |
| Tandon 2014                     | Cross-sectional | 713 (child-parent pairs) | 6-11 years              | United States | Safety Rules (Outdoor Play), Media Use | Screen Time<br>Sedentary PA | N/A                      | Family rules about safety were positively associated with SB. Family rules about TV were negatively associated with SB. Screen time was negatively associated with rules about TV. | 7     |
| Velduis 2014                    | Cross-sectional | 3,067                    | 5 years                 | Netherlands   | Screen Time                            | Screen Time                 | N/A                      | Less likely to watch > 2 hr TV if have a TV rule (OR: 0.60). More likely to use computer/game console >30 min if have computer/ GC rule (OR: 1.91)                                 | 3     |

*Note.* BMI: Body Mass Index; zBMI: BMI z-scores; F/V: Fruit and Vegetable; MVPA: Moderate to Vigorous PA; OR: Odds Ratio; PA: Physical Activity; SB: Sedentary Behavior; SES: Socio-Economic Status; SSB: Sugar Sweetened Beverage; TV: Television; (-): Negative Association.

**Table 3.2:** Summary of Studies Evaluating the Relationship between Family Rules and Child Weight Status ( $N = 13$ )

| First author & publication year | Study design                                 | Sample size for analysis | Age range (at baseline) | Country       | Family rules                 | Obesity related behaviors | Weight status/ body comp | Results (related to rules)  | Score |
|---------------------------------|--|--------------------------|-------------------------|---------------|------------------------------|---------------------------|--------------------------|---|-------|
| Alia 2013                       | Cross-sectional                              | 67                       | 11-15 years             | United States | Sedentary Behaviors          | N/A                       | zBMI                     | SB rules significantly contributed to variance in adolescent zBMI in the hierarchical regression model. They were a main effect with a negative relationship. | 5.5   |
| Couch 2014                      | Cross-sectional                              | 699 parent-child pairs   | 6-11 years              | United States | Food Rules                   | Dietary intake            | zBMI                     | Family rules around child eating were associated with high diet quality, but not associated with child weight status.   | 6.5   |
| Crawford 2010                   | Prospective Observational                    | 301                      | 10-12 years             | Australia     | Watching TV, Playing Outside | PA                        | zBMI                     | Number of PA rules was significantly positively predictive of girls MVPA. Number of SB rules was negatively associated with zBMI.                             | 6     |
| Crawford 2015                   | Longitudinal Observational                   | 200                      | 5-12 years              | Australia     | Limit Sedentary Behaviors    | N/A                       | zBMI & zBMI change score | Rules to limit sedentary time predictive of resilience of weight gain.  | 7     |
| Haines 2016                     | Individual level (Family) parallel group RCT | 112                      | 2-5 years               | United States | Setting TV limits            | Sleep TV Active play SSB  | BMI                      | Positive intervention trend on BMI at 9mo follow up (rules were incorporated in the invention)  | 5     |

*(table continues)*

**Table 3.2:** Continued

| First author & publication year | Study design                            | Sample size for analysis             | Age range (at baseline)     | Country       | Family rules                                     | Obesity related behaviors   | Weight status/ body comp                       | Results (related to rules)  | Score |
|---------------------------------|---|--------------------------------------|-----------------------------|---------------|--|---|--|---|-------|
| Hauser 2014                     | Cross-sectional                         | 820                                  | -7 years                    | United States | Snack intake; kitchen access                     | Snack intake; kitchen access<br>Child intake of F/V, low fat dairy, SSB, vitamin-mineral use; Screen Time | BMI for age                                    | Having food rules increased the likelihood of child being overweight (OR: 2.6). Having two food rules increased the likelihood even more (OR: 3.5). | 5     |
| Hearst 2012                     | Two independent cross-sectional samples | 301                                  | 11-17.6 yrs;<br>12-18.7 yrs | United States | What/when children eat; Time spent TV/video game | N/A   | BMI percentile; Parent/child 2x2 weight status | Overweight parent/child dyads reported fewer rules vs. healthy weight parent/child dyads.   | 6.5   |
| Johnson 2012                    | Longitudinal quasi-experimental         | 1,756 intervention;<br>1,183 control | 4-12 yrs                    | Australia     | TV viewing                                       | F/V, packaged snacks, SSB, fast food intake; PA; SB   | zBMI   | Not having rules for TV viewing was associated with an increase in zBMI   | 4.5   |
| Jones 2009                      | Cross-sectional                         | 144 children<br>102 parents          | 2-4 years                   | Wales         | PA<br>Food<br>TV watching                        | PA;<br>SB   | BMI  | Rules were similar between parents of overweight/obese and healthy weight kids.   | 6.5   |

*(table continues)*

**Table 3.2:** Continued

| First author & publication year | Study design    | Sample size for analysis | Age range (at baseline) | Country                  | Family rules               | Obesity related behaviors                                | Weight status/ body comp                     | Results (related to rules)   | Score |
|---------------------------------|-----------------|--------------------------|-------------------------|--------------------------|----------------------------|--|--|--|-------|
| Lederer 2015                    | Cross-sectional | 2,819                    | 9-11 years              | United States            | Food Rules<br>SB rules     | SB; Dietary Behaviors; PA                                | BMI, BMI percentile, & weight categorization | Having family rules about eating was associated with less fast food and soft drink intake, as well as increased F/V intake compared to students without food rules. Having SB rules was associated to less time using screen devices (e.g., TV). Rules had no relationship with weight status. | 4     |
| Ness 2012                       | Cross-sectional | 5,342                    | 10-17 years             | United States (7 states) | TV Rules                   | Past sports<br>Vigorous PA<br>TV viewing<br>Computer use | BMI percentile                               | Rules were not associated with overweight/obese for either race/ethnicity in this sample.  | 6     |
| Sharif 2014                     | Qualitative     | 41 (5 Fgs)               | 6-12 years              | United States            | Rules discussed during Fgs | Potential causes of change in weight status              | BMIz and BMI percentile                      | Parents identified rules and limits as “critical factors in changing behavior patterns”  | 7     |
| Van Zutphen 2007                | Cross-sectional | 1,926                    | 4-12 years              | Australia                | TV limits                  | TV viewing   | BMI & weight categorization                  | 41% of families had no TV rules. TV rules were not associated with weight status.  | 5.5   |

*Note.* BMI: Body Mass Index; zBMI: BMI z-scores; F/V: Fruit and Vegetable; MVPA: Moderate to Vigorous PA; OR: Odds Ratio; PA: Physical Activity; SB: Sedentary Behavior; SES: Socio-Economic Status; SSB: Sugar Sweetened Beverage; TV: Television.

**Table 3.3:** Summary of Studies Evaluating the Relationship between Child Sleep and Child Weight Status ( $N = 19$ )

| First author & publication year | Study design    | Sample size for analysis | Age range (at baseline) | Country | Family rules | Obesity related behaviors                                   | Weight status/ body comp           | Results (related to rules)  | Score |
|---------------------------------|-----------------|--------------------------|-------------------------|---------|--------------|---|------------------------------------|---|-------|
| Bornhorst 2012                  | Cross-sectional | 609                      | 2-9 years               | Germany | N/A          | Sleep duration<br>Screen Time                               | zBMI,<br>Skinfold<br>PBF, &<br>zFM | Significant effects of sleep duration on zBMI were observed in all models. Approx ½ the effect of sleep duration percent (SDP) on zBMI was explained by the effect of SDP on zFM, meaning that BMI with high fat mass is more inversely associated with sleep duration than BMI with high muscle mass.  | 6     |
| Cao 2015                        | Cross-sectional | 8,760                    | 6-18 years              | China   | N/A          | Sleep duration<br>Daily food intake<br>Daily PA<br>Daily SB | BMI (Chinese criteria)             | Kids with <7 hours of sleep were older, taller, weighed more, greater BMI, less F/V intake, higher meat & SSB intake, less high & moderate PA, and more walking and SB, compared to kids with > 9 hours of sleep. Kids with < 7 hours and 7-9 hours of sleep had higher odds of obesity compared to kids with > 9 hours of sleep. Results differ by gender. | 5     |

*(table continues)*

**Table 3.3: Continued**

| First author & publication year | Study design    | Sample size for analysis | Age range (at baseline) | Country                 | Family rules | Obesity related behaviors   | Weight status/ body comp                         | Results (related to rules)  | Score |
|---------------------------------|-----------------|--------------------------|-------------------------|-------------------------|--------------|---|--|---|-------|
| Chamorro 2014                   | Cross-sectional | 96                       | 10 years                | United States and Chile | N/A          | Polysomnography (PSG) assessment                                  | zBMI   | BMI was negatively associated with PSG total sleep time, sleep efficiency, and stage N2 and R. BMI was positively associated with stage W (wake) amount and percentage.   | 6     |
| Hart 2013                       | RCT             | 37                       | 8-11 years              | United States           | N/A          | Sleep duration<br>Food intake                                     | zBMI   | Children weighed less at the end of the increase sleep duration condition compared to the decreased condition, with a mean difference in weight of 0.22kg.  | 8     |
| He 2015                         | Cross-sectional | 305                      | 6-12 years              | United States           | N/A          | Habitual sleep duration (HSD)<br>Habitual sleep variability (HSV) | BMI percentile & DXA-derived abdominal adiposity | HSD was negatively associated DXA-derived abdominal fat measures (AGR, VAT). HSV was positively associated with abdominal adiposity measures.<br>After adjustment, HSD was no longer significant, whereas HSV remained significant. | 7     |

*(table continues)*



**Table 3.3: Continued**

| First author & publication year | Study design    | Sample size for analysis | Age range (at baseline) | Country                  | Family rules | Obesity related behaviors                             | Weight status/ body comp        | Results (related to rules)   | Score |
|---------------------------------|-----------------|--------------------------|-------------------------|--------------------------|--------------|---|---------------------------------|--|-------|
| Jarrin 2013                     | Cross-sectional | 240                      | 8-17 years              | United States and Canada | N/A          | Sleep duration<br>Sleep patterns<br>PA<br>Screen Time | BMI, zBMI, BIA<br>PBF, WC, & HC | Sleep duration was significantly associated with WC & HC, but lost significance after controlling for covariates. Sleep patterns were associated with WC, HC, & BMI, and maintained its significance with all obesity measures after controlling for covariates. | 5     |
| Jung 2014                       | Cross-sectional | 1,309/1,736 (10 schools) | ~ 10 years              | China                    | N/A          | Sleep habits<br>Sleep duration<br>TV time<br>Appetite | BMI, Skinfold<br>PBF, WC, WHtR  | In unadjusted models, children with the shortest sleep duration had higher odds (OR: 2.3) of being obese. In adjusted models, children with the shortest sleep duration had higher BMI, WHtR, and PBF. Results vary by gender in stratified analyses.            | 6     |
| Khan 2015                       | Cross-sectional | 5,560                    | 10-11 years             | Nova Scotia, Canada      | N/A          | Sleep duration<br>Diet quality<br>PA                  | BMI                             | After controlling for covariates, longer sleep duration was significantly associated with decreased odds of being overweight/obese.  | 5.5   |

*(table continues)*

**Table 3.3: Continued**

| First author & publication year | Study design               | Sample size for analysis | Age range (at baseline) | Country                  | Family rules | Obesity related behaviors   | Weight status/ body comp             | Results (related to rules)   | Score |
|---------------------------------|----------------------------|--------------------------|-------------------------|--------------------------|--------------|---|--------------------------------------|--|-------|
| Kovacs 2015                     | Cross-sectional            | 5,343                    | 2-9.9 years             | Eight European countries | N/A          | Sleep duration<br>H <sub>2</sub> O, SSB, F/V intake; Screen Time PA | BMI                                  | Normal weight children had optimal sleep duration 1.5x more frequently than overweight children  | 5     |
| Lee 2014                        | Cross-sectional            | 1,187/1,315              | 12-18 years             | S. Korea                 | N/A          | Sleep duration<br>24 hr dietary recall<br>PA                        | BMI & WC                             | BMI and WC was higher in participants who slept < 5 hours compared to the other groups. After adjustment, participants sleeping < 5 hours were at increased odds (OR: 2.04) of being overweight.   | 6.5   |
| Lytle 2013                      | Longitudinal Observational | 723                      | 10-16 years             | United States            | N/A          | Sleep duration<br>Screen Time/<br>SB; Energy Intake<br>PA           | BMI & BIIA<br>percent body fat (BPF) | No statistically significant longitudinal relationships between total sleep and BMI or PBF in either boys or girls.  | 6.5   |
| Magee 2013                      | Longitudinal Observational | 1,079                    | 4-5 years               | Australia                | N/A          | Sleep duration  | BMI                                  | Identified three distinct BMI trajectories over the 6 years of follow up: healthy, early onset overweight, later onset overweight. Sleep duration and BMI were significantly related in the early onset group, where the others were weak non-significant relationships. | 4     |

*(table continues)*

**Table 3.3: Continued**

| First author & publication year | Study design                           | Sample size for analysis | Age range (at baseline) | Country       | Family rules | Obesity related behaviors   | Weight status/ body comp              | Results (related to rules)   | Score |
|---------------------------------|--|--------------------------|-------------------------|---------------|--------------|---|---------------------------------------|--|-------|
| Martinez 2014a                  | Longitudinal Observational             | 229                      | 8-10 years              | United States | N/A          | Sleep duration<br>Sleep categorization  | zBMI, WHtR, & weight gain @ 24 months | Only 18% met NSF sleep recommendation for age. Children who slept longer at baseline had significantly lower zBMI and WHtR at 24 months. Children who slept longer had lower weight gain at 24 months.       | 7     |
| Martinez 2014b                  | Cross-sectional                        | 303 parent-child pairs   | 8-10 years              | United States | N/A          | Sleep duration  | BMI percentiles & zBMI                | Mother reported & accelerometer derived sleep duration were weakly negatively zBMI. Children who did not meet recommendations were at greater risk of being overweight/obese.                                | 6     |
| Pileggi 2013                    | Cross-sectional                        | 542                      | 9-11 years              | Italy         | N/A          | Sleep duration;<br>Frequency of sports activities;<br>Food Habits;<br>Screen Time | BMI & BMI percentiles                 | BMI and sleep patterns were associated, with short sleepers demonstrating a 0.77kg/m <sup>2</sup> increase.  | 5     |
| Roberts 2015                    | Prospective Observational cohort study | 4,175                    | 11-17 years             | United States | N/A          | Sleep duration  | BMI & weight status                   | No cross-sectional association between sleep and obesity. While prior sleep duration did not significantly increase the risk of obesity, OR: 1.85. No association between obesity leading to sleep duration. | 6     |

*(table continues)*

**Table 3.3: Continued**

| First author & publication year | Study design    | Sample size for analysis | Age range (at baseline) | Country   | Family rules | Obesity related behaviors  | Weight status/ body comp | Results (related to rules)  | Score |
|---------------------------------|-----------------|--------------------------|-------------------------|-----------|--------------|--|--------------------------|---|-------|
| Taylor 2012                     | Cross-sectional | 641                      | 5-15 years              | Australia | N/A          | Sleep<br>Dietary Habits<br>PA                                    | BMI                      | Children in the overweight group, compared to the healthy weight group were more likely to spend no time studying, > 2 hours in daily screen time activity, and sleep < 10 hours/night.   | 6     |
| Thivel 2015                     | Cross-sectional | 236                      | 6-10 years              | France    | N/A          | Sleep duration<br>Eating Habits<br>Physical<br>Fitness           | zBMI & skinfold<br>PBF   | Late sleepers (> median of individual child sleep mid-point) had significantly higher body weight for the total 7 days of study. PBF & WC were significantly higher in the whole week late sleepers group.  | 5     |
| Wilkie 2016                     | Cross-sectional | 374; 26 schools          | 9-11 years              | UK        | N/A          | Sleep duration<br>Daily PA;<br>Sedentary time;<br>Dietary habits | BMI & zBMI               | 40% of sample met sleep recommendations. Higher MVPA & sleep duration were associated with lower odds of overweight/obese. Post hoc analyses showed that not meeting PA or sleep guidelines had significantly higher zBMI than those meeting recommendations. | 7     |

*Note.* AGR: Android-Gynoid Ratio; BIA: Bioelectrical Impedance Analysis; BMI: Body Mass Index; zBMI: BMI z-scores; DXA: Dual Energy X-ray Absorptiometry; F/V: Fruit and Vegetable; HC: Hip Circumference; HSD: Habitual Sleep Duration; HSV: Habitual Sleep Variability; H2O: Water; MVPA: Moderate to Vigorous PA; NSF: National Sleep Foundation; OR: Odds Ratio; PA: Physical Activity; PBF: Percent Body Fat; PSG: Polysomnography; SB: Sedentary Behavior; SDP: Sleep Duration Percentile; SES: Socio-Economic Status; SF: Skinfold; SSB: Sugar Sweetened Beverage; TV: Television; VAT: Visceral Adipose Tissue; WC: Waist Circumference; WHtR: Waist-to-Height Ratio.

**Table 3.4:** Summary of Studies Evaluating the Relationship between Family Rules, Child Sleep and Other Obesity Related Behaviors, and Child Weight Status ( $N = 3$ )

| First author & publication year | Study design    | Sample size for analysis | Age range (at baseline) | Country       | Family rules                       | Obesity related behaviors                             | Weight status/ body comp                         | Results (related to rules)   | Score |
|---------------------------------|-----------------|--------------------------|-------------------------|---------------|------------------------------------|---|--|--|-------|
| Appelhans 2014                  | Cross-sectional | 103 households           | 6-13 years              | United States | General family practices           | Sleep duration<br>PA<br>Screen Time<br>Dietary Intake | BMI & BMI percentiles                            | Sleep duration was the only health behavior associated with weight status. Normal weight kids slept an average of 33 minutes more than overweight/obese. Sleep duration had direct effects on weight status during modeling. Sleep duration was also a mediator between CHAOS in the home, screen time, caregiver screen time monitoring, bedtime, TV time, and weight status. | 6     |
| Jones 2014                      | Cross-sectional | 84                       | 3 years                 | England       | Bedtime<br>TV time<br>Food related | Sleep duration  | BMI, WC, Triceps & Subscapular skinfold (SF) fat | Body composition did not vary significantly by implementing sleep rules. BMI, WC, & SF were significantly greater in children whose parents did not implement a TV rule, and subscapular SF was higher in children whose parents did not implement   | 6.5   |

*(table continues)*

**Table 3.4:** Continued

| First author & publication year | Study design    | Sample size for analysis | Age range (at baseline) | Country                  | Family rules             | Obesity related behaviors                                     | Weight status/body comp | Results (related to rules)   | Score |
|---------------------------------|-----------------|--------------------------|-------------------------|--------------------------|--------------------------|---|-------------------------|--|-------|
|                                 |                 |                          |                         |                          |                          |   |                         | food rules. For each individual rule, among children whose parents implemented the rule, children had a longer sleep duration compared to those whose parents did not.                       |       |
| Mantziki 2015                   | Cross-sectional | 1,266                    | ~ 7 years               | Seven European countries | F/V intake<br>TV viewing | F/V intake<br>SSB/H2O intake<br>Screen Time<br>Sleep duration | N/A                     | Rules varied SES in each country, with higher SES having more rules. F/V intake was higher in higher SES, whereas TV viewing and SSB intake was lower in higher SES. No SES effect on sleep. | 5     |

*Note.* BMI: Body Mass Index; F/V: Fruit and Vegetable; H2O: Water; PA: Physical Activity; SES: Socio-Economic Status; SF: Skinfold; SSB: Sugar Sweetened Beverage; TV: Television; WC: Waist Circumference.

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## DISCUSSION

This dissertation examined three hierarchical levels of the Behavioral Ecological Model (BEM) related to childhood obesity. Chapter 1 initiated the assessment of the physiological level (“inside the skin”) of the BEM by evaluating the relationship between body composition and bone health in a subsample of 8-14 year old boys and girls. Chapter 2 built on Chapter 1 and evaluated the individual level of the BEM by exploring the influence of the child’s physical activity and sedentary behavior on their body composition. Chapter 3 built on the first two chapters and incorporated the social component of the BEM by performing a systematic review regarding the influence parental household rules (e.g., social contingencies) have on child and preteen obesity-related behaviors and body composition.

Results from Chapter 1 indicate that body composition influences on bone mass differ by composition type (i.e., fat mass vs. lean mass) and that these relationships are gender specific. Chapter 1 results highlighted and emphasized that boys and girls are physiologically different, and that they need to be evaluated separately as their age increases. Bivariate relationships between lean mass and bone mass were positive as expected; however, after controlling for covariates, the positive association dissipated. In Chapter 1, inverse relationships between fat mass and bone mass were observed. Specifically, after controlling for age in days, gender, height, weight, and pubertal status, a weak to moderate negative association was seen between fat mass index (FMI) and android fat mass, and total body less head bone mineral content (TBLH BMC), TBLH bone mineral density (BMD), and L1L4 BMC. Essentially, Chapter 1

results indicate that in our sample of preadolescents having higher FMI and/or android (abdominal) fat mass was associated with preadolescents having lower bone mass values.

Results from Chapter 2 indicate that objectively measured time spent in moderate to vigorous physical activity (MVPA) is associated with DXA-derived body composition measures. Participant characteristics in Chapter 2 were similar to those in the literature in that bivariate trends indicated that older, taller, heavier children, further into puberty spent a greater percentage of their time being sedentary and less time being physically active. After controlling for age in days, gender, height, weight, pubertal status, and leg length, any relationship between sedentary time and body composition disappeared, and the only physical activity measures associated with body composition were moderate physical activity (MPA), vigorous physical activity (VPA), and MVPA. Specifically, MPA, VPA, and MVPA were all positively associated with TBLH lean mass and TBLH lean mass index (LMI), and were all negatively associated with TBLH tissue percent fat (TPF), fat mass, FMI, and android adiposity. Essentially, Chapter 2 results indicate that in our sample of preadolescents, spending a greater percent of time engaged in MVPA was associated with having more lean mass (muscle mass), and less total body and abdominal fat mass.

Results from Chapter 3 demonstrated a few important themes related to childhood obesity. First, among higher fidelity studies parental household rules (i.e., contingency management system) influenced child obesity-related behaviors in expected directions (e.g., a rule limiting screen time is associated with less child

screen time). However, the literature was inconsistent regarding the relationship between parental household rules and child weight status/body composition. This may depend on the rule being implemented or why the rule was initially implemented (was it implemented because the child is overweight/obese?). Sleep duration was consistently inversely associated with child weight status, irrespective of study fidelity scores. Nevertheless, the literature was scant with articles evaluating the relationship between parental household rules, child sleep, other obesity-related behaviors, and/or child weight status. Still, articles evaluating these relationships showed that parental household rules may impact sleep duration, and sleep duration may mediate the relationship between rule/behaviors and weight status. More research is needed to establish these relationships. Three main gaps/issues in the literature were identified as well: (1) Few studies have evaluated the multi-level dynamic relationships related to child/adolescent weight status/body composition, (2) a limited number of studies have employed more robust study designs, and (3) inconsistent operational definitions and measurement of key variables.

### **Theoretical Model: The Behavioral Ecological Model**

Childhood obesity is a multifaceted, dynamic, complex issue impacted by a multitude of factors, such as the child's physiology, their individual behaviors, the social environment (e.g., parental rules, parent behavior, friend behaviors etc.), the physical environment, the culture of the community, etc. In an effort to determine evidence based best practices, researchers focus on different factors and their

relationships with child behavior and/or weight status; however, all of these levels/factors interact and compete with each other, and we need to expand the research to reflect this.

As an attempt to evaluate some of the different hierarchical levels of the BEM, this dissertation used the chapters to focus on the “inside the skin” level, the individual level, and social (local) level of the BEM.

Chapter 1 focused on the “inside the skin” level. This level was previously described and shown in Figure 0.1 (p. 22). It illustrates the various components within the person from the genome to the individuals’ learning history. The individuals’ biological components and the coordinated movements of these components (e.g., physiology) potentiate the individuals’ ability to engage in any given behavior or to interact with itself (1, 2). In Chapter 1 this level of the theory is addressed by accounting for Wolff’s Law (3) and Frost’s Mechanostat Theory (4, 5), and evaluating if and how total body fat and lean mass, as well as their distribution throughout the body is associated with the child’s bone mass and density in our subsample of 8- to 14-year-old boys and girls. This level of the BEM is addressed throughout all three chapters by continuously assessing/attempting to assess these various components of body composition (i.e., fat mass, lean mass, their respective distributions), instead of solely evaluating BMI. Evaluating body composition, instead of BMI, reflects the understanding that the underlying biological and physiological mechanisms respond to different types of tissues and their properties. For example, fat impacts the endocrine system as it secretes hormones and other molecules, visceral abdominal adiposity



impacts the mechanism by which cholesterol is transported through the body, muscle mass is more metabolically active than fat mass and increases energy expenditure throughout the day. All of these biological and physiological mechanisms/systems interact, and thus from a theoretical perspective, as well as a health outcomes and program development perspective, it is important to study the different body composition components and their relationship with each other, such as bone mass/density, as well as their relationship with behavior (e.g., physical activity).

The “outside of the skin” system in Figure 0.1 (p. 23) depicts the various societal levels from the individual to the cultural levels that may influence the occasion of a behavior. It may be best to view these levels as a continuum that displays which societal contingencies are more or less proximal to the specified behavior rather than as distinct levels. Chapter 2 focuses on the individual level of the BEM, by evaluating the relationship between objectively measured physical activity and sedentary time with body composition (fat and lean mass). It has been recently recognized that sedentary behavior is a functionally separate class of behavior from physical activity, and not simply the absence of MVPA (6, 7). Because sedentary behavior is its own response class, both from a theoretical and physiological perspective, (8, 9), it is possible to meet MVPA recommendations and still be considered sedentary, and thus both behaviors must be evaluated. From a theoretical perspective, sedentary behaviors function to produce common reinforcing consequences (i.e., similar functional similarities), such as relief, ease, social reinforcement, and they tend to share similar topographical appearances (e.g., sitting).

Similarly, physical activity behaviors function to produce a different set of common reinforcing contingencies even though they tend to vary by topographical appearance more than sedentary behaviors. Finally, these response classes are incompatible with one another, meaning the child cannot engage in both physical activity and sedentary behavior at the same time. All of these underlying functions contributed to the development of Chapter 2. Further, results from Chapter 2 indicating that specific PA intensities were associated differently with fat and lean mass, validates the importance of evaluating both the “inside the skin” body composition measures (fat mass and lean mass) and individual behaviors (physical activity and sedentary behavior). Evaluating objectively measured sedentary time versus self-reported screen time was important, theoretically, as it addressed the entire response class, versus one component within the response class (despite there being no association with body composition after controlling for covariates).

Chapter 3 attempts to build on the first two chapters, by incorporating the physiology “inside the skin” level (child weight status/body composition), the individual level (obesity-related behaviors), and the social context (parental household rules). Using parental household rules as a means of targeting the social context comes from a few key principles of behavior highlighted in the BEM. First, social groups that are more proximal to the child/preteen tend to have a stronger influence on them. Second, parental household rules draw on generalized rule-governed behavior and contingency management systems. Incorporating the varying hierarchical levels

of the BEM into the third chapter is a means of starting to address the need of approaching childhood obesity from a multi-level approach.

### **Future Directions and Conclusion**

To adequately address the public health issue of childhood obesity, multi-level, dynamic, robust studies are needed. Results from this dissertation demonstrate that components of body composition (fat mass, lean mass, and their distributions) need to be evaluated instead of relying on BMI when studying childhood obesity, given that fat and lean mass may be impacted differently and may have different effects on the child's health. Results further emphasized the need for evaluating boys and girls separately, both at the physiological and behavior level. Ideally, future studies would incorporate multiple obesity-related behaviors, such as physical activity (total, light, moderate, and vigorous), sedentary behavior (total vs. screen time only), sleep duration, and eating habits, as well as behavior patterns, in an effort to identify which behaviors and their patterns most effect child body composition. Moreover, the dissertation highlights the need for more longitudinal or more robust study designs to examine causal mechanisms in this area of research. Cross-sectional study designs limit our ability to determine causality and thus our ability to determine true effects on child body composition and related health outcomes. Finally, as seen in Chapter 3, the dissertation highlights the need for future studies to use more consistent definitions/ measures of key variables related to childhood obesity. With the multitude of

variables used, it is no wonder we still struggle in addressing this critical public health issue.

In summary, this dissertation contributed to the literature by evaluating multiple body composition components and demonstrating their relationship with bone mass and density. Specifically, we found an inverse association between fat mass index and android fat mass and bone mass in our 8- to 14-year-old sample. Few studies have included android fat mass in child studies to date. It further contributed to the literature by evaluating the relationship between physical activity and sedentary behavior with multiple body composition components. Specifically, this dissertation showed that in addition to MPA, VPA, and MVPA being inversely associated with fat mass measures, increases in MPA, VPA, and MVPA were positively associated with lean mass and lean mass index, something that to our knowledge has not been extensively studied in children to date. Finally, it demonstrated that parental household rules appear to improve obesity-related behaviors, but that more research is needed to determine if rules are related with child weight status/body composition. Through our systematic review we show the need for more multi-level dynamic studies in an effort to determine efficacious methods for combating childhood obesity.

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