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**PHYSICAL ACTIVITY AMONG PRESCHOOL-AGED CHILDREN:
CONSIDERATIONS FOR WAKING ACTIVITY PATTERNS AND
HEALTH**

ERIN DOOLEY

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2019

DEDICATION

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CONSIDERATIONS FOR WAKING ACTIVITY PATTERNS AND HEALTH

by

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PHYSICAL ACTIVITY AMONG PRESCHOOL-AGED CHILDREN:
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The University of Texas
School of Public Health, 2019

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With nearly one-quarter (23%) of U.S. preschool children (ages 3-5 years) having overweight or obesity, supporting healthy growth and development is paramount. Hispanic children have the highest prevalence within this age group (15.6%) and a large projected population growth. Energy expenditure through physical activity is one way to combat excess development of obesity and poor health outcomes. Yet there is limited evidence about the correlates associated with physical activity and health within this population. The three studies of this dissertation examined sociodemographic-, cultural-, and context-related factors related to waking activity patterns and the subsequent impact on health indicators.

The overall sample was a majority-minority sample of preschool-aged children, aged 2-5 years, with overweight and obesity participating in the baseline assessment of the Texas Childhood Obesity Research Demonstration (TX CORD). The specific aims were to describe and compare waking activity patterns by individual- (age, sex), family- (language spoken at home, family income) (Paper #1), and context-related (day-type, school) (Paper #2) factors. Paper #3 examined the adiposity, cardiovascular, and quality of life outcomes related to these waking activity behaviors. Studies #1 and #2 used Mann-Whitney U test or Kruskal-Wallis tests, depending on the number of categories, to compare differences in waking activity patterns across

the correlates. Paper #1 additionally used logistic regressions to examine the odds of meeting physical activity guidelines by correlate. Paper #2 additionally used Wilcoxon signed-rank tests to determine differences in activity patterns by type of day. Isotemporal substitution modeling examined the hypothetical effect on health when adding and substituting waking activity behaviors (Paper #3).

Paper #1 results show 75% of participants met the daily physical activity guideline, with clear sociodemographic and cultural differences. Being male (Δ 23.5 min), non-Hispanic (Δ 22.6 min), speaking primarily English (Δ 19.1 min), and living in a family with a higher income to poverty ratio (Δ 18.6 min) were significantly associated with more moderate to vigorous physical activity (MVPA). Paper #2 found preschool children attending school/ child care had significantly higher light intensity activity (Δ 15.7 min), MVPA (Δ 13.2 min), and TPA (Δ 28.1 min) estimates than children not enrolled. Paper #3 found substituting as little as 15 minutes a day of sedentary, light intensity, or moderate intensity activity with vigorous intensity activity was beneficial in lowering systolic and diastolic blood pressure, body mass index (BMI) z-score, percentage of the 95th percentile, fat mass percent, fat mass index (FMI), waist circumference, and waist to height ratio. This association was particularly important for boys, as girls did not show a significant association with adiposity indicators.

The results of this dissertation emphasize the need to utilize an ecological perspective when examining waking physical activity patterns and the impact on health. Promoting vigorous intensity physical activity in this age group can help reduce the burden of poor health. Longitudinal study designs are still needed to determine the impact of these correlates on physical activity and long-term health.

TABLE OF CONTENTS

List of Tables	i
List of Figures	iii
List of Appendices	v
Background and Literature Review	1
Early Childhood	1
Obesity	1
Obesity and Cardiovascular Indicators	3
Obesity and Quality of Life	5
Disparities in Obesity Levels	6
Physical Activity	11
Physical Activity and Adiposity	18
Physical Activity and Cardiovascular Indicators	21
Physical Activity and Quality of Life	22
Disparities in Physical Activity Levels	22
The 24-hour Activity Cycle	24
Public Health Significance	28
Conceptual Model	29
Research Aims and Objectives	32
Study Population	32
Paper 1: Sociodemographic and cultural correlates of waking activity patterns in preschool children with overweight and obesity	33
Paper 2: The association between waking activity patterns and context- related factors in preschool children with overweight and obesity	34
Paper 3: Adiposity, cardiovascular, and quality of life indicators and reallocation of time in preschool children with overweight and obesity: An isotemporal data analysis	35
Parent Study Methods	35
Study Design	35
Participants	37
Data Collection	37
Parent Surveys	38
Physical Activity	38
Health Indicators	44
IRB Statement	47
Paper 1: Sociodemographic and cultural correlates of waking activity patterns in preschool children with overweight and obesity	48
Introduction	48
Methods	51
Study Design	51
Data Collection	51
Data Analysis	53

Results.....	54
Age.....	55
Sex.....	55
Ethnicity.....	55
Language Spoken.....	56
Income to Poverty Ratio	56
Prevalence Meeting Physical Activity Guidelines.....	57
Discussion.....	57
Strengths and Limitations	61
Conclusions.....	63
 Paper 2: The association between waking activity patterns and context-related factors in preschool children with overweight and obesity	77
Introduction.....	77
Methods.....	79
Study Design.....	79
Data Collection	79
Data Analysis.....	82
Results.....	83
Day of the Week	83
School Enrollment	84
Discussion.....	86
Strengths and Limitations	88
Conclusions.....	90
 Paper 3: Adiposity, cardiovascular, and quality of life indicators and reallocation of time in preschool children with overweight and obesity: An isothermal data analysis.....	102
Introduction.....	102
Methods.....	104
Study Design.....	104
Data Collection	104
Data Analysis.....	108
Results.....	110
Adiposity Indicators.....	110
Cardiovascular Indicators	112
Health-related Quality of Life.....	114
Discussion.....	115
Strengths and Limitations	119
Conclusions.....	121
 Conclusion	131
Program Recommendations.....	132
Overall Strengths and Limitations	134
Research Implications.....	136
Overall Conclusions.....	138

Appendices.....	139
References.....	144

LIST OF TABLES

Table 1. Characteristics of studies investigating the prevalence of preschool-age children meeting physical activity guidelines.....	16
Table 2. Items for the PedsQL Measurement Model for measuring health-related quality of life (HRQOL) (Varni et al., 2001).....	47
Paper 1 Table 1. Characteristics of the TX CORD Secondary Prevention preschool-aged participants and physical activity levels at baseline (n = 131).	64
Paper 1 Table 2. Prevalence and unadjusted odds of meeting physical activity guidelines among TX CORD Secondary Prevention preschool-aged participants at baseline.....	66
Paper 2 Table 1. Characteristics of the TX CORD Secondary Prevention preschool-aged participants at baseline N = 114	91
Paper 2 Table 2. Averaged daily physical activity estimates of the TX CORD Secondary Prevention preschool-aged participants at baseline stratified by type of day (N = 114).....	92
Paper 2 Table 3. Overall, weekday, and weekend averaged daily physical activity estimates of the TX CORD Secondary Prevention preschool-aged participants at baseline stratified by school enrollment status (N = 114).....	93
Paper 2 Table 4. Differences in percent of time of weekday averaged daily physical activity estimates of the TX CORD Secondary Prevention preschool-aged participants at baseline by school enrollment status stratified by in-school and out-of-school hours (N = 114)	94
Paper 2 Table 5. Minutes of time of weekday averaged daily physical activity estimates of the TX CORD Secondary Prevention preschool-aged participants at baseline stratified by in-school and out-of-school hours (N = 114).....	95
Paper 3 Table 1. Characteristics of the TX CORD Secondary Prevention preschool-aged participants at baseline.	122
Paper 3 Table 2. Associations and isotemporal substitution of waking behaviors with adiposity health indicators in preschool children with overweight and obesity participating in the baseline assessment of the TX CORD Secondary Prevention Study (N = 131)	123
Paper 3 Table 3. Associations and isotemporal substitution of waking behaviors with adiposity health indicators for only the male preschool children with overweight and obesity participating in the baseline assessment of the TX CORD Secondary Prevention Study (N = 62)	124
Paper 3 Table 4. Associations and isotemporal substitution of waking behaviors with adiposity health indicators for only the female preschool children with	

overweight and obesity participating in the baseline assessment of the TX CORD Secondary Prevention Study (N = 69)	125
Paper 3 Table 5. Associations and isothermal substitution of waking behaviors with cardiovascular health indicators in preschool children with overweight and obesity participating in the baseline assessment of the TX CORD Secondary Prevention Study (N = 131)	126
Paper 3 Table 6. Associations and isothermal substitution of waking behaviors with health-related quality of life in preschool children with overweight and obesity participating in the baseline assessment of the TX CORD Secondary Prevention Study (N = 131)	127
Paper 3 Appendix Table 1. Associations and isothermal substitution of waking behaviors with adiposity health indicators in preschool children with overweight and obesity participating in the baseline assessment of the TX CORD Secondary Prevention Study (N = 131)	128
Paper 3 Appendix Table 2. Associations and isothermal substitution of waking behaviors with cardiovascular health indicators in preschool children with overweight and obesity participating in the baseline assessment of the TX CORD Secondary Prevention Study (N = 131)	129
Paper 3 Appendix Table 3. Associations and isothermal substitution of waking behaviors with health-related quality of life in preschool children with overweight and obesity participating in the baseline assessment of the TX CORD Secondary Prevention Study (N = 131)	130

LIST OF FIGURES

Figure 1. Conceptual model of potential pathways and correlates related to physical activity and health in preschool-aged children.	31
Figure 2. Flow chart for the development of accelerometer outcome estimates	43
Paper 1 Figure 1. Mean proportion of time spent in activity type by hour of TX CORD Secondary Prevention preschool-aged participants at baseline for overall sample (N = 131)	67
Paper 1 Figure 2. Mean minutes spent in activity type by hour of TX CORD Secondary Prevention preschool-aged participants at baseline for overall sample (N = 131)	68
Paper 1 Figure 3. Mean proportion of time spent in activity type by hour of TX CORD Secondary Prevention preschool-aged participants at baseline stratified by sex (N = 131)	69
Paper 1 Figure 4. Mean minutes of time spent in activity type by hour of TX CORD Secondary Prevention preschool-aged participants at baseline stratified by sex (N = 131)	70
Paper 1 Figure 5. Mean proportion of time spent in activity type by hour of TX CORD Secondary Prevention preschool-aged participants at baseline stratified by ethnicity (N = 131)	71
Paper 1 Figure 6. Mean minutes of time spent in activity type by hour of TX CORD Secondary Prevention preschool-aged participants at baseline stratified by ethnicity (N = 131).....	72
Paper 1 Figure 7. Mean proportion of time spent in activity type by hour of TX CORD Secondary Prevention preschool-aged participants at baseline stratified by primary language spoken at home (N = 131)	73
Paper 1 Figure 8. Mean minutes of time spent in activity type by hour of TX CORD Secondary Prevention preschool-aged participants at baseline stratified by primary language spoken at home (N = 131)	74
Paper 1 Figure 9. Mean proportion of time spent in activity type by hour of TX CORD Secondary Prevention preschool-aged participants at baseline stratified by income to poverty ratio (N = 131)	75
Paper 1 Figure 10. Mean minutes of time spent in activity type by hour of TX CORD Secondary Prevention preschool-aged participants at baseline stratified by income to poverty ratio (N = 131)	76
Paper 2 Figure 1. Mean proportion of time spent in activity type for overall sample of TX CORD Secondary Prevention preschool-aged participants at baseline stratified by type of day (N = 114)	96

Paper 2 Figure 2. Mean minutes of time spent in activity type by hour of TX CORD Secondary Prevention preschool-aged participants at baseline stratified by type of day (N = 114).....	97
Paper 2 Figure 3. Mean proportion of weekday time spent in activity type of TX CORD Secondary Prevention preschool-aged participants stratified by school enrollment status (N = 114).....	98
Paper 2 Figure 4. Mean minutes of weekday time spent in activity type by hour of TX CORD Secondary Prevention preschool-aged participants at baseline stratified by school enrollment status (N = 114).....	99
Paper 2 Figure 5. Mean proportion of weekend time spent in activity type of TX CORD Secondary Prevention preschool-aged participants stratified by school enrollment status (N = 114).....	100

LIST OF APPENDICES

Appendix A: American Academy of Pediatrics Blood Pressure Table for Boys, ages 1-5	139
Appendix B: American Academy of Pediatrics Blood Pressure Table for Girls, ages 1-5	140
Appendix C: The Six-Cs developmental ecological model of contributors to overweight and obesity in childhood	141
Appendix D: Common CORD Parent Secondary Prevention Survey	142
Appendix E: TX CORD: Parent Secondary Prevention Survey	143

BACKGROUND AND LITERATURE REVIEW

EARLY CHILDHOOD

Early childhood encompasses the period from birth to age eight and is comprised of a number of life stages: infant, toddler, preschool, and school-aged (U.S. Department of Health and Human Services, Office of Disease Prevention and Health Promotion [HHS ODPHP], 2018; Shonkoff & Phillips, 2000). The preschool years are defined as being between the ages of 3-5 years of age. The preschool years are a critical period for growth and development, including cognitive development, psychosocial health, motor skill development, bone and skeletal health, and the development of adiposity (LeBlanc et al., 2012; Shonkoff & Phillips, 2000; Timmons et al., 2012). Nurturing care is one of the most important contexts to impact early childhood development (Britto et al., 2017). Nurturing care is a stable environment sensitive to a child's health, safety, nutritional needs, and learning and includes both the home and child care settings (Britto et al., 2017).

OBESITY

Childhood overweight and obesity is defined as having a body mass index (BMI) at or above the 85th and 95th percentile, respectively, for children of the same age and sex (Dietz & Bellizzi, 1999). The prevalence of U.S. preschool-aged children, ages 3-5 years, that have overweight and obesity is 22.8%, of which 13.9% have obesity (Hales, Fryar, Carroll, Freedman, & Ogden, 2018; Ogden, Carroll, Kit, & Flegal, 2014; Ogden et al., 2016). There are notable racial/ethnic differences. Hispanic children (15.6%) have the highest prevalence of obesity during the preschool years, followed by Non-Hispanic black (10.4%), Non-Hispanic white (5.2%), and Non-Hispanic Asian children (5.0%) (Ogden et al., 2016). Early childhood has been found to be an important time for the development of obesity within the

life course. Specifically, the obesity trajectory has been found to start by age three (Stuart & Panico, 2016) and establish by age five (Cunningham, Kramer, & Narayan, 2014). Incident obesity is highest during the preschool years compared to any other time during the lifespan (Cunningham et al., 2014). Furthermore, half of the childhood obesity prevalence occurs among children who have overweight during their preschool years (Cunningham et al., 2014), suggesting body weight and energy balance behaviors in early life is strongly associated with obesity in later year. Preschoolers with overweight have over four times the odds ($OR = 4.1$, 95% CI: 2.9, 5.7) of having obesity by age 14 compared to normal weight peers (Cunningham et al., 2014). This is especially important as obesity that persists from childhood to adolescence and into adulthood is a leading cause of health problems (Nader et al., 2006).

A study by Stuart and Panico (2016) found the development of childhood obesity (age 3 through age 11) starts in preschool-aged children and occurs in four distinct trajectories: 1) an early-onset, chronically obese group; 2) a mid-to-overweight group; 3) a mid-to-normal BMI group; and 4) a low-to-normal BMI group (Stuart & Panico, 2016). While 82.5% of the cohort of nationally representative British children remained within a normal range for BMI (belonging in the mid-to-normal BMI group or low-to-normal BMI group) throughout the study, 17.5% of the sample either had overweight or became overweight across time. The largest proportion of overweight children at 11 years of age (14.4%), had slightly elevated BMIs in the preschool years but continued to increase their BMI throughout their early childhood years. The early-onset, chronically obese group, which was characterized by starting age three as having overweight or obese and remaining obese into childhood, made up 3.1% of the population. This study's findings suggest that ages 3-5

are a particularly important time for development and sustainment of excess adiposity. Furthermore, the authors found that the mid-to-normal group and the mid-to-overweight group were of similar BMIs at age three, but had diverging obesity paths starting at age five (Stuart & Panico, 2016). This suggests that in almost 15% of the overweight population, obesity may be preventable if intervention resources were implemented during this critical time of development.

Further understanding of the factors related to incident obesity occurring between the ages of three and five is needed. Excess adiposity during these years can lead to early adiposity rebound. Early adiposity rebound is associated with poor health outcomes, such as obesity, high blood pressure, and diabetes in later life (Taylor, Grant, Goulding, & Williams, 2005). As prevalence of obesity among U.S. preschool children is nearly 10% higher than those in the British cohort examined by Stuart and Panico (2016) (Ogden et al., 2016), impacting obesity rates within the preschool years may help diminish the number of children in these trajectories and ultimately reduce the large number of U.S. children that experience obesity into childhood. Reducing the number of children who become on the obese trajectory track during the preschool years is especially important as the childhood obesity prevalence increases with age, with the 6-11 years age group (17.5% all race/ethnicity and 25.0% of Hispanic children), and the 12-19 years age group having the highest prevalence of youth obesity in the U.S. (20.5% all race/ethnicity and 22.8% of Hispanic children) (Ogden et al., 2016).

Obesity and Cardiovascular Indicators

Obesity in the early childhood years is associated with numerous physiological and psychological health problems. Higher childhood BMI has been found to be associated with

elevated resting blood pressure, asthma, poor dental health, nonalcoholic fatty liver disease, attention-deficit/hyperactivity disorder (ADHD), and poor sleep habits (Macdonald-Wallis et al., 2017; Pulgarón, 2013). Of particular importance are cardiovascular risk factors. Heart disease is the leading cause of death in the U.S. for most racial/ethnic groups and affects one out of every four American adults (Benjamin et al., 2017). Indicators that are present during childhood can contribute to the development of cardiovascular disease in adulthood (Raitakari et al., 2003), signifying this age group as an important target for both obesity and cardiovascular disease prevention.

In preschool-aged children, overweight and obesity is associated with elevated blood pressure (BP) (Gopinath et al., 2011; He, Ding, Fong, & Karlberg, 2000; Macdonald-Wallis et al., 2017; Vale, Trost, Rêgo, Abreu, & Mota, 2015). Among overweight youth, the prevalence of high BP is between 3.8% – 24.8% (Flynn et al., 2017; Rosner, Cook, Daniels, & Falkner, 2013). In 2017, the American Academy of Pediatrics released new normative BP tables for children and adolescents based on age, sex, and height (Flynn et al., 2017). The American Academy of Pediatrics BP tables for boys and girls ages 1-5 are presented in **Appendix A** and **Appendix B**, respectively. The American Academy of Pediatrics tables denote elevated BP occurs at >90th percentile, stage 1 hypertension at the ≥95th percentile, and stage 2 hypertension at the ≥95th percentile + 12 mmHg.

In both boys and girls between the ages of 3-5, a higher BMI category is significantly associated with higher systolic and diastolic BP. Overweight children have two times the odds (OR = 2.0, 95% CI: 1.2, 3.5) of high-normal systolic BP than non-overweight peers (Vale et al., 2015). A study by Gopinath and colleagues (2011) found that a one kg/m² unit change in BMI is associated with an average of 0.6 mmHg increase in systolic BP and a 0.6

mmHg increase in diastolic BP (Gopinath et al., 2011). Waist circumference, a marker of central adiposity, has also been found to be positively associated with BP measures. The Gopinath et al. (2011) study also found that a one centimeter increase in waist circumference was associated with a 0.1 mmHg increase in systolic BP and a 0.2 mmHg increase in diastolic BP, after adjusting for height, ethnicity, and parental employment status (Gopinath et al., 2011). Furthermore, the association between adiposity and BP has been found to be robust to changes in BMI and BP that occur naturally with maturation (Macdonald-Wallis et al., 2017). Additionally, overweightness is associated with a 1.6 (95% CI: 0.9, 2.8) higher odds of clinically-diagnosed systolic hypertension and a 1.7 (95% CI: 1.0, 2.6) higher odds of clinically-diagnosed diastolic hypertension than normal weight preschoolers (Macdonald-Wallis et al., 2017). Despite the somewhat stronger association with elevated diastolic BP, few studies have measured diastolic BP (Bell, Fletcher, Timperio, Vuillermin, & Hesketh, 2018). There is a need in the literature to examine obesity and systolic and diastolic measures of elevated BP and hypertension status, especially using the newest American Academy of Pediatrics standardized BP tables.

There is evidence that elevated BP tracks from childhood into adulthood (Chen & Wang, 2008; Flynn et al., 2017). As the prevalence of elevated BP in children grows (Rosner et al., 2013), the early childhood years becomes an increasingly important time for managing elevated BP levels and, conceivably, reducing the risk of hypertension and heart disease in adulthood.

Obesity and Quality of Life

Health-related quality of life (HRQOL) is the assessment of the effect of a health condition on daily activities, physical symptoms, social interactions, and emotional well-

being (Friedlander, Larkin, Rosen, Palermo, & Redline, 2003). Obesity is shown to reduce HRQOL in adults (Jia & Lubetkin, 2005), school-aged children (Friedlander et al., 2003), and preschoolers (Kuhl, Rausch, Varni, & Stark, 2012). Parents typically report worse overall HRQOL in preschoolers with obesity than parents with non-overweight children (Kuhl et al., 2012; Wake, Hardy, Sawyer, & Carlin, 2008). Parents with preschoolers who have overweight and obesity rated their child's walking, running, ability to lift something heavy, and energy level as lower and their trouble sleeping as more difficult than parents of normal weight children (Kuhl et al., 2012). Compared to non-overweight children, children with clinical obesity are 72% more likely to have additional health care needs (Wake et al., 2008). In addition, parents report worse emotional functioning and social functioning in preschoolers with obesity (Kuhl et al., 2012).

Disparities in Obesity Levels

Six-Cs model for obesity

Ecological models provide a framework to understand environments that affect people's health. The Six-Cs model (cell, child, clan, community, country, and culture), developed by Harrison et al., (2011) is an ecological model for understanding factors that influence child overweight and obesity (Harrison et al., 2011) (**Appendix C**). Focusing on nutrition and physical activity, the model indicates key factors at the individual-level (child), at the family-level (clan), and the context-level (community) that influence children's weight status.

Individual-level factors of obesity

There are notable individual-level factors that impact obesity prevalence, including sex and race/ethnicity. Notable sex differences in obesity levels occur. Boys typically have

higher overweight and obesity prevalence than girls (Cunningham et al., 2014; Flores & Lin, 2013; Maher, Li, Carter, & Johnson, 2008; Ogden et al., 2014), except among Non-Hispanic Asian preschool youth (Ogden et al., 2014; Ogden et al., 2016). Overall, the U.S. prevalence of overweight in children between the ages of 2-5 years is 23.9% for boys and 21.7% for girls (Ogden et al., 2014) and the prevalence for obesity is 9.2% and 8.6%, respectively (Ogden et al., 2016). In addition, racial/ethnic differences in prevalence of obesity have been shown. The highest prevalence of overweight and obesity during the preschool years occurs in Hispanic children (29.8%, 15.6%), followed by Non-Hispanic black (21.9%, 10.4%), Non-Hispanic white (20.9%, 5.2%), and Non-Hispanic Asian children (9.0%, 5.0%) (Copeland et al., 2011; Ogden et al., 2014). Hispanic boys have the highest prevalence of overweight in this age group (31.4%, 16.7%), compared to all other race/ethnic/sex groups (Chen & Wang, 2008; Ogden et al., 2014). Latinx preschool children have 2.3 (95% CI: 1.4, 3.7) higher odds of being severely overweight than non-Hispanic white children (Flores & Lin, 2013). Moreover, ethnicity is also associated with difference in BMI trajectory in this age group. Compared to white children, Latinx and African American U.S. children have higher BMI incidence at younger ages and maintain these higher BMI across childhood (Guerrero et al., 2016).

Family-level factors of obesity

In addition to individual-level factors, differences in obesity can occur due to family-level factors. In a study by Maher et al. (2008) examining the prevalence of obesity using a cohort representative of the U.S. population, the Early Childhood Longitudinal Study, the authors found that children with obesity were significantly more likely to reside in lower income households (Maher et al., 2008). Additionally, using the same dataset, Cunningham

and colleagues (2014) similarly found that young children from the wealthiest 20% of families had the lowest prevalence of obesity (7.4%) than those in all the other socioeconomic levels (12.0% - 16.5%) (Cunningham et al., 2014). This relation between income and obesity was also found among Latinx youth (Innella, Breitenstein, Hamilton, Reed, & McNaughton, 2016).

Language spoken at home is another potential correlate of obesity. Non-English primary language was associated with predicting severe obesity in children (Flores & Lin, 2013; Guerrero et al., 2016). Almost 30% of children who had severe obesity in a nationally representative U.S. cohort, the Birth Cohort of the Early Childhood Longitudinal Study (ECLS-B), spoke another language at home (Flores & Lin, 2013). Additionally, BMI growth trajectories were different among Hispanic-English speaking and Hispanic-Spanish speaking youth, with Spanish speaking predicting a higher rate of obesity growth (Guerrero et al., 2016). In a study conducted in Los Angeles County, language spoken was a curvilinear association. Preschoolers residing in neighborhoods where 40% - 80% of residents speak Spanish, had the highest levels of obesity (Nobari et al., 2013). Language at home has also been included as a proxy measure for acculturation among Latinx preschool youth (Mendoza, McLeod, Chen, Nicklas, & Baranowski, 2014). While the study by Mendoza et al. (2014) did not find a significant association between acculturation and BMI, this may have been due to the use of a composite proxy measure. The authors used language at home, county of birth, and years living in the U.S to characterize the acculturation construct and did not assess these variables separately.

The association between obesity and cardiovascular indicators may also be influenced by race/ethnicity. Gopinath et al. (2011) found the association between BMI and waist

circumference was significant for Caucasian children but not for East Asian, South-East Asian, or Middle Eastern children (Gopinath et al., 2011). In children ages 8-17, Black children had a 1.3 (95% CI: 1.1, 1.5) higher odds of having elevated BP than non-Hispanic white children (Rosner et al., 2013). In preschool-aged youth, higher BMI and waist circumference is associated with higher levels of high-density lipoprotein in Hispanic children but was not associated in non-Hispanic white or non-Hispanic black preschoolers (Messiah et al., 2012). The study by Messiah et al., (2012) only examined cardiovascular markers found in serum blood – fasting triglyceride, high- and low-density lipoprotein, total cholesterol, non- high-density lipoprotein cholesterol, and C-reactive protein (Messiah et al., 2012). There are no known studies that examine if there is effect with obesity and BP in Hispanic preschool-aged children.

The influence of family-level factors can be quite complex. It has been found that there are differences in predictors even among children experiencing obesity. For example, becoming overweight was associated with low parental incomes, however, becoming obese was associated with low parental education among British preschool youth (Stuart & Panico, 2016). Examining family-level correlates among a primarily Hispanic population with overweight and obesity is warranted and may help elucidate the relation between family-level predictors and excess adiposity.

Context-level factors of obesity

Context refers to the settings and time in which physical activity takes place. Child care and preschool may be an important context-related factor that is associated with obesity prevalence. In the U.S., 54.1% of preschool-aged children are enrolled in full-day child care programs and 81.1% are enrolled in full-day kindergarten (Snyder, de Brey, & Dillow, 2019).

As full-day and school programs are typically eight hours per day, five days per week, the school is an important setting in children's lives. A systematic review by Alberdi et al., (2016) examined the relation between type of care and obesity risk and found mixed results across 15 publications. While some studies reported a positive association between child care and obesity, some studies reported no association (Alberdi et al., 2016). This may be due to the authors' bias in including "informal care" as child care. Informal care was defined as both relative and non-relative home-based care; however, this type of care is quite different than the traditional "formal" center-based care. Informal care, especially care conducted by relatives of the children, have been found to have different feeding practices than formal care which could also lead to excess adiposity (Alberdi et al., 2016). Formal child care facilities have specific policies regarding physical activity and feeding practices, while informal care by relatives may introduce food earlier to ease care practices (Alberdi et al., 2016). Additionally, the mixed results of the relation between child care and obesity may be due to differences among populations. There is some evidence for an interaction effect with child care type and ethnicity. In Latinxs, children receiving care from a family, friend, or neighbor (OR = 0.71, 95% CI: 0.51, 0.99) and those attending center-based care (Head Start) (OR = 0.53, 95% CI: 0.35, 0.8), were significantly less likely to have obesity than Latinx children in parental care (Maher et al., 2008). Additionally, the review by Innella et al., (2016) examining determinants of obesity in Latinx preschool youth, found a negative association between the amount of time in child care and obesity (Innella et al., 2016). Thus, especially among certain populations, specific types of child care can be associated with lower risks of obesity.

PHYSICAL ACTIVITY

As childhood obesity rates continue to rise across the U.S. (Ogden et al., 2014) and globally (De Onis, Blössner, & Borghi, 2010), public health approaches to reduce excess weight or attenuate a poor obesity trajectory in younger children is vital. Energy-balance behaviors – sleep, diet, and physical activity – are important for weight management. The systematic review by te Velde et al. (2012) found strong evidence for an inverse association of total physical activity and adiposity with insufficient evidence for dietary intake or dietary behaviors among preschool-aged children (te Velde et al., 2012). In addition, physical activity is associated with enhanced growth and development in this age group. Physical activity has been shown to have many proximal benefits including improved cognitive, bone, skeletal, and motor development, psychosocial and cardiometabolic health in young children (Carson, Lee, et al., 2017; Timmons et al., 2012).

A systematic review by Hnatiuk et al. (2014) exploring physical activity and time spent sedentary among preschool-aged children using device-based measures, found that the median prevalence estimate of MVPA throughout the 24-hour cycle was 5.9% which equates to 47 minutes of MVPA per day (Hnatiuk, Salmon, Hinkley, Okely, & Trost, 2014). This systematic review included 40 publications across 37 studies and found that the range of accelerometer-estimated MVPA per day was between 1.7% – 41.2% (Hnatiuk et al., 2014). The authors standardized these estimates to a 13-hour waking period, assuming an average 11-hour sleep period for this age group (Iglowstein, Jenni, Molinari, & Largo, 2003), and concluded that preschoolers obtain between 13 minutes and 5.4 hours of MVPA per day. Additionally, the authors examined the percentage of time spent in light activity. The median prevalence estimate for total light activity was 16.9% (standardized to 130 minutes), with a

range of 3.9% – 32.6% (30 minutes to 4.2 hours) (Hnatiuk et al., 2014). However, differences in accelerometer cut points, wear time algorithms, and number of days counted across studies makes examining and comparing MVPA across studies difficult and may have contributed to the large variability in the systematic review estimates.

There are multiple physical activity guidelines for preschool-aged children from various U.S. organizations, countries, and international organizations. Within the U.S., the *2018 Physical Activity Guidelines for Americans* suggests that preschool-aged children (ages 3 through 5 years) should be physically active throughout the day to enhance growth and development (2018 Physical Activity Guidelines Advisory Committee, 2018). Additionally, adult caregivers, which includes caregivers at home and during child care, of preschool-aged children should encourage active play that includes a variety of activity types (Committee, 2018). However, there is a notable lack of providing an established amount of activity minutes or physical activity intensity level. The *Physical Activity Guidelines for Americans* suggests only a reasonable target is three hours per day (180 minutes) of activity of all intensities: light, moderate, and/or vigorous intensity (Committee, 2018).

In addition to national guidelines, U.S. organizations have also published guidelines for this age group. The National Association for Sport and Physical Education (NASPE), now known as SHAPE America, is a non-profit organization in the U.S. that suggests children should engage in a minimum of 120 minutes of daily physical activity, of which caregivers should plan opportunities for preschoolers to engage in 60 minutes of MVPA (SHAPE America, 2009). The other half of daily accumulation may come in the form of unstructured play. Another organizational physical activity guideline includes the Institute of Medicine (IOM), now the National Academies of Science, Engineering, and Medicine

(NASEM). The IOM guidelines suggest child care providers should provide toddlers and preschoolers with “opportunities for light, moderate, and vigorous intensity physical activity for at least 15 minutes per hour while children are in care” (Institute of Medicine, 2011), which, ultimately, corresponds to three hours of physical activity over a period of 12 waking hours (Pate & O’Neill, 2012).

Most recently (April 24, 2019), at the international level, the World Health Organization (WHO) released a set of guidelines that provides recommendations on the amount of time in a 24-hour day that young children should spend being physically active or sleeping for health and wellbeing (Organization, 2019). The WHO suggests children ages 3-4 should spend at least 180 minutes in a variety of types of physical activity, of which at least 60 minutes should be spent in MVPA. Ideally, the movement should be spread throughout the day. Additionally, children should not be restrained for more than 60 minutes at a time, or sit for long periods, and sedentary screen time should be no more than 60 minutes per day. Children of this age group should also have 10-13 hours of good quality sleep, which may include nap times. The WHO guidelines reflect the 24-hour guidelines first established by Canada (M. S. Tremblay et al., 2016) and Australia (Okely et al., 2017) that integrate guidelines from a variety of movement behaviors.

Examining the prevalence of children meeting guidelines is paramount for physical activity surveillance. **Table 1** provides a summary of the characteristics of studies examining the prevalence of preschool-aged children meeting the various physical activity guidelines. Most studies that examine prevalence of meeting guidelines occur in countries other than the United States. The Canadian, Australian, and United Kingdom guidelines focus on 180 minutes of activity and have therefore been included under the WHO umbrella guideline. The

prevalence of meeting the WHO guidelines of 180 minutes of total physical activity range from 5% – 100% (Andersen et al., 2017; Chaput et al., 2017; Cliff et al., 2017; Dawson-Hahn, Fesinmeyer, & Mendoza, 2015; De Craemer, McGregor, Androutsos, Manios, & Cardon, 2018; Dias et al., 2019; K. R. Hesketh, Griffin, & van Sluijs, 2015; K. R. Hesketh et al., 2014; Hinkley, Salmon, Okely, Crawford, & Hesketh, 2012). In the U.S., most studies have examined prevalence using the NASPE guidelines (Beets, Bornstein, Dowda, & Pate, 2011; Dawson-Hahn et al., 2015; Tucker, 2008) and IOM guidelines (Copeland, Khoury, & Kalkwarf, 2016; Pate et al., 2015). Only Australia had studies that also measured NASPE guidelines (Hinkley, Crawford, Salmon, Okely, & Hesketh, 2008) and IOM guidelines (Ellis et al., 2017); however, the study measuring IOM was conducted specifically measured during child care which limits 24-hour generalizability. In one study that examined total activity, 85.2% met the WHO guidelines on at least five days (Dawson-Hahn et al., 2015); however, they did not examine meeting guidelines across all seven days, which makes comparisons across countries difficult.

Between 41.6% – 50.2% of U.S. children meet the IOM guideline for 15 minutes of activity every hour during waking hours (Pate et al., 2015). When looking at total activity over the course of the day, a systematic review found that, on average, only 54% of U.S. children obtain 60 minutes of total MVPA per day (Tucker, 2008). Much like the findings by Hnatiuk et al. (2014) which found large variance in total activity estimates, the large differences in prevalence estimates may be due to author decision points regarding device cut points and wear time and regarding decisions in the number of inclusion days. These differences in subjective decisions makes comparison across surveillance studies difficult. A recent study by Dias et al. (2019) using the International Children's Accelerometry Database

(ICAD), a group of pooled and reduced raw accelerometer data from 20 projects across Europe, the U.S., Brazil, and Australia, tried to reduce subjective bias by using standardized methods for accelerometer reduction to determine the prevalence of meeting guidelines worldwide. The analyses found that 70.0% of young children met recommended WHO daily guidelines of ≥ 180 minutes of total physical activity and 78.8% of participants met daily guidelines of ≥ 60 minutes of MVPA (Dias et al., 2019). However, children contributed only 4.8 days of valid accelerometer days, on average (3.8 weekdays and 1.0 weekend days). Thus, Dias et al. (2019) threshold of “meeting guidelines” was not indicative of across all 7 days of the week. Therefore, the prevalence of meeting guidelines on all days of the week may be much lower than estimated. The low prevalence of overall MVPA and percentage of children meeting activity guidelines are especially concerning as physical activity in early years can be associated with activity later in life (Friedman et al., 2008; Malina, 1996; Telama et al., 2005).

Table 1. Characteristics of studies investigating the prevalence of preschool-age children meeting physical activity guidelines

Reference	Study Population	Guideline	Measurement tool	Results
Anderson et al. (2017)	Norway N = 130 <i>M</i> age = 3.7 ± 0.4	WHO 60 min of MVPA	ActiGraph accelerometers (GT1M & GT3X+)	32% of girls; 67% of boys Children in most active quartile achieved guidelines on 82% of measured weekdays compared to 8% in least active quartiles
Beets et al. (2011)	USA N = 357 <i>M</i> age = 4.2 ± 0.6 51% African American	NASPE 120 min of total PA 120 min of MVPA 60 min of MVPA	ActiGraph accelerometer (7164)	Meeting guidelines depends on accelerometer cut points used. All cut points: 13.5% - 99.5% Pate: 99.5% All cut points: 0.0% - 99.5% Pate: 3.4 - 7.9% All cut points: 0.5% - 99.5% Pate: 54.9 – 65.6%
Chaput et al. (2017)	Canada N = 803 <i>M</i> age = 3.5 ± 0.1	WHO 180 min of total PA	Actical accelerometer	61.8%
Cliff et al. (2017)	Australia N = 248 <i>M</i> age = 4.2 ± 0.6	WHO 180 min of total PA 60 min of MVPA	ActiGraph accelerometer (GT3X+)	93.1%
Copeland et al. (2016)	USA N = 365 <i>M</i> age = 4.3 ± 0.7	IOM 15 min/hr	Actical accelerometer	Over the 24-hr day: 2.0 min/hr MVPA; 19.9 min/hr in light PA. Males and older children had higher total active time than females and younger children. No significant effects by BMI or parent education.
Dawson-Hahn et al. (2015)	USA N = 96 Latino in Head Start <i>M</i> age = 4.7 ± 0.5	NASPE 120 min of MVPA WHO 180 min of total PA	ActiGraph accelerometer (GT1M)	Child age, parental education, & neighborhood disorder were positively associated with % PA 90.1% met guidelines for at least 5 days 85.2% met guidelines for at least 5 days
De Craemer et al. (2018)	Belgium N = 595 <i>M</i> age = 4.2 ± 0.1	WHO 180 min of total PA	ActiGraph accelerometers (GT1M, GT3X, & GT3X+)	11% total. 17.3% met on weekdays and 11.1% met on weekends.

Dias et al. (2019)	UK, Switzerland, Belgium, USA N = 1052 pooled from 6 studies	WHO 180 min of total PA 60 min of MVPA	ActiGraph accelerometers (7164, 71256, & GT1M)	Older vs younger children, males, country, season, and weekday vs weekend significantly associated with meeting guidelines for total PA and MVPA. 69.96% 78.8%
Ellis et al. (2017)	Australia N = 301 <i>M</i> age = 3.7 ± 1.0	IOM 15 min/hr	actiPAL	16% 24% for boys, 8% for girls 37% for toddlers, 10% for preschoolers
Hesketh et al. (2015)	UK N = 202	WHO 180 min of total PA	Actiheart	100%
Hinkley et al. (2012)	Australia N = 939 <i>M</i> age = 4.5	NASPE 120 min of MVPA WHO 180 min of total PA	ActiGraph accelerometer (GT1M)	56.3% avg day, 11.5% on all 7 days 63.9% for boys, 46.8% for girls 5.1% avg day, 0% of all 7 days 6.7% for boys, 3.2% for girls
Pate et al. (2015)	USA N = 623 from CHAMPS and SHAPES	IOM 15 min/hr	CHAMPS: ActiGraph accelerometer (7164) SHAPES: ActiGraph accelerometers (GT1M & GT3X)	41.6% - 50.2%
Tucker et al. (2008)	Systematic review of 39 primary studies (published 1986–2007) N = 10,316	NASPE 60 min of MVPA	Accelerometers in 49% of the studies, direct observation was used 33%, self-reports 21%, heart rate monitors 15%, pedometers 13% DLW 10%.	54%

WHO guidelines include the UK, Canada, and Australia guidelines that suggest 180 minutes of total physical activity.

Abbreviations: PA, physical activity; WHO, World Health Organization; NASPE, National Association for Sport and Physical Education; IOM, Institute of Medicine

Physical Activity and Adiposity

Higher levels of total physical activity is associated with reduced risk for excessive increases in body weight and adiposity and increased bone health (Pate et al., 2019; Sijtsma, Sauer, Stolk, & Corpeleijn, 2011; te Velde et al., 2012; Timmons et al., 2012). Previous studies have generally examined parent-reported activity and/or total activity (te Velde et al., 2012). However, technology advances have led to the ability to derive specific intensity minutes and dose of activity, which are more reflective measures of physical activity energy expenditure (PAEE) – an important component of the energy-balance paradigm.

A systematic review by Sijtsma et al. (2010) examined directly-assessed physical activity (accelerometer, pedometer, doubly labelled water (DLW) method, heart rate monitoring, direct observation) and adiposity (BMI, percent body fat, fat mass) in preschool children. Only 29% (5/17) of studies found an inverse relationship between physical activity and adiposity (Sijtsma et al., 2011). The mixed results may, in part, be due to the differences in methodology of both measuring the physical activity behavior and assessment of adiposity. The various methods to assess physical activity, such as frequency, duration, and intensity of activity with accelerometer use, and total energy expenditure with DLW, may have led to inaccurate a definition of “physical activity” and comparison across studies. For adiposity assessment, the majority of studies (65%) measured BMI, 29% examined body fat, and 24% examined fat mass. Only 18% of studies that examined BMI found a relationship, while one out of four studies (25%) found an inverse relationship with intensity vigorous activity and fat mass, and 60% of studies examining body fat found an inverse relationship (Sijtsma et al., 2011). A more recent systematic review by Carson and colleagues (2017) also noted mixed associations between physical activity and adiposity. The authors suggest this

may be due to the majority of studies using BMI as a surrogate adiposity measure rather than more objective measures of adiposity such as fat mass (Carson, Lee, et al., 2017). This is a major limitation of the current literature as BMI may not be the best indicator of adiposity in growing children (Pereira-da-Silva et al., 2016). Only 5 of 57 studies assessed adiposity using bioelectrical impedance, BodPod, or dual energy x-ray absorptiometry (DXA) as assessment tools (Carson, Lee, et al., 2017).

The review by Sijtsma also noted a lack of literature examining potential moderators. Only three studies analyzed sex differences, which found mixed results. One study found similar relations for boys and girls (Janz et al., 2002), one found a relation for boys but not girls (Trost, Sirard, Dowda, Pfeiffer, & Pate, 2003), and one study found no relation for either boys or girls (Heelan & Eisenmann, 2006). Thus, examining sex differences in physical activity and adiposity studies is still warranted, especially among studies that use objective measurement tools for assessing adiposity in addition to calculating BMI and BMI z-score. Furthermore, few studies have examined race/ethnic differences when assessing the relation of physical activity and adiposity in young children (Pate et al., 2019). While Hispanic families with preschool children report a significantly higher number of sedentary devices in the home (television, video games, computer) compared to White families (Boles et al., 2014), it is unknown how this specifically affects adiposity levels.

When assessing specific types of activity, studies indicate that total physical activity (cumulative of light, moderate, vigorous intensity activity), time in MVPA, and time in vigorous intensity physical activity are associated with improved health markers (Carson, Lee, et al., 2017). However, studies have found that the association between MVPA and adiposity is fully explained by vigorous intensity activity as no associations were found for

moderate intensity activity alone (Collings et al., 2013; Leppänen et al., 2016). A total of 15 minutes per day of vigorous intensity physical activity was associated with 0.4% less body fat, 1.8% lower fat mass index, and 1.9% lower abdominal fat mass (Collings et al., 2013). While no associations were found between adiposity indicators and sedentary time, light, or moderate intensity activity (Collings et al., 2013; Leppänen et al., 2016), substituting five minutes per day within these activity categories with five minutes per day of vigorous activity was associated with higher fat free mass and increased physical fitness (Leppänen et al., 2016). Despite the known benefits of vigorous intensity activity, preschool children with overweight have significantly less mean daily vigorous minutes (22.9 minutes) than non-overweight children (32.1 minutes) (Metallinos-Katsaras, Freedson, Fulton, & Sherry, 2007).

While vigorous intensity activity has important benefits for adiposity health in preschoolers, the racial/ethnic impact on these associations is not well understood. To date, studies have been conducted in primarily white populations with low overweight/obesity percentages (8.5% – 16%) (Collings et al., 2013; Leppänen et al., 2016). Only one study was found that was conducted in a Hispanic population with clinical overweight (Mendoza et al., 2014). The authors found that greater accelerometer MVPA was associated with lower BMI z-score (Mendoza et al., 2014). However, as mentioned previously, BMI and BMI z-score may not be the best indicator of adiposity in growing children (Pereira-da-Silva et al., 2016). Fat mass index and percent fat mass may be more accurate measures of adiposity in this age group. Thus, the extent to which other indicators of adiposity are associated with physical activity in this population has not been extensively studied. There is a need for studies that examine the relation between physical activity and adiposity indicators using more rigorous measures, such as BIA, in Hispanic preschool-aged children with overweight and obesity.

Physical Activity and Cardiovascular Indicators

In adults, there is consistent evidence of the benefits of physical activity as a protective factor against cardiovascular indicators, cardiovascular disease, and mortality (Nocon et al., 2008). Among children and adolescents, higher levels of MVPA is associated with better cardiometabolic risk factors regardless of the amount of sedentary time (Ekelund et al., 2012) or weight status of the school-aged children (Knowles et al., 2013). However, less is known about the effects in young children under the age of five. A systematic review conducted by Bell and colleagues (2018), found only 12 published studies examining the association between physical activity and cardiovascular measures in preschoolers (Bell et al., 2018). Of these, six studies examined lipid profile and BP, four studies measured insulin resistance, two studies measured a combined score, and one study examined arterial thickness and arterial stiffness. In the six studies that measured the association between physical activity and BP, the results were mixed and may be dependent on the way in which physical activity was measured (device vs. observational). Only one study of the six studies examining the relation between physical activity and BP utilized a device-based physical activity measurement (Vale et al., 2015). The study found that children with overweight who had less than 60 minutes per day of accelerometry-derived MVPA have four times the odds (OR = 3.8, 95% CI: 1.6, 8.6) to have high systolic BP compared to normal weight, more active children (Vale et al., 2015). Parent proxy-reported activity shows mixed results with BP with some studies showing no association (Bell et al., 2018). As the physical activity guidelines suggest total activity regardless of intensity, the role of light intensity activity in combating elevated BP is unknown. Studies that measure BP and a device-based measurement of physical activity are still needed.

Physical Activity and Quality of Life

A positive association between physical activity and health-related quality of life (HRQOL) has been found in adults (Bize, Johnson, & Plotnikoff, 2007) and children (Shoup, Gattshall, Dandamudi, & Estabrooks, 2008). Children that meet the recommended physical activity guidelines reported higher physical HRQOL than children not meeting physical activity guidelines (Shoup et al., 2008). This relation was seen in children with overweight as well, where overweight and meeting the recommended guidelines reported higher physical QOL (88.4 ± 12.0) than children with overweight not meeting physical activity guidelines (76.5 ± 16.2) (Shoup et al., 2008). Few studies examine HRQOL and physical activity among preschoolers. A longitudinal study conducted in Swiss preschool youth found that low MVPA was associated with lower HRQOL measures (Michels, Susi, Marques-Vidal, Nydegger, & Puder, 2016). Additionally, in those with high sedentary time, low QOL was associated with increased adiposity (Michels et al., 2016). The intersection between adiposity, cardiovascular indicators, and quality of life needs further exploration. How physical activity in young children affects these measures is needed.

Disparities in Physical Activity Levels

Six-Cs model and physical activity

The Six-Cs model for understanding child overweight and obesity (Harrison et al., 2011), focuses on multiple levels that specifically influence nutrition and physical activity of children (**Appendix C**). For physical activity, Zone 2: Activity-related opportunities and resources, Zone 4: Activity-related practices, and Zone 5: Personal and relational attributes, are of particular interest. Zone 2 includes energy and sleep at the individual-level (child), parent knowledge and encouragement at the family-level (clan), and neighborhood and

school-level factors the context-level (community). Zone 4 includes physical activity, sedentary behavior, and screen use at the individual-level (child), parent and family practices at the family-level (clan), race/ethnicity marketing and employment factors the context-level (community). In Zone 5, includes gender, BMI, and race/ethnicity at the individual-level (child), parent BMI, family race/ethnicity, and socioeconomic status at the family-level (clan), and community BMI, race/ethnicity, and socioeconomic status the context-level (community).

Individual-level factors of physical activity

There are notable age and sex differences among preschool children's physical activity levels. Older children typically have higher levels of activity (Copeland et al., 2016; Copeland et al., 2011; Dawson-Hahn et al., 2015; Dolinsky, Brouwer, Østbye, Evenson, & Siega-Riz, 2011; Taylor et al., 2018) and are more likely to meet the WHO guidelines of 180 minutes of total activity (72.4%) and 60 minutes of MVPA (80.7%) than younger children (65.0% and 74.9%, respectively) (Dias et al., 2019). Additionally, preschool boys typically have more activity than girls (Andersen et al., 2017; Copeland et al., 2016; Dolinsky et al., 2011; Ellis et al., 2017; Finn, Johannsen, & Specker, 2002) and have a higher prevalence (53.5% – 76.9%) of meeting the 180 minutes guidelines activity guidelines than girls (33.5% – 63.0%) and the 60 minutes of MVPA guidelines (85.4% vs. 72.1%) (Dias et al., 2019; Pate et al., 2015).

Family-level factors of physical activity

At the family-level, socioeconomic disparities can affect physical activity levels. Children in households with a household income of at least \$60,000 had more MVPA than children living in households with less than \$60,000 annual income (Dolinsky et al., 2011).

Despite the noted disparities, few studies have examined the impact of sex, race/ethnicity, and socioeconomic disparities and physical activity and health indicators (Pate et al., 2019). Most studies that examine the impact of physical activity on health, control for these differences rather than conduct stratified analyses to examine the potential effect modification of these factors. Conducting a stratified analysis may lead to findings that suggest the strength of the association between physical activity and health is different among subgroups of individuals.

Context-level factors of physical activity

Type of day may also be related to physical activity levels. Children have a higher prevalence of meeting guidelines for 180 minutes of total physical activity on the weekday (68.4%) than on a weekend day (61.7%) and meeting guidelines of 60 minutes of MVPA (77.3% weekday vs. 67.6% weekend) (Dias et al., 2019). This difference may be due to school enrollment status. As mentioned earlier, school and home are two of the most important settings for children. Children who attend non-parental care are more active and less sedentary than children who do not attend child care (K. R. Hesketh et al., 2015). Boys in care have been found to have 5.0 (95% CI: 3.2, 6.9) more minutes of MVPA per hour and girls have 3.0 (95% CI: 1.3, 4.5) more minutes of MVPA than children who do not attend care (K. R. Hesketh et al., 2015). As children, on average, spend 30 hours per week in child care (Snyder et al., 2019), this is potentially 18-30 minutes more MVPA per day than children in parental care.

THE 24-HOUR ACTIVITY CYCLE

The WHO (Organization, 2019), Canadian (M. S. Tremblay et al., 2016), and Australian (Okely et al., 2017) guidelines focus on the 24-hour integration of a variety of

movement behaviors. The 24-hour Activity Cycle (24-HAC) model, developed by Rosenberger and colleagues (2019) (Rosenberger et al., 2019), includes four basic components – sedentary behavior, light intensity physical activity, MVPA, and sleep. A systematic review by Kuzik et al., (2017) examined 10 studies that assessed the relation between combinations of movement behaviors on health indicators in children under five years (Kuzik et al., 2017). These relations included, 1) physical activity and sedentary behavior and 2) sleep and sedentary behavior. No studies examined the combination of physical activity and sleep, nor a combination of all three movement behaviors together (Kuzik et al., 2017). The authors found that the ideal combination for preschool-aged children is low sedentary behavior and high physical activity, which is associated with better motor development, fitness, and favorable adiposity outcomes (Kuzik et al., 2017). This suggests waking activity patterns impact health and development in young children.

The advances in technology have allowed for measurement of the composition of movement behaviors occurring throughout the day. Wearable accelerometer devices have the ability to estimate the amount and intensity of activity, physical activity energy expenditure, and sleep-related behaviors. However, devices pose challenges for researchers to select the most appropriate classification of wear time, activity intensities, and distinguish sleep for their study population. Age-specific wear time, sleep algorithms, and activity intensity cut-points must be appropriate. In young children, hip and wrist placement and an epoch length between 1-15 seconds are most common, however less is known about the most appropriate wear time definition and sleep algorithm in preschoolers (Migueles et al., 2017).

Compositional and isotemporal analytic techniques have become popular ways to examine associations between activity behaviors and health (Chastin, Palarea-Albaladejo,

Dontje, & Skelton, 2015; Grgic et al., 2018; Rosenberger et al., 2019). The belief surrounding these analyses methodologies is due to fixed 24-hour (compositional) or wear time (isotemporal) period. The thought is: examining effects in isolation is not the most appropriate methodology due to the fixed time in a day – if one component decreases (vigorous intensity activity), then another component must increase (sleep, sedentary time, light, or moderate intensity activity) (Taylor et al., 2018). The composition of movement behaviors and sleep has been found to be related to cardiometabolic health indicators including BMI, waist circumference, and blood pressure in adults (Chastin et al., 2015).

As there is only a finite time in the day, these analyses allow for assessing health and hypothetical substitutions between movement behaviors. For example, replacing 10 minutes of MVPA with 10 minutes of sedentary time is associated with a 1.2% increase in BMI in adults (Chastin et al., 2015). In school-aged children, replacing 15 minutes of MVPA with sedentary time led to a 0.83 unit higher BMI z-score and a 5.0% increase in waist circumference-to-height ratio (Fairclough et al., 2017). The magnitude of the association was even greater for children with overweight as there was an observed 1.8 unit increase in BMI z-score and 10.7% increase in waist circumference-to-height ratio (Fairclough et al., 2017). Additionally, a meta-analysis conducted in youth found that substituting 60 minutes sedentary behavior with 60 minutes of MVPA is associated with a 2.5 decrease in body fat percentage (95% CI: -4.2, -0.9) (García-Hermoso, Saavedra, Ramírez-Vélez, Ekelund, & del Pozo-Cruz, 2017). It seems the worst health effects occur when sedentary time replaces a proportion of MVPA within the day (Chastin et al., 2015; Fairclough et al., 2017; García-Hermoso et al., 2017).

To date, there are few studies in preschool children using compositional and/or isotemporal analyses to examine the association of movement behaviors and body composition (Carson, Tremblay, & Chastin, 2017; Collings et al., 2017; Leppänen et al., 2017; Leppänen et al., 2016; Taylor et al., 2018). Measures of adiposity include BMI z-score (Carson, Tremblay, et al., 2017; Collings et al., 2017; Leppänen et al., 2016; Taylor et al., 2018), waist circumference (Carson, Tremblay, et al., 2017; Collings et al., 2017; Leppänen et al., 2016), fat mass (Leppänen et al., 2017; Leppänen et al., 2016; Taylor et al., 2018), and skinfolds (Collings et al., 2017). The study by Carson et al. (2017), found that children spend 30.9% in sedentary behaviors, 15.9% in light intensity physical activity, 4.5% in MVPA, and 48.7% of time sleeping (Carson, Tremblay, et al., 2017). Children who have overweight spend a greater proportion of the day in sedentary behavior and less time in MVPA and sleep than children at a healthy weight. The compositional analyses revealed the combined effects of movement is significantly associated with BMI z-score but not waist circumference (Carson, Tremblay, et al., 2017), however higher intensity activity may be more beneficial. Higher intensity activity has been found to have an inverse dose response with skinfold thickness (Collings et al., 2017) and substituting just five minutes a day of vigorous intensity activity for other movement behaviors is associated with higher fat free mass and better cardiorespiratory fitness and motor fitness (Leppänen et al., 2016). The study by Taylor et al. (2018) found considerable differences in movement composition across age. By age five, there are large increases in light intensity activity and MVPA and a corresponding reduction in sleep (Taylor et al., 2018). However, the authors found only a small relation with body composition. The only significant relation occurred at age 3.5 when spending 10% more time sleeping led to a 0.25 unit (95% CI: -0.42, -0.08) reduction in BMI z-scores (Taylor et al.,

2018). Additionally, spending 10% more time in sedentary or in light activities was associated with a 0.12 (95% CI: 0.01, 0.23) and 0.08 (95% CI: 0.02, 0.15) unit higher BMI z-score, respectively (Taylor et al., 2018).

While these studies in preschool-aged children show the usefulness of compositional and isothermal analyses in examining adiposity indicators, the participants are predominantly white and of parents with high educational attainment (Carson, Tremblay, et al., 2017; Leppänen et al., 2017; Leppänen et al., 2016; Taylor et al., 2018). Thus, there is a need to examine activity behaviors in a diverse sample. Furthermore, no studies were found that examined compositional and isothermal analyses with cardiovascular indicators or HRQOL in preschool-aged youth and few studies explore how light intensity physical activity affects health separately from other behaviors (Rosenberger et al., 2019). As physical activity behaviors can track from childhood into adulthood (Telama et al., 2005), examining correlates and patterns of energy expenditure behaviors has implications for intervention development to impact proximal and distal health outcomes.

PUBLIC HEALTH SIGNIFICANCE

Over 20.2 million children in the U.S. are under the age of five (Howden & Meyer, 2010). Since 26% – 42% of preschoolers with obesity remain obese as adults (Serdula et al., 1993), this age group is exceedingly important to target for obesity prevention efforts. Obesity prevention efforts include supporting energy balance behaviors, such as physical activity. However, there is a dearth of literature exploring waking activity patterns, especially amongst Hispanic preschool children. The Hispanic population is one of the fastest growing ethnicities in the U.S. with persons of two or more having the highest rate of population growth (Vespa, Armstrong, & Medina, 2018). Projected to double in population within the

next 40 years, there will be a large financial and healthcare burden if the high obesity rates continue within this group (Withrow & Alter, 2011).

There are many notable gaps in the literature surrounding physical activity and the effects on adiposity, cardiovascular health, and quality of life within the Hispanic population. By utilizing device-based measurements of physical activity, clinical measures of health, and a diverse, clinically-relevant study sample, the current study fill gaps noted by the *Physical Activity Guidelines* Advisory Committee and the WHO Guideline Development Group:

1. Insufficient evidence is available to determine the effects of physical activity on cardiometabolic risk factors in children under 6 years of age.
2. Insufficient evidence is available to determine whether the relation between physical activity and health is moderated by age, sex, race/ethnicity, weight status, or socioeconomic status.
3. A continuing need for high-quality studies that examine the entire 24-hour day and physical activity, sedentary behavior, and sleep duration in young children.

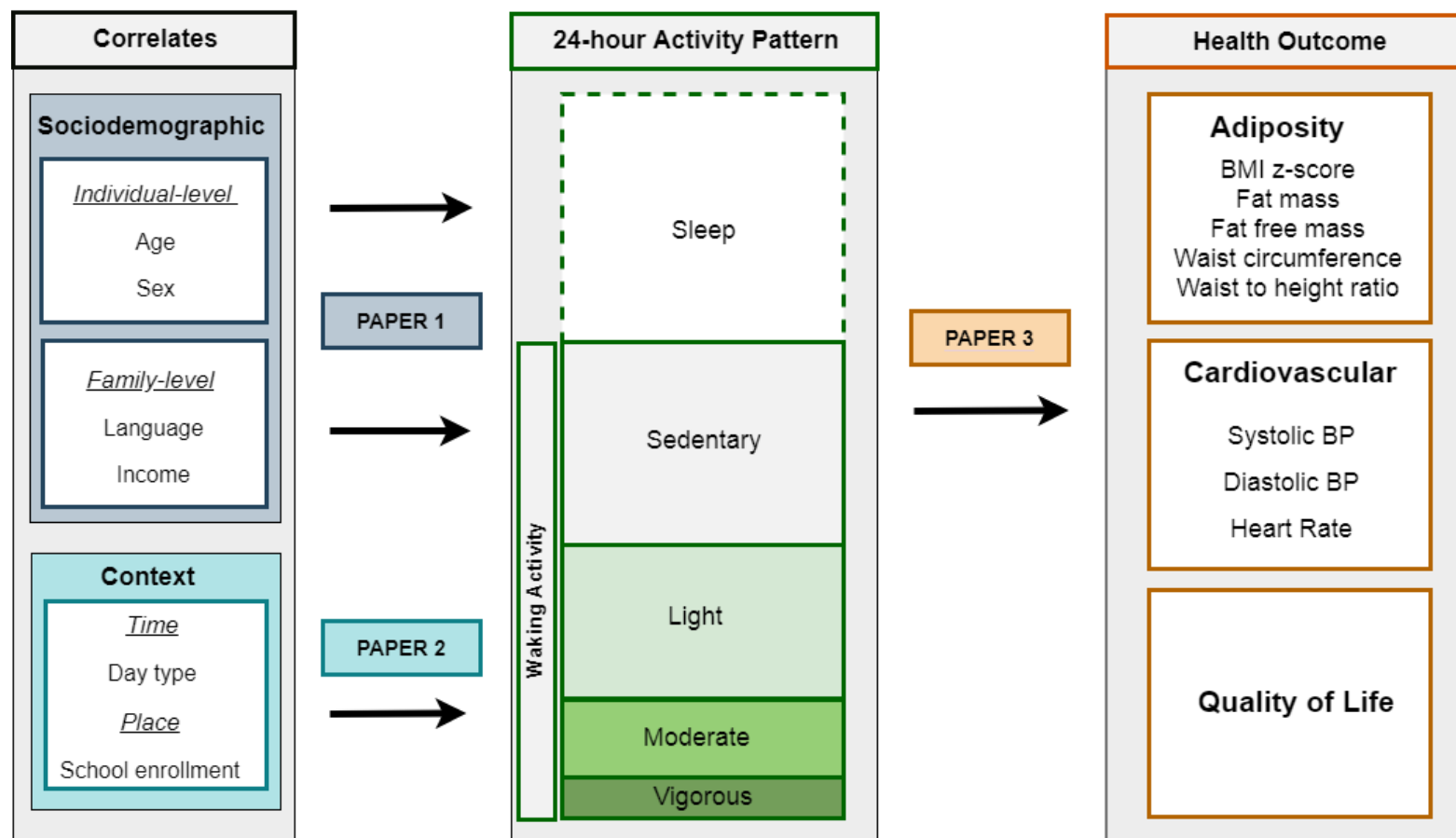
Examining waking activity cycles and the effects of these behaviors on health has great implications for designing interventions. The impact of socioecological constructs on behaviors, both separately and jointly, can help develop more tailored interventions to increase program effectiveness.

CONCEPTUAL MODEL

The conceptual model explores the potential pathways and correlates of physical activity and health in preschool-aged children (**Figure 1**). Paper 1 of the dissertation examines waking activity patterns, which includes the proportion of time spent in sedentary

activities, and light, moderate, and vigorous intensity activity, of the 24-HAC. Potential sociodemographic correlates, at the individual-level and family-level, on physical activity and health are also included within this model. Individual-level factors that were explored in this dissertation include sex and age. Potential family-level factors that were explored were primary language spoken at home and family income. The potential moderating effect of the context-level factors was explored in paper 2. The context-level factors that were explored include type of day (weekday and weekend) and within the weekday differences in school/child care enrollment status compared to children with other types of care (i.e. parental). The impact of waking activity patterns on health indicators was examined in paper 3 of this dissertation. Adiposity, cardiovascular disease indicators, and overall quality of life was investigated.

Figure 1. Conceptual model of potential pathways and correlates related to physical activity and health in preschool-aged children.



Adapted from the Framework for Physical Activity as a Complex and Multidimensional Behavior by Gabriel et al., (2012)

RESEARCH AIMS AND OBJECTIVES

Understanding physical activity patterns in racially diverse preschool youth is not well understood. Thus, the objective of this dissertation work is to examine factors related to movement and health in racial/ethnic minority children experiencing obesity. This dissertation used a sample of racial/ethnic minority children, aged 2-5 years with overweight and obesity, from the Texas Childhood Obesity Research Demonstration (TX CORD) secondary prevention study. The overall goal of the TX CORD Study was to use a systems-oriented approach to address child obesity among low income, ethnically diverse children with overweight and obesity, ages 2-12 years, residing in Houston and Austin, TX (Hoelscher et al., 2015). The secondary study was a randomized controlled trial (RCT) comparing two secondary prevention child obesity programs (MEND/CATCH and Next Steps). In order to obtain a large sample size and not include the influence of potential intervention effects, this dissertation work used baseline only data from the enrolled children ages 2-5. Measurements included accelerometry, parent proxy indicators, and health data collected during the secondary prevention study.

The overall aims of this dissertation are:

Aim 1: To examine sociodemographic and context-related factors related to waking patterns of activity.

Aim 2: To examine the impact of waking activity patterns on health indicators.

Study Population

The study population is a majority-minority sample of children with overweight and obesity, aged 2-5 years, participating in the baseline assessment of the TX CORD secondary

prevention study. The sample is primarily children of Hispanic origin (88%), 49.1% are female, and 80% fall below 100% income to poverty ratio.

Paper 1: Sociodemographic and cultural correlates of waking activity patterns in preschool children with overweight and obesity

The purpose of this paper was to examine and describe waking activity patterns among a majority-minority sample of preschool-aged children, age 2 to 5, with overweight and obesity. The activity pattern is comprised of time spent in sedentary, and in light, moderate, and vigorous intensity physical activity. Additionally, this study examined sociodemographic factors that may influence activity pattern and also determine the number of children meeting guidelines for physical activity. The study aims are:

Aim 1: To describe and compare accelerometer-determined waking activity patterns by individual-level factors (age, sex) and family-level factors (language spoken at home, family income).

Hypothesis 1: Older preschool children will have significantly more physical activity than younger children.

Hypothesis 2: Boys will have significantly more physical activity than girls.

Hypothesis 3: Children living in homes that predominately speak English will have significantly more physical activity than children living in households that speak another language more than English.

Hypothesis 4: Among low income families, children in families with higher household income will have significantly more physical activity than children in families with less income.

Aim 2: To determine the odds of meeting guidelines by potential individual and family correlates. Guidelines include:

- 1) ≥ 180 minutes of variety of physical activity intensities and
- 2) ≥ 60 minutes of moderate to vigorous intensity physical activity.

Paper 2: The association between waking activity patterns and context-related factors in preschool children with overweight and obesity

The purpose of this paper was to understand accelerometer-determined physical activity patterns in preschool-aged youth. Context-specific activity patterns were examined. Context-related factors included differences across type of day (weekend vs. weekday) and school/child care enrollment. First, this study examined activity pattern stratified by weekday and weekend. Then, differences in patterns of activity occurring during the weekday by children enrolled in school and in parental care (not enrolled in school or child care) were assessed. The study aims are:

Aim 1: To examine waking activity patterns stratified by weekday and weekend.

Hypothesis 1: Children will have significantly more physical activity on the weekday than on the weekend.

Aim 2: To examine weekday waking activity patterns stratified by parental care and children attending school/child care.

Hypothesis 1: Children enrolled in preschool programs will have significantly more physical activity than children in alternative care.

Hypothesis 2: Children enrolled in preschool programs will have significantly more physical activity during normal care hours (8:00 – 14:59) than non-school hours.

Paper 3: Adiposity, cardiovascular, and quality of life indicators and reallocation of time in preschool children with overweight and obesity: An isothermal data analysis

The purpose of this paper was to examine the health outcomes related to waking activity behaviors among a majority-minority sample of preschool-aged children with overweight and obesity. The study aims are:

Aim 1: To examine the association of waking activity behaviors on adiposity health indicators, including BMI z-score, fat mass, fat mass index, and waist circumference.

Aim 2: To examine the association of waking activity behaviors on cardiovascular health indicators, including resting systolic blood pressure, resting diastolic blood pressure, and resting heart rate.

Aim 3: To examine the association of waking activity behaviors on parent-reported health-related quality of life.

PARENT STUDY METHODS

STUDY DESIGN

This dissertation work used data from an existing randomized controlled trial (RCT), the Texas Childhood Obesity Research Demonstration (TX CORD). The goal of the TX CORD study was to address childhood obesity through primary and secondary obesity prevention efforts (Hoelscher et al., 2015). Data from the secondary prevention study, which was the implementation of a community-centered weight management program, were used (Hoelscher et al., 2015). The secondary prevention program was a 12-month RCT in which

child participants, ages 2-12 years, and their families were randomly assigned to 1) a community-centered program or 2) a primary health care-centered program.

The community-centered program was a combination of Mind, Exercise, Nutrition...Do It! (MEND) (Sacher et al., 2010) and the Coordinated Approach To Child Health (CATCH) program (Kelder et al., 2005). Briefly, the 12-month community-centered program included a 3-month intensive phase with multiple curriculum components of behavioral, nutrition, and physical activity, group discussion with parents, and feedback reports to healthcare providers and parents. The 2-5 age group consisted of nine weekly sessions (90 minutes) and the 6-12 age groups consisted of 18 twice-weekly sessions (120 minutes) plus access to YMCA sports twice weekly (Butte et al., 2017). The twice-weekly sessions included 1-hour of parents and children together in a didactic lesson, and a 1-hour parent group session, while the children participated in CATCH activities. The 9-month transition phase included monthly review sessions that included: role model stories, activities that reinforced MEND themes, CATCH activities, cooking classes, a healthy strategies booklet for families, and access to the MEND website. Total contact time was 27 hours for the 2-5 age group and 49.5 hours of sessions plus 72 hours of YMCA sports for the 6-12 group (Butte et al., 2017).

The clinic-based program included a culturally-adapted version of the Next Steps counseling program (Fanburg et al., 2014) plus a parent/child workbook. Next Steps included counseling materials for primary care providers. The workbook included nutrition and physical activity targets for parents and children (Butte et al., 2017). Families were encouraged to attend follow-up clinic visits for the 12-month duration. The estimated

maximum contact hours were eight. For the purposes of this dissertation, only baseline data were utilized to remove the effect of the intervention arms on the targeted health outcomes.

PARTICIPANTS

Child participants for the TX CORD secondary prevention study were recruited from 12 primary care clinics located in Austin and Houston, TX. The clinics were selected based on serving in the area-level catchment area for TX CORD which was based on socioeconomic status and racial/ethnic diversity (Oluyomi et al., 2015). Participant recruitment involved electronic medical record review for eligibility, physician referrals, and phone calls to parents of eligible participants after medical record review. Eligibility criteria for the overall study included: 1) between the ages of 2 to 12 years, and 2) a BMI at or above the 85th percentile for age and sex. Exclusion criteria included complications that were contraindicated for exercise, having obesity-related conditions (e.g., endocrine abnormalities, steroid use) and/or severe psychological problems, and underwent a clinical obesity treatment program within the past year prior to enrollment. At least one parent provided consent, children older than 6 provided written assent, and children under the age of 6 provided verbal assent. After recruitment, children were then stratified into three groups based on age, 2-5 years, 6-8 years, and 9-12 years of age. Participants between the ages of 2-5 were used for this dissertation, N = 167.

DATA COLLECTION

Baseline data collection occurred between September 2012 and February 2014. Data collection included parent surveys, accelerometers, and measures of health indicators.

Parent Surveys

Parents completed the Parent Common CORD Survey (**Appendix C**) and the Parent Texas CORD Survey (**Appendix D**) during each visit. The Common CORD Survey included questions regarding 1) sociodemographics of the parent, 2) demographics of the participating child, 3) healthcare utilization, 4) nutrition and eating practices at the parent and child level, 5) physical activity and screen time at both the parent and child level, and 6) food purchasing behaviors.

The Parent Texas CORD Survey included questions regarding, 1) parent health condition, 2) child strengths and difficulties questionnaire, 3) child well-being, 4) child's growth, 5) child feeding practices, and 6) parent self-efficacy assessment.

Physical Activity

Physical activity was measured using ActiGraph GT3X+ devices (*Actigraph, Pensacola, FL, USA*). Participants were asked to wear the accelerometer on their right hip (via elastic belt) for 24 hours a day for 7 consecutive days. Devices were initialized to sample raw data at 30 hertz (Hz). University of Houston (UH) staff prepared accelerometer kits which included the accelerometer, belt, activity log, and a prepaid and addressed return envelope. UH staff delivered accelerometers to the TX CORD sites for distribution to participants. After participants wore the device for 7 days, they returned the device to UH using the return envelope. UH staff downloaded the raw accelerometer data using the ActiLife v6.3.1 software and uploaded to a secure server. For the purposes of this dissertation, data were reintegrated and reprocessed.

Accelerometer Processing

In August 2019 accelerometer files were downloaded from a secure server and processed at the hourly level in the ActiLife v6.13.4 software using 10-second epoch lengths, which has been widely used in studies conducted in preschool-aged children (Cain, Sallis, Conway, Van Dyck, & Calhoun, 2013; Migueles et al., 2017). A total of 141 files were available for preschool-aged participants.

Wear time periods

Due to children wearing the accelerometer for 24 hours, data were examined hourly to parse out waking time and remove activity accumulated during sleep or usual sleep time hours. While the U.S. based bedtime recommendation is 21:00 for preschool-aged children, children of nonwhite race/ethnicity and those living in lower-income households have been found to have a later bedtimes (Anderson, Andridge, & Whitaker, 2016; Hale, Berger, LeBourgeois, & Brooks-Gunn, 2009; Patrick, Millet, & Mindell, 2016). Therefore, the bedtime for the overall sample was determined two ways. First, by using the question, “*What time does your child usually go to bed?*” and secondly, examining mean hourly activity estimates of the sample. Bedtime responses range from 19:00 – 01:00 hours, with 93.5% of the parent sample reporting a bedtime before 23:00 hours. Examining the minutes of the accelerometer-determined mean hourly activity minutes from 19:00 – 01:00 found that mean activity for the sample was lowest beginning at 23:00 hours; therefore, bedtime was set at 22:59 hours. ActiLife and the use of sleep algorithms (Cole-Kripke and Sadeh) were not used in this study because they were validated for use in children/ adolescents (10-25 years) and adults (35-65 years) and have not be validated for preschool-aged children (Migueles et al., 2017).

While the average wake time for preschool-aged children has been found to be 07:00 (Patrick et al., 2016; Scharf & DeBoer, 2015), differences in wake time have been found across obesity status, racial/ethnic, and socioeconomic groups. Therefore, wake time for the sample was determined by examining the mean hourly activity estimates between the hours of 04:00 – 09:00. In the sample, the hours between 06:00 and 07:00 hours had the largest change in accelerometer mean hourly activity minutes with sedentary time decreasing and an accumulation of light, moderate, and vigorous intensity activity increasing, thus the wake time was set at 06:00. This wake time has also been used in other samples examining waking physical activity patterning within this age population (Dias et al., 2019; van Sluijs et al., 2013).

After clock times defining the waking periods were determined (06:00 – 22:59), the accelerometer data were screened for wear periods using both the Choi wear time algorithm (Choi, Liu, Matthews, & Buchowski, 2011). Valid wear time was ≥ 10 hours of data on ≥ 3 days (≥ 2 weekdays, ≥ 1 weekend) (Hinkley, O'Connell, et al., 2012; Rich et al., 2013). Any three days has been found to be a sufficient and reliable estimate of habitual physical activity in this age group (ICC = 0.7-0.9) (Bingham et al., 2016; Cain et al., 2013; Rich et al., 2013). If children wore the device for more than 7 days ($M = 7.1$, $SD = 1.2$, Range 3-13), only the first 7 days of wear time were used for the analyses. A total of 131 participants had valid wear time. There were no significant differences in demographics between preschool-aged children that had valid wear time and children that were excluded due to wear time compliance.

Count cut point set for classifying intensity categories

For each waking period with ≥ 10 hours per day of valid wear, the Butte VM preschool accelerometer count cut point thresholds (2013) were used to estimate activity intensity (Butte et al., 2014). Cut points were set for sedentary: ≤ 819 counts per minute (CPM); light: 820 - 3907 CPM; moderate: 3908 - 6111 CPM; and vigorous: ≥ 6112 CPM. Although Pate cut point thresholds (Pate, Almeida, McIver, Pfeiffer, & Dowda, 2006) for preschoolers have been widely used (Janssen et al., 2013; Migueles et al., 2017), they utilize only vertical axis counts and have been found to be overall less sensitive to predicting activity intensity (62%) than Butte VM cut points (70%).

Estimates by each waking hour

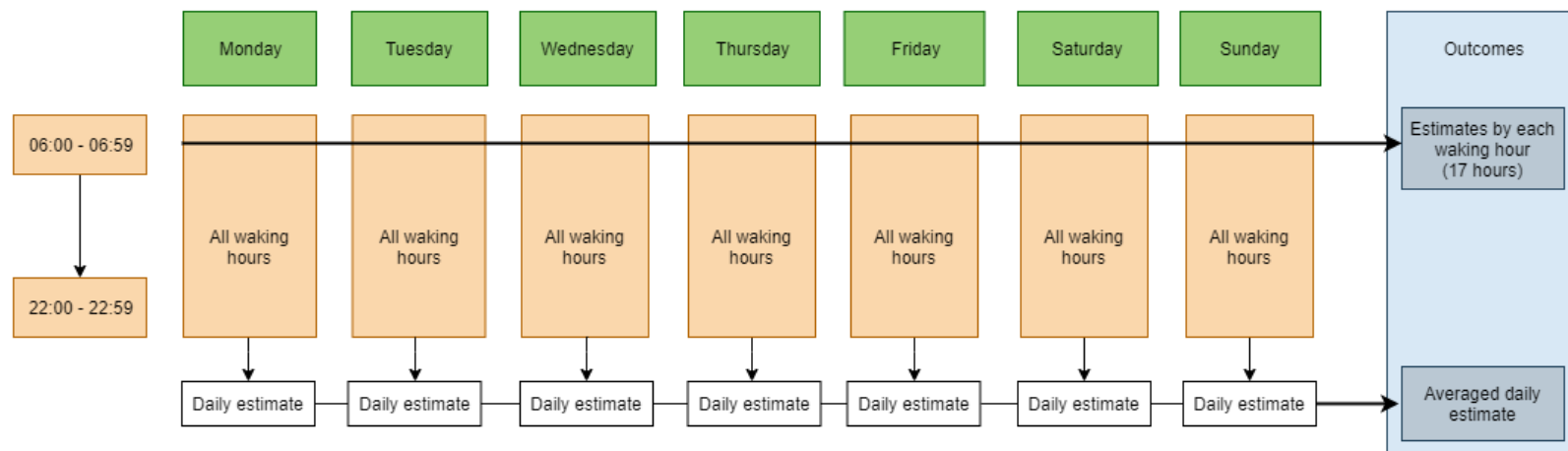
Accelerometer data were processed at the hour level per valid day. Activity estimates were summed across all valid days for an activity estimate for each individual waking clock-hour between the hours of 06:00 – 22:59 (total = 17 individual clock-hours). Hourly outcomes by each waking hour included 1) sedentary activity (minutes per hour), 2) light intensity activity (minutes per hour), 3) moderate intensity activity (minutes per hour), and 4) vigorous intensity activity (minutes per hour). Proportion of each hour (out of 60 minutes) spent in sedentary, light, moderate, and vigorous intensity activity were also calculated. Additionally, hourly outcomes were computed for type of day to include weekday only estimate (Monday – Friday), and a weekend only estimate (Saturday and Sunday) for each waking clock-hour.

Averaged daily estimate

In order to develop averaged daily estimates, hourly estimates were first summed across all waking hours (06:00 – 22:59) per individual day to compute daily summary estimates. Daily summary estimates included 1) sedentary activity (minutes per day), 2) light intensity activity (minutes per day), 3) moderate intensity activity (minutes per day), 4) vigorous intensity activity (minutes per day), 5) total accumulated MVPA (minutes per day), and 6) total physical activity (light + MVPA) (TPA) (minutes per day). Daily summary estimates were averaged across all valid days to compute an averaged daily estimate. Additionally, averaged daily estimates for type of day were computed for a weekday only daily estimate (Monday – Friday), and a weekend only daily estimate (Saturday and Sunday).

Figure 2 represents the development of the accelerometer-derived physical activity estimates for this dissertation work.

Figure 2. Flow chart for the development of accelerometer outcome estimates



Health Indicators

Adiposity indicators

BMI and BMI z-score

Research staff measured height with a stadiometer and weight with a digital scale. Participants were measured in light clothes and without shoes. Weight was measured to the nearest 0.1 kg. Weight was measured twice for each participant, with an optional third measurement if the two measurements differed by 0.1 kg. The final variable equates to the average score between the measurements. Height was measured to the nearest 0.1 cm. Height was measured twice for each participant, with an optional third measurement if the two measurements differed by 0.1 cm. The final variable equates to the average score between the trials. Body Mass Index (BMI) was calculated using the equation:

$$BMI = weight (kg) \div height(m)^2$$

Additionally, BMI percentile and BMI z-score were computed using *A SAS Program for the 2000 CDC Growth Charts* (<https://www.cdc.gov/nccdphp/dnpao/growthcharts/resources/sas.htm>).

Fat mass and fat mass index

Fat mass was measured using bioelectrical impedance analysis (BIA) (*TBF- 410GS, Tanita, Arlington Heights, Illinois*), measured to the nearest 0.1 kg. Mass was measured twice with the final variable equating to the average score between the two trials. Fat mass percent was calculated as:

$$Fat\ mass\ \% = \frac{fat\ mass\ (kg)}{total\ body\ weight\ (kg)}$$

Fat mass index (FMI) was calculated as:

$$\text{Fat mass index (FMI)} = \frac{\text{fat mass (kg)}}{\text{height}^2 \text{ (m)}}$$

Waist circumference

Waist circumference was measured to the nearest 1.0 mm using a measurement tape. Waist circumference was measured twice with the final variable equating to the average score between the two trials. Total waist circumference is provided as a continuous scale. Additionally, a waist to height ratio was calculated as a proportion, from 0-1.

Cardiovascular indicators

Systolic and diastolic blood pressure

Resting systolic blood pressure (SBP) and diastolic blood pressure (DBP) were measured using an automated monitor to the nearest 1.0 mmHg (*8100T, Dinamap, Berlin, Massachusetts*). Children were instructed to sit quietly for five minutes prior to measurement. During measurement, children were seated with their feet flat on the floor. Resting BP was measured twice with the summary variable equating to the average score of both SBP and DBP between the two trials. Participants rested one minute between the two trials. If there was more than a 5.0 mmHg variation between the two trials, a third measurement was taken. Age, sex, and height determined elevated BP, stage 1 hypertension, and stage 2 hypertension were computed using the simplified BP tables developed by the American Academy of Pediatrics (Flynn et al., 2017).

Heart rate

Resting heart rate was measured at the same time as BP using the automated monitor. The measurements were recorded to the nearest beat per minute (bpm). The final variable

equates to the average score between the two trials. If there was more than a 5.0 bpm variation between the two trials, a third measurement was taken.

Quality of life

The PedsQL Measurement Model for the Pediatric Quality of Life Inventory was used to measure health-related quality of life (HRQOL). PedsQL is a 23-item multidimensional scale, measuring 1) Physical functioning (8 items), 2) Emotional functioning (5 items), 3) Social functioning (5 items), and 4) School functioning (5 items). Two items were removed from the School functioning sub-scale for children ages 2-5, for a final survey of 21-items. For children ages 2-5, HRQOL was measured via parent proxy-report, which has been shown to have good reliability (Cronbach's $\alpha = 0.90$) (Varni, Seid, & Kurtin, 2001). Each item has a 5-point response scale of (0 = never a problem; 1 = almost never a problem; 2 = sometimes a problem; 3 = often a problem; 4 = almost always a problem). Items were transformed to a 0-100 scale using (0 = 100, 1 = 75, 2 = 50, 3 = 25, 4 = 0) and divided by the number of items answered for each sub-scale. Higher scores indicate better HRQOL. A total score was measured as the sum of all items over the number of items answered on all scale.

Table 2. Items for the PedsQL Measurement Model for measuring health-related quality of life (HRQOL) (Varni et al., 2001)

In the past month, how much of a problem has your child had with...?	
Physical Functioning	Ordinal:
Walking	0 = Never
Running	1 = Almost never
Participating in active play or exercise	2 = Sometimes
Lifting something heavy	3 = Often
Bathing	4 = Almost always
Helping to pick up his or her toys	
Having hurts or aches	
Low energy level	
Emotional Functioning	
Feeling afraid or scared	
Feeling sad or blue	
Feeling angry	
Trouble sleeping	
Worrying	
Social Functioning	
Playing with other children	
Other kids do not want to play with him or her	
Getting teased by other children	
Not being able to do things that other children his or her age can do	
Keeping up when playing with other children	
School Functioning (completed if child attends school or daycare)	
Doing the same school activities as peers	
Missing school/daycare because of not feeling well	
Missing school/daycare to go to the doctor or hospital	

IRB STATEMENT

The TX CORD Study protocol was approved by the University of Texas Health Science Center and Baylor College of Medicine (HSC-SPH-11-0513). This dissertation work was approved through expedited review and approval in August 2019.

PAPER 1: SOCIODEMOGRAPHIC AND CULTURAL CORRELATES OF WAKING ACTIVITY PATTERNS IN PRESCHOOL CHILDREN WITH OVERWEIGHT AND OBESITY

INTRODUCTION

Physical activity during early childhood (3-5 years of age) is associated with numerous health benefits including a reduced risk for excessive weight gain and improved bone health (Pate et al., 2019). Preventing excess weight gain during this critical period in development is necessary as childhood obesity that persists into adulthood is one of the leading causes of health problems in adults (Nader et al., 2006). As obesity percentages continue to rise across the U.S. (Ogden et al., 2014; Ogden et al., 2016) and globally (De Onis et al., 2010), encouraging healthy behaviors for this age group is imperative.

A number of guidelines have been developed to promote healthy behaviors in youth under the age of five. The U.S. *Physical Activity Guidelines for Americans* recommends that preschool-aged children should be physically active throughout the day by doing a variety of activity types (Committee, 2018). However, the *Physical Activity Guidelines for Americans* has no specific guideline for dose of activity, only a suggestion that a reasonable target may be three hours per day of activity across all intensity categories: light, moderate, or vigorous intensity. Emphasizing the whole day approach, the Canadian (M. S. Tremblay et al., 2016) and Australian (Okely et al., 2017) 24-hour guidelines focus on the integration of a variety of movement behaviors that impact health: physical activity, sedentary behavior, and sleep. Recently, the World Health Organization (WHO) (Organization, 2019) published guidelines that reflect the idea of the whole day movement paradigm. The WHO recommendations include 180 minutes of activity per day at any intensity, of which 60 minutes should be

moderate to vigorous physical activity (MVPA), no more than 60 minutes of screen time, and 10-13 hours per night of quality sleep.

Studies that have examined the prevalence of children meeting guidelines have found a large range of compliance (5 – 100%) (Andersen et al., 2017; Chaput et al., 2017; Cliff et al., 2017; Dawson-Hahn et al., 2015; De Craemer et al., 2018; Dias et al., 2019; K. R. Hesketh et al., 2015; K. R. Hesketh et al., 2014; Hinkley, Salmon, et al., 2012). A pooled estimate across 20 studies found that 70.0% of young children meet the ≥ 180 minutes of total physical activity recommendation and 78.8% meet guidelines of ≥ 60 minutes of MVPA (Dias et al., 2019). Although studies have found differences in activity by age and sex, previous studies have been primarily conducted in normal weight youth. Few studies have examined activity patterns in a clinically overweight population.

In the U.S., 13.9% of children 2-5 years old have obesity (Hales et al., 2018). Understanding the correlates of physical activity dose and patterning in overweight youth are of particular importance as adiposity and energy balance behaviors in early life are associated with numerous physiological and psychological health problems, such as elevated resting blood pressure, asthma, poor dental health, nonalcoholic fatty liver disease, attention-deficit/hyperactivity disorder (ADHD), and poor sleep habits (Macdonald-Wallis et al., 2017; Pulgarón, 2013), and obesity and poor health in later years (Cunningham et al., 2014; Nader et al., 2006). Furthermore, few studies have examined activity patterns in racially/ethnically diverse young children. Hispanic preschool-aged children have the highest prevalence of obesity (29.8%) compared to other race/ethnic groups in the U.S. (Ogden et al., 2014) and have increased odds of maintaining higher body mass index (BMI) across childhood

compared to white children (Guerrero et al., 2016). Within the next four decades, Hispanic children are projected to make up one-third of the youth population in the U.S. (Vespa et al., 2018), thus examining factors associated with physical activity in racially diverse youth is needed in order to develop more effective tailored interventions for this population.

Physical activity in early years is associated with numerous health benefits across the lifecourse (Pate et al., 2019; Sijtsma et al., 2011; te Velde et al., 2012; Timmons et al., 2012); however, limited evidence assesses physical activity and sedentary behavior patterns in racially diverse children with obesity. Additionally, the extent to which racially diverse preschool children experiencing obesity are meeting physical activity guidelines is unknown. Thus, using a majority-minority sample of preschool-aged children with overweight and obesity, this study aims to fill the gaps in the literature. The purpose of this paper is to: 1) examine and describe physical activity patterns, and 2) examine the association of sociodemographic and cultural factors (age, sex, ethnicity, income to poverty ratio, language spoken) and activity patterns. The hypotheses based on the literature are: a) older children compared to younger, b) boys compared to girls, c) Non-Hispanic compared to Hispanic children, d) children living in homes that predominately speak English, and e) children in families with higher income to poverty ratio compared to families with lower ratios will have significantly more minutes of physical activity. A secondary aim is to explore odds of meeting physical activity guidelines in this population based on guidelines that suggest: 1) ≥ 180 minutes of total physical activity (TPA) (light, moderate, and vigorous intensity), and 2) ≥ 60 minutes of moderate to vigorous intensity physical activity (MVPA).

METHODS

Study Design

The study is a cross-sectional analysis of baseline data of preschool-aged participants (2-5 years of age) from the Texas Childhood Obesity Research Demonstration (TX CORD) Secondary Prevention Study (N = 167). Briefly, the TX CORD Secondary Prevention Study was a 12-month RCT in which child participants, ages 2-12 years, and their families were randomly assigned to 1) a community-centered program or 2) a primary health care-centered program (Hoelscher et al., 2015). The current study included participants between the ages of 2-5 years, who returned the baseline accelerometer, and had completed parent surveys (N = 141). The analytic sample included only preschool-aged children with valid accelerometer wear time of ≥ 10 hours of data between the hours of 6:00 – 22:59 on ≥ 3 days (≥ 2 weekdays, ≥ 1 weekend) (N = 131).

Data Collection

Baseline data collection occurred between September 2012 and February 2014. For this study, TX CORD parent surveys and child worn accelerometers were used. Analyses were conducted in September 2019.

Sociodemographic and cultural constructs

Sociodemographic variables (individual and family-level) were obtained from the Parent Common CORD Survey. Individual-level items included child age, sex, and ethnicity. Family-level variables included language child primarily speaks and income to poverty ratio. Language was stratified as: a) speaks English, more English than another language, or both English and another language equally, b) speaks more of another language than English, and c) speaks only another language. Income to poverty ratio was determined by dividing the

reported total family income by the 2013 U.S. Census Bureau poverty threshold for the number of adults and children living in the household (www.census.gov). Income was determined by taking the median value of the following categories: a) >\$10,000, b) \$10,001 to \$15,000, c) \$15,001 to \$20,000, d) \$20,001 to \$25,000, e) \$25,001 to \$35,000, f) \$35,001 to \$50,000, g) \$50,001 to \$75,000, and h) \geq \$75,001. Income to poverty ratio was stratified as: <49%, 50-99%, and \geq 100%.

Accelerometer-derived physical activity

This study used the estimates by each waking hour and the averaged daily estimate described previously in the parent methods. Briefly, ActiGraph GT3X+ devices were used to collect data. In August 2019, accelerometer files were downloaded from a secure server and processed in ActiLife v6.13.4 software using 10-second epoch lengths. Data were examined hourly to parse out waking time and remove activity accumulated during sleep or usual sleep time hours. Waking periods (06:00 – 22:59) were then screened for wear periods using the Choi wear time algorithm (Choi et al., 2011). Valid wear time was set at \geq 10 hours of data on \geq 3 days (\geq 2 weekdays, \geq 1 weekend).

Estimates by each waking hour

In order to examine hourly patterns, accelerometer data were processed at the hour level per valid day. Activity estimates were summed across all valid days for an activity estimate for each individual waking clock-hour between the hours of 06:00 – 22:59 (total = 17 individual clock-hours). Hourly outcomes by each waking hour included 1) sedentary activity (minutes per hour), 2) light intensity activity (minutes per hour), 3) moderate intensity activity (minutes per hour), and 4) vigorous intensity activity (minutes per hour).

Proportion of each hour (out of 60 minutes) spent in sedentary, light, moderate, and vigorous intensity activity were also calculated.

Averaged daily estimate

The averaged daily estimate was computed by averaging daily estimates. Daily summary estimates were first computed by summing hourly estimates across all waking hours (06:00 – 22:59) per individual day. Daily summary estimates were averaged across all valid days to compute an averaged daily estimate, which included 1) sedentary activity (minutes per day), 2) light intensity activity (minutes per day), 3) moderate intensity activity (minutes per day), 4) vigorous intensity activity (minutes per day), 5) total accumulated MVPA (minutes per day), and 6) total physical activity (light + MVPA) (TPA) (minutes per day).

Data Analysis

Statistical analyses were performed using SAS 9.4 (*SAS Institute Inc., Cary, NC*) with figures developed using the RStudio Tidyverse package (*RStudio, Inc.*). Descriptive statistics including frequencies and percentages were conducted for each sociodemographic and cultural variables. Physical activity variables were assessed for normality both visually and through the Shapiro-Wilk test. Shapiro-Wilk tests were significant ($p < 0.05$) indicating the data were non-parametric. Medians and 25th and 75th percentiles were calculated for 1) average vector magnitude counts (counts per minute per day), 2) sedentary activity (minutes per day), 3) light intensity activity (minutes per day), 4) moderate intensity activity (minutes per day), 5) vigorous intensity activity (minutes per day), 6) total accumulated MVPA (minutes per day), and 7) total physical activity (minutes per day). Mann-Whitney U test or

Kruskal-Wallis tests, depending on number of categories, compared differences across groups at $\alpha = 0.05$. Dunn's test with a Bonferroni correction was used for multiple comparisons after significant Kruskal-Wallis tests.

Proportion of the hour spent in sedentary, light, moderate, and vigorous intensity activity and mean minutes spent in each intensity category were plotted for every hour between waking hours – 06:00 to 22:59. Figures were developed for the overall sample and stratified by categories of significant independent variables.

The percentages of participants meeting the WHO guidelines of ≥ 180 minutes of total physical activity and ≥ 60 minutes of MVPA were calculated. The prevalence of children meeting each guideline were compared across categories of the independent variables using chi-squared tests with an $\alpha = 0.05$. Logistic regressions were run to examine the association between the independent variables and prevalence of meeting physical activity guidelines.

RESULTS

The overall sample of TX CORD participants between the ages of 2-5 years was 167. The final analytical sample with valid wear time data included 131 participants. There were no significant differences between the overall sample and the analytical sample on demographic variables. The analytic sample had a mean age of 4.3 (SD=1.1), was 52.7% female, and 87.0% Hispanic. The analytic sample had a median average daily wear time of 964.1 (IQR: 922.3-996.7) minutes between 06:00 – 22:59 hours (1,020 total minutes) which included 578.4 average daily sedentary minutes, 285.6 average daily light intensity minutes, and 79.3 average daily total MVPA minutes (**Table 1**). This equated to 60.0% sedentary, 29.6% in light intensity, and 8.3% in MVPA. Mean proportion of time spent in activity type

by hour (**Figure 1**) show preschoolers were sedentary greater than 50% of the hour for all waking hours. Preschoolers had the highest minutes of activity per hour between the hours of 11:00 – 17:00 (**Figure 2**). Light intensity activity was consistent across these hours with MVPA minutes increasing throughout the day and peaking between the hours of 18:00 – 19:00.

Age

The Kruskal-Wallis test for age was not significant for average accelerometer averaged daily summary estimates $p > 0.05$. There were no significant differences for age. Age group was not associated with daily total MVPA ($\chi^2 (2) = 5.69, p = 0.058$) or average daily TPA ($\chi^2 (2) = 3.29, p = 0.193$).

Sex

There were significant differences for accelerometer averaged daily summary estimates by sex, ethnicity, language spoken, and income to poverty ratio. Males had significantly higher median average daily minutes of total MVPA (91.6, IQR: 74.7-110.3) than females (MVPA: 68.1, IQR: 52.0-86.1) ($p < 0.001$). Males also had significantly higher median average daily TPA (383.5, IQR: 333.9-424.3) than females (356.3, IQR: 308.6-392.8) ($p = 0.026$). Activity patterns by hour (**Figures 3 & 4**) show females had greater sedentary time between the hours of 06:00 – 17:00 than males (non-significant). Males had significantly higher minutes of vigorous intensity physical activity than females between 09:00 – 20:00 hours.

Ethnicity

Non-Hispanic preschoolers had significantly higher median average daily minutes of total MVPA (98.1, IQR: 87.6-107.5) than Hispanic preschool children (75.5, IQR: 55.9-96.5)

($p=0.005$). Activity patterns by hour (**Figures 5 & 6**) show greater variation in proportion per hour in Non-Hispanic preschool children, which is marked by an increase in sedentary time and decrease in light activity during the hours between 12:00 – 14:59. Non-Hispanic children had consistently higher minutes of MVPA minutes per hour and had significantly more MVPA at 10:00 hour than Hispanic preschool children.

Language Spoken

The Kruskal-Wallis test for language spoken at home was significant for average daily total MVPA ($\chi^2 (2) = 10.22, p = 0.006$). Results of the Dunn's test indicate that preschool children that speak only English or English and another language equally (90.6, IQR: 70.0-107.5) had significantly higher median average daily total MVPA than preschool children that speak more of another language than English (71.5, IQR: 56.4-89.21) ($p=0.014$) or children that spoke only another language (71.6, IQR: 52.0-91.9) ($p=0.011$). No significant findings were found between children that speak more of another language than English and children that speak only another language ($p= 0.853$). Activity patterns by hour (**Figures 7 & 8**) show children that speak only English or English and another language equally have higher minutes MVPA from 09:00 – 19:00 hours than other children, with significant differences at 15:00, 19:00, and 20:00 hours.

Income to Poverty Ratio

The Kruskal-Wallis test for income to poverty ratio was significant for average daily total MVPA ($\chi^2 (2) = 6.29, p = 0.043$). Results of the Dunn's test indicate that preschool children living in families that have a ratio at or above 100% (94.0, IQR: 77.0-107.5) have significantly higher average daily total MVPA than preschool children in families than have an income to poverty ratio at or below 49% (72.8 IQR:55.7-90.0) ($p=0.020$). No significant

differences were found for children in households with a ratio between 50-99% (75.5, IQR: 62.4-97.0). Activity patterns by hour (**Figures 9 & 10**) show children in families with a poverty ratio at or above 100% have the highest minutes of activity in the morning and the highest amounts of MVPA than other groups.

Prevalence Meeting Physical Activity Guidelines

All participants (100%, n = 131) met the WHO physical activity guidelines for total physical activity. The sample had a median average daily estimate of 362.2 (IQR: 320.5-409.2) total physical activity minutes. A total of 74.8% (n=98) participants met the ≥ 60 minutes of MVPA guideline (**Table 2**). The overall sample had a median average daily estimate of 79.3 (IQR: 59.7-99.0) total MVPA minutes. Females had significantly lower prevalence (63.8 %) than males (87.1%) ($\chi^2 (1) = 9.43, p = 0.002$) and had 0.26 odds (95% CI: 0.11-0.64) of meeting MVPA guidelines compared to males. Compared to preschool children that speak only English or English and another language equally, preschool children that only speak another language had 0.33 odds (95% CI: 0.11-0.98) of meeting MVPA guidelines. No significant differences in the odds of meeting MVPA guidelines were found for age or income to poverty ratio.

DISCUSSION

This study examined sociodemographic and cultural correlates of waking activity patterns among a majority-minority sample of preschool-aged children, ages 2 to 5, with overweight and obesity. In this sample of 131 preschool children, individual-levels factors such as sex and ethnicity were significantly associated with activity and activity patterns, with males and Non-Hispanic preschoolers having higher levels of overall physical activity. Additionally, within family-level factors – speaking primarily English or English and another

language equally and living in a family with a higher income to poverty ratio – were significantly associated with higher MVPA levels.

Examining physical activity and prevalence of preschool children meeting physical activity guidelines have been primarily limited to normal weight youth and few studies have examined activity patterns in racial diverse youth. Among this predominately Hispanic population with overweight, a total of 74.8% of participants met the 60 minutes of daily MVPA guideline, which is consistent with the pooled estimate (78.8%) found by Dias and colleagues using the International Children’s Accelerometry Database (ICAD) (Dias et al., 2019). However, it is necessary to further understand how preschool children are obtaining physical activity throughout the day. Therefore, this study examined hourly physical activity patterns in order to assess differences in pattern by potential correlates and determine if there are areas of the day in which to intervene and increase activity levels.

Consistent with previous findings that boys typically have more activity than girls (Andersen et al., 2017; Copeland et al., 2016; Dolinsky et al., 2011; Ellis et al., 2017; Finn et al., 2002), this study provides deeper understanding about the differences in waking activity patterns by sex among preschoolers through exploring this relation both daily and hourly, in addition to exploring the relation in an unique subsample of primarily minority and overweight sample. While males had higher average total daily MVPA and average total physical activity minutes, no differences by sex were found for light intensity activity. Our approach to visualize the proportion of time and minutes per hour spent at each activity intensity stratified by sex provides insight into differences in activity patterns per day. Females are consistently more sedentary and have less MVPA than males but have equal amounts of light activity throughout the day. These differences in daily estimates ultimately

lead to females having 74% lower odds (95% CI: 0.11-0.64) of meeting the physical activity guidelines for 60 minutes of MVPA per day compared to males.

Although previous studies have shown that older preschool-aged children typically have higher levels of activity and meet physical activity guidelines more often than younger preschool-aged children (Copeland et al., 2016; Copeland et al., 2011; Dawson-Hahn et al., 2015; Dias et al., 2019; Dolinsky et al., 2011; Taylor et al., 2018), this study found no differences across age within this sample. These data suggest there may be an interaction between adiposity and age. Future studies should examine this potential interaction as children's weight status has been found to negatively influence motor skill development (D'Hondt et al., 2014).

Ethnic differences among this sample were found. While this sample is predominately Hispanic (87%), disparities in activity level were found. Non-Hispanic preschoolers had significantly more minutes of higher intensity activity than Hispanic preschoolers. When looking at the patterns across hours, Non-Hispanic preschoolers had consistently more minutes of moderate intensity and vigorous intensity each hour, though it was not significant at the hour-level. Ultimately, the higher amounts of activity throughout the day equated to 23 more minutes of averaged daily MVPA among Non-Hispanic participants than Hispanic participants. As greater total physical activity is associated with more favorable adiposity indicators (Pate et al., 2019; Sijtsma et al., 2011; te Velde et al., 2012; Timmons et al., 2012), promoting activity among Latinx families is crucial. Hispanic preschool children in the U.S. have the highest prevalence of overweight and obesity in this age-group (29.8%, 15.6%) (Copeland et al., 2011; Ogden et al., 2014) and have 2.3 (95% CI: 1.4, 3.7) higher odds of having severe overweight ($\text{BMI} \geq 99^{\text{th}}$ percentile) than non-Hispanic white children (Flores

& Lin, 2013). Latinx and African American U.S. children have higher BMI incidence at younger ages and maintain these higher BMI across childhood (Guerrero et al., 2016).

At the family-level, income to poverty ratio was examined as a potential correlate. Although this study was conducted in primarily low-income families (80% below 100% income to poverty ratio), disparities in activity levels continue to exist. While Dolinsky et al. (2011) found that preschool children in families with a household income of at least \$60,000 had more MVPA than children living in households with less than \$60,000 annual income (Dolinsky et al., 2011), the current study was able to examine differences amongst families with household incomes less than \$50,000, finding similar results. Compared to children living in families with the highest income to poverty ratio for the sample ($\geq 100\%$), children in families making less than half of their poverty threshold ($< 49\%$), had significantly lower MVPA minutes per day. Physical activity interventions should take income to poverty ratio into consideration when designing programming.

Lastly, language spoken at home was found to be a cultural correlate associated with physical activity levels in this sample. Preschoolers who spoke English or English and another language equally had, on average, 20 minutes more of averaged daily MVPA than children who spoken primarily another language. This association may be especially important for health. Non-English primary language has been previously found to be associated with predicting severe obesity in children (Flores & Lin, 2013; Guerrero et al., 2016). Further, BMI growth trajectories through the preschool years vary based on language at home. Hispanic, Spanish-speaking youth have the highest mean BMI trajectory (Guerrero et al., 2016). These results may be influenced by the primary caregiver's acculturation status. Previous studies conducted in Latina mothers found that less acculturated mothers face

different challenges and have differing views on physical activity (Evenson, Sarmiento, Macon, Tawney, & Ammerman, 2002). Additionally, this may be one factor in why boys had higher activity levels than girls, as gender roles vary based on acculturation. Further investigation, especially qualitative in nature, should be done to understand these relations and potential mechanisms.

This study examines the unique patterning in waking activity patterns in a sample of preschool children with overweight and obesity. Promoting healthy growth and development is paramount for this age. Examining waking activity cycles has great implications for designing interventions. The results suggest that even within a primarily homogenous population (majority-minority, low-income, overweight and obese), disparities exist. In order to design more effective tailored interventions, programs should consider differences in gender, income and poverty levels, and cultural diversity. In order to increase health programs effectiveness, researchers need to consider differences in physical activity amongst these sub-populations.

Strengths and Limitations

This study has a number of strengths including using a clinical population. Previous studies examining correlates of physical activity in preschool youth have been done in primarily normal weight populations. Few studies have examined activity patterns in a preschool population with overweight. Additionally, few studies have been conducted in ethnically-diverse Hispanic youth. With the highest prevalence of obesity (29.8%) compared to other race/ethnic groups in the U.S. (Ogden et al., 2014), and a future projection to make up one-third of the youth population in U.S. (Vespa et al., 2018), studying Hispanic preschool youth is of utmost importance. This is the first study to examine the prevalence of

meeting physical activity guidelines (total MVPA) in this population and the first to examine hourly activity patterns. This study can help future researchers develop more effective tailored interventions for this population. Further strengths include utilization of a device-based measure of physical activity and age-specific VM cut points. Accelerometers are valid measures of activity in preschool children (Pate, O'Neill, & Mitchell, 2010) and allow for the assessment of specific intensity minutes. Due to advances in technology, VM cut points allow for the integration of vertical, longitudinal, and lateral axes. As young children's movement is sporadic, the use of VM cut points is able to take into account multiple directions and is more representative of behavior – a limit of vertical only cut points. Additionally, the use of devices reduces potential recall-bias that limit many self-report physical activity measures.

Limitations should be noted. This is a cross-sectional study so it is unable to determine causality. However, with limited research in this population, this study provides the first step in identifying correlates of activity patterns in Hispanic youth with obesity. While this study is able to examine meeting MVPA physical activity guidelines, it does not examine all aspects of the 24-HAC (e.g. sleep) or the prevalence of meeting all guidelines suggested by the WHO, such as sleep and screen time recommendations. Screen time measures within the Common CORD Parent survey only ask time spent watching TV/DVDs or playing video and computer games, and thus are not indicative of all screen time behaviors (e.g. cell phone usage). Additionally, sleep was measured as an average amount of sleep during the past week and may not have been answered at the same time as the child wore the accelerometer. Furthermore, no measure of nap time was included. It may be that sleep was misclassified as sedentary time in these analyses. This is a limitation, as sleep is known to

provide unique contributions to health within the 24-HAC (Rosenberger et al., 2019). While sleep algorithms have been developed for use with waist-worn accelerometers, little is known about the most appropriate sleep algorithm in preschoolers (Migueles et al., 2017).

Surveillance studies have recently been placing the accelerometer on the wrist to accommodate collection of 24-HAC. Further limitations include no measure of reliability or validity of the parent survey measures. However, these measures have been used in previous studies (Hoelscher, Barroso, Springer, Castrucci, & Kelder, 2009). Future studies will need to be conducted that examine these associations over time.

Conclusions

This research is one of the first studies to show the unique hourly differences in waking activity patterns among preschool-aged youth and the first to show patterns in preschoolers with overweight and obesity. Future research should continue to examine correlates of hourly activity patterns among diverse samples of preschool youth.

Additionally, further research should examine physical activity patterns in relation to context-related factors, such as type of day and school enrollment, to inform if differences exist across daily patterning. As preschool children have been found to meet physical activity guidelines more on the weekday than on the weekend (Dias et al., 2019), the hourly patterns of waking activity should continue to be explored for potential areas of intervention targeting parents at home.

Paper 1 Table 1. Characteristics of the TX CORD Secondary Prevention preschool-aged participants and physical activity levels at baseline (n = 131).

		Wear time		Average Counts (ct×min/d)		Sedentary Activity (min/d)		Light Intensity Activity (min/d)		Moderate Intensity Activity (min/d)		Vigorous Intensity Activity (min/d)		Total MVPA (min/d)		TPA (min/d)	
Correlate	% (n)	Median (IQR)	p	Median (IQR)	p	Median (IQR)	p	Median (IQR)	p	Median (IQR)	p	Median (IQR)	p	Median (IQR)	p	Median (IQR)	p
Overall Sample (N = 131)		964.1 (922.3-996.7)		1125.4 (945.7-1237.6)		578.4 (538.0-627.2)		285.6 (248.6-317.0)		59.0 (44.5-69.6)		21.5 (14.0-29.7)		79.3 (59.7-99.0)		362.2 (320.5-409.2)	
Age																	
≤ 3	30.5 (40)	947.4 (894.1-988.2)		1064.5 (891.2-1192.7)		579.6 (540.2-626.4)		278.5 (248.5-306.3)		50.8 (38.8-66.4)		17.3 (12.6-25.5)		68.2 (51.9-92.8)		345.7 (305.4-385.7)	
4	33.6 (44)	973.9 (939.9-999.6)	0.350	1133.1 (998.8-1253.3)	0.220	578.5 (552.3-622.5)	0.920	290.1 (255.4-312.3)	0.519	63.9 (48.5-74.5)	0.065	24.4 (15.4-30.8)	0.119	87.5 (64.6-103.8)	0.058	374.0 (336.2-420.2)	0.193
5	35.9 (47)	964.1 (922.9-996.0)		1153.1 (996.0-1244.0)		578.4 (536.7-627.5)		284.6 (241.7-321.5)		58.8 (47.9-69.6)		21.5 (16.1-31.9)		79.3 (64.0-98.1)		367.5 (320.6-423.9)	
Sex																	
Male	47.3 (62)	976.6 (939.6-1001.9)	0.016	1192.7 (1073.1-1325.3)	<0.001	578.0 (538.0-625.7)	0.389	288.0 (241.7-318.5)	0.450	65.8 (56.6-71.9)	<0.001	37.0 (20.5-35.1)	<0.001	91.6 (74.7-110.3)	<0.001	383.5 (333.9-424.3)	0.026
Female	52.67 (69)	953.7 (907.3-984.0)		1050.0 (882.3-1201.6)		578.4 (541.1-630.0)		284.6 (252.0-313.0)		50.2 (40.7-61.7)		16.7 (12.6-24.3)		68.1 (52.0-86.1)		356.3 (308.6-392.8)	
Ethnicity																	
Non-Hispanic	13.0 (17)	980.3 (931.5-998.9)	0.165	1206.9 (1079.6-1282.6)	0.034	567.5 (546.4-624.07)	0.409	288.8 (257.1-321.5)	0.250	65.6 (56.9-75.8)	0.010	28.5 (23.1-312.8)	0.005	98.1 (87.6-107.5)	0.005	380.1 (339.8-419.5)	0.097
Hispanic	87.0 (114)	963.0 (919.3-990.7)		1112.6 (931.0-1232.0)		579.9 (537.3-627.5)		283.2 (248.5-316.6)		57.9 (43.1-67.6)		19.5 (13.3-28.1)		75.5 (55.9-96.5)		361.6 (308.6-408.0)	
Language Spoken																	
Only English/English & another equally	43.5 (57)	972.3 (927.0-996.7)		1176.4 (1050.0-1244.0)		575.6 (537.3-624.4)		285.6 (245.2-318.5)		64.5 (51.3-74.0)		22.6 (16.7-33.5)		90.6 (70.0-107.5)		367.5 (325.7-430.0)	
More another language	37.4 (49)	957.4 (907.3-1000.4)	0.772	1078.9 (910.2-1205.3)	0.095	581.5 (549.0-627.2)	0.839	288.8 (252.6-308.3)	0.871	51.3 (43.1-65.8)	0.153	19.5 (13.6-25.6)	0.006	71.5 (56.4-89.2)	0.006	356.8 (320.6-395.7)	0.521
Only another language	19.1 (25)	963.4 (939.6-990.7)		1103.2 (854.5-1262.9)		603.3 (532.2-643.8)		282.8 (248.6-325.5)		58.1 (36.3-66.4)		16.4 (12.1-23.3)		71.6 (52.0-91.9)		362.2 (303.4-416.2)	

Income to Poverty Ratio																	
≥100%	19.9 (26)	979.4 (931.5-1002.4)		1199.6 (1073.1-1244.0)		576.0 (546.4-626.9)		289.7 (248.8-321.5)		67.0 (51.3-76.5)		25.7 (16.7-32.2)		94.0 (77.0-107.5)		368.2 (339.7-431.8)	
50-99%	48.9 (64)	969.7 (927.5-993.7)	0.527	1113.7 (956.2-1230.2)	0.162	580.0 (542.9-625.9)	0.960	285.1 (260.7-314.8)	0.322	58.1 (46.8-68.0)	0.024	21.0 (14.5-27.0)	0.230	75.5 (62.4-97.0)	0.043	364.4 (332.4-407.6)	0.162
≤49%	31.2 (41)	944.7 (894.3-989.6)		1076.5 (894.3-1206.9)		585.3 (521.5-630.0)		277.0 (229.4-310.7)		53.2 (39.9-63.3)		18.2 (12.6-28.7)		72.8 (55.7-90.0)		349.9 (291.0-395.7)	

Abbreviations: MVPA, moderate to vigorous intensity physical activity; TPA, total physical activity; ct, count; min, minutes; d, day

Note: p-value is of Mann-Whitney *U* test or Kruskal-Wallis depending on number of groups

Total MVPA is the accumulated sum of moderate intensity and vigorous intensity

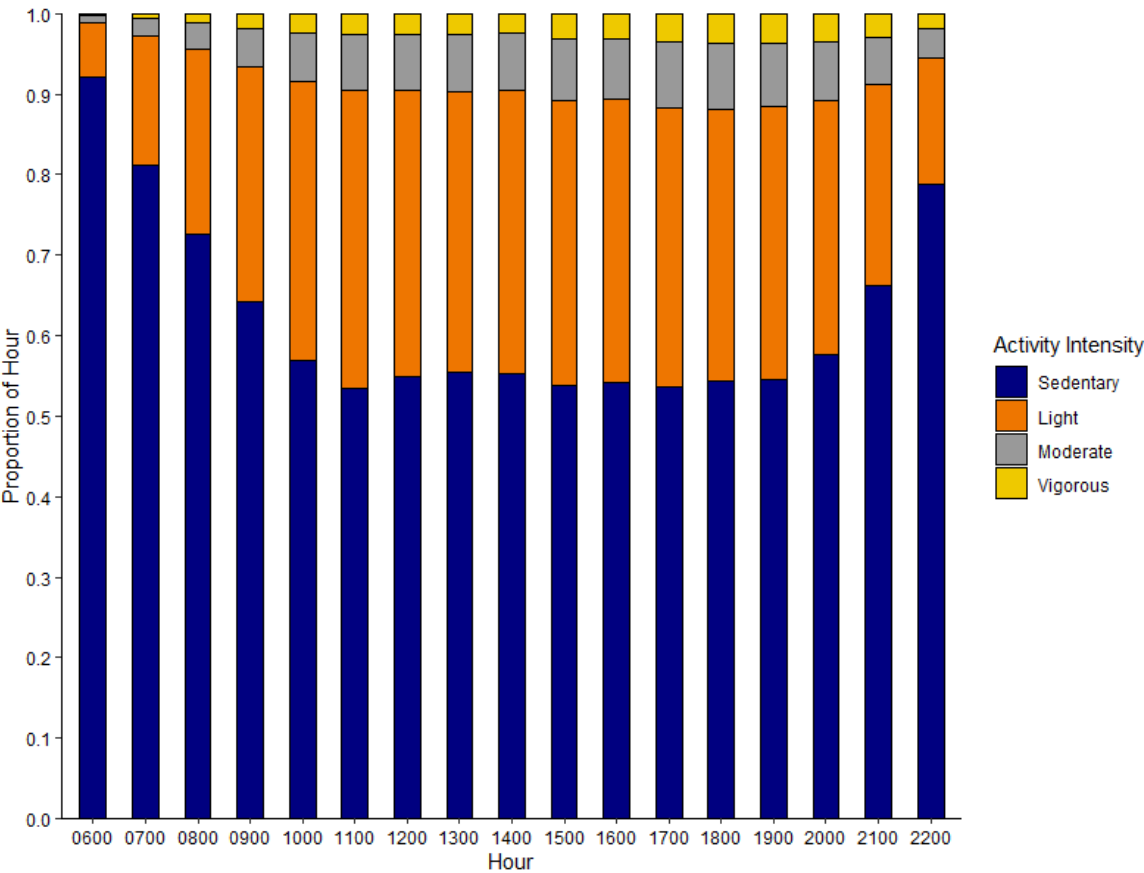
TPA is the accumulated sum of light intensity, moderate intensity, and vigorous intensity

Paper 1 Table 2. Prevalence and unadjusted odds of meeting physical activity guidelines among TX CORD Secondary Prevention preschool-aged participants at baseline

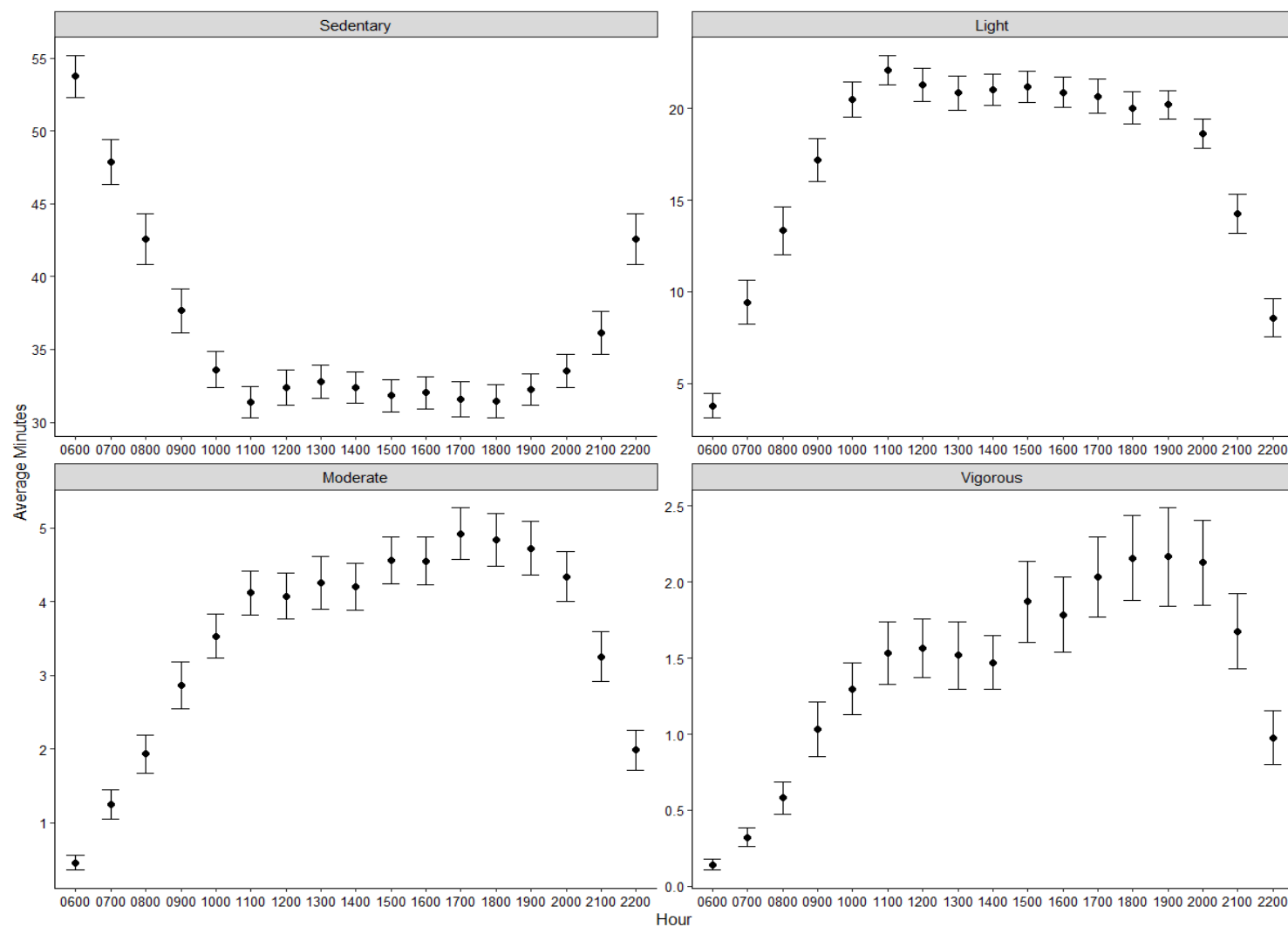
Physical Activity Guideline ≥60 minutes MVPA				
Correlate	n	Prevalence (%)	p	OR (95% CI)
Overall Sample (N = 131)		74.8 (98)		
Age				
≤ 3	40	65.0 (26)	0.229	[Referent]
4	44	79.6 (35)		2.09 (0.79-5.58)
5	47	78.7 (37)		1.99 (0.77-5.17)
Sex				
Male	62	87.1 (54)	0.002	[Referent]
Female	69	63.8 (44)		0.26 (0.11-0.64)
Ethnicity				
Non-Hispanic	17	94.1 (16)	0.070	[Referent]
Hispanic	114	71.9 (82)		0.16 (0.02-1.26)
Language Spoken				
Only English/ English & another equally	57	84.2 (48)	0.083	[Referent]
More another language	49	69.4 (34)		0.43 (0.17-1.08)
Only another language	25	64.0 (16)		0.33 (0.11-0.98)
Income to poverty Ratio				
≥100%	26	80.8 (21)	0.468	[Referent]
50-99%	64	76.6 (49)		0.78 (0.25-2.42)
≤49%	41	68.3 (28)		0.51 (0.16-1.66)

Abbreviations: MVPA, moderate to vigorous intensity physical activity; OR, odds ratio; CI, confidence interval

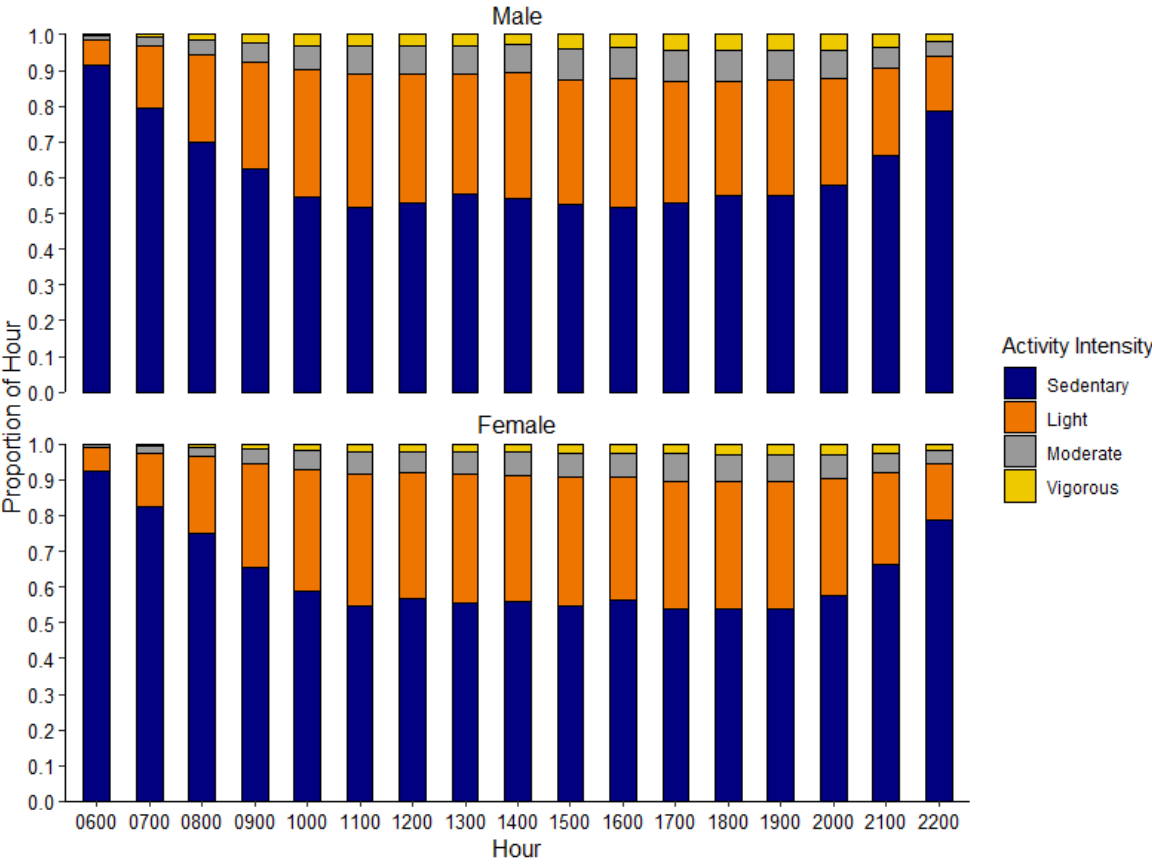
Paper 1 Figure 1. Mean proportion of time spent in activity type by hour of TX CORD
Secondary Prevention preschool-aged participants at baseline for overall sample (N = 131)



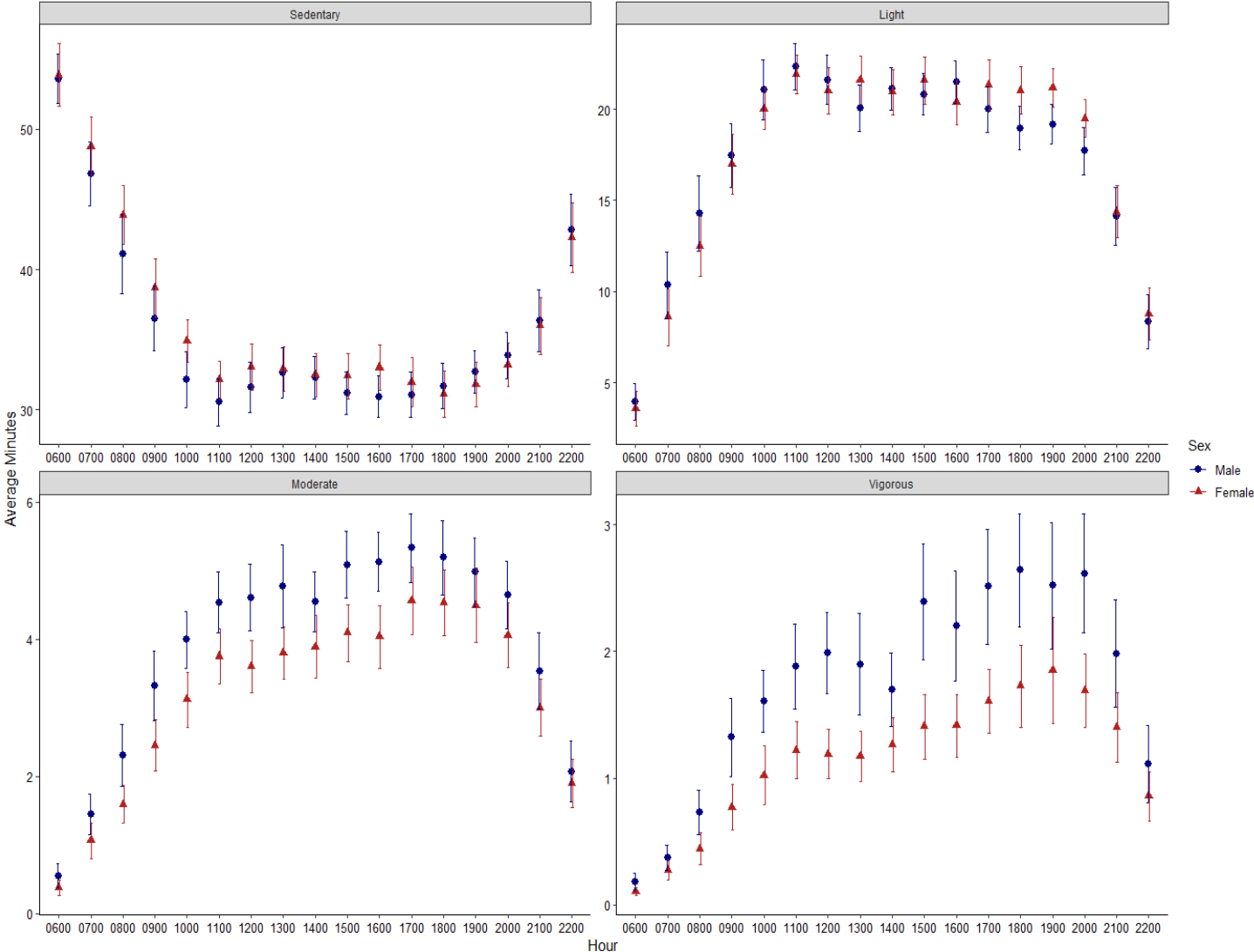
Paper 1 Figure 2. Mean minutes spent in activity type by hour of TX CORD Secondary Prevention preschool-aged participants at baseline for overall sample (N = 131)



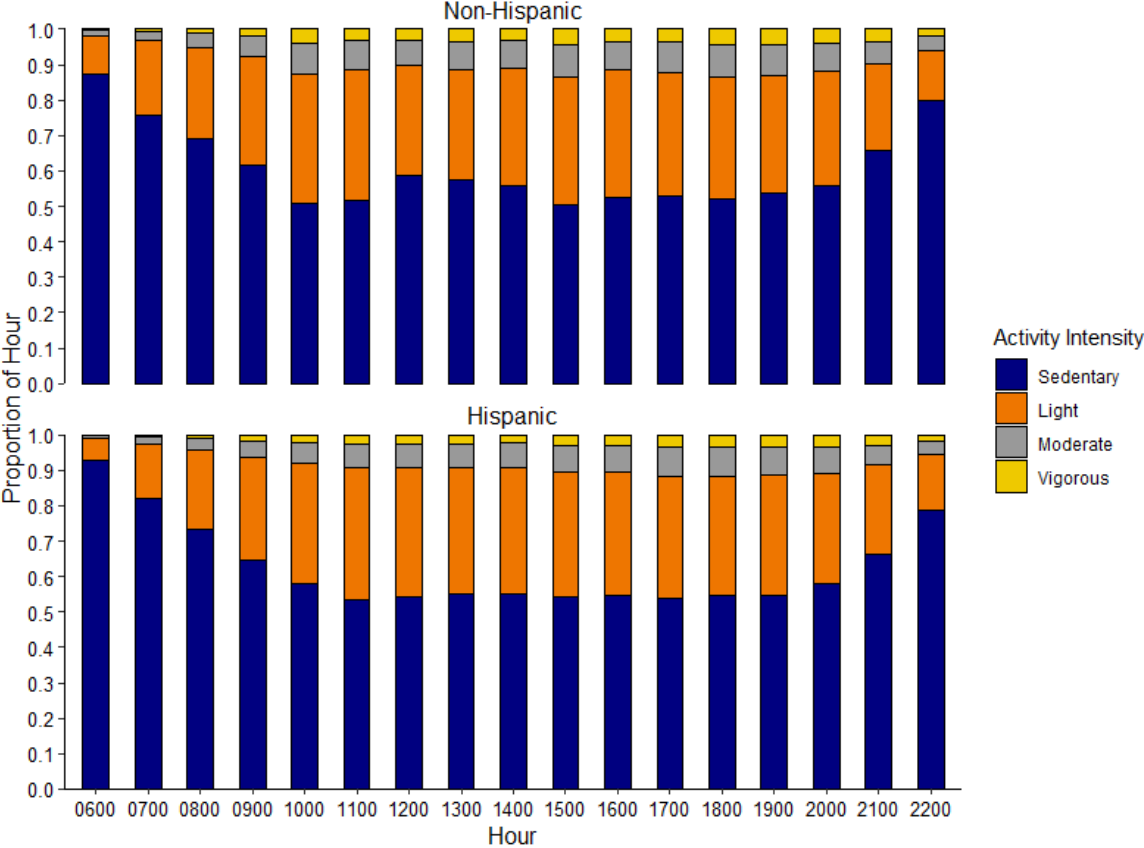
Paper 1 Figure 3. Mean proportion of time spent in activity type by hour of TX CORD Secondary Prevention preschool-aged participants at baseline stratified by sex (N = 131)



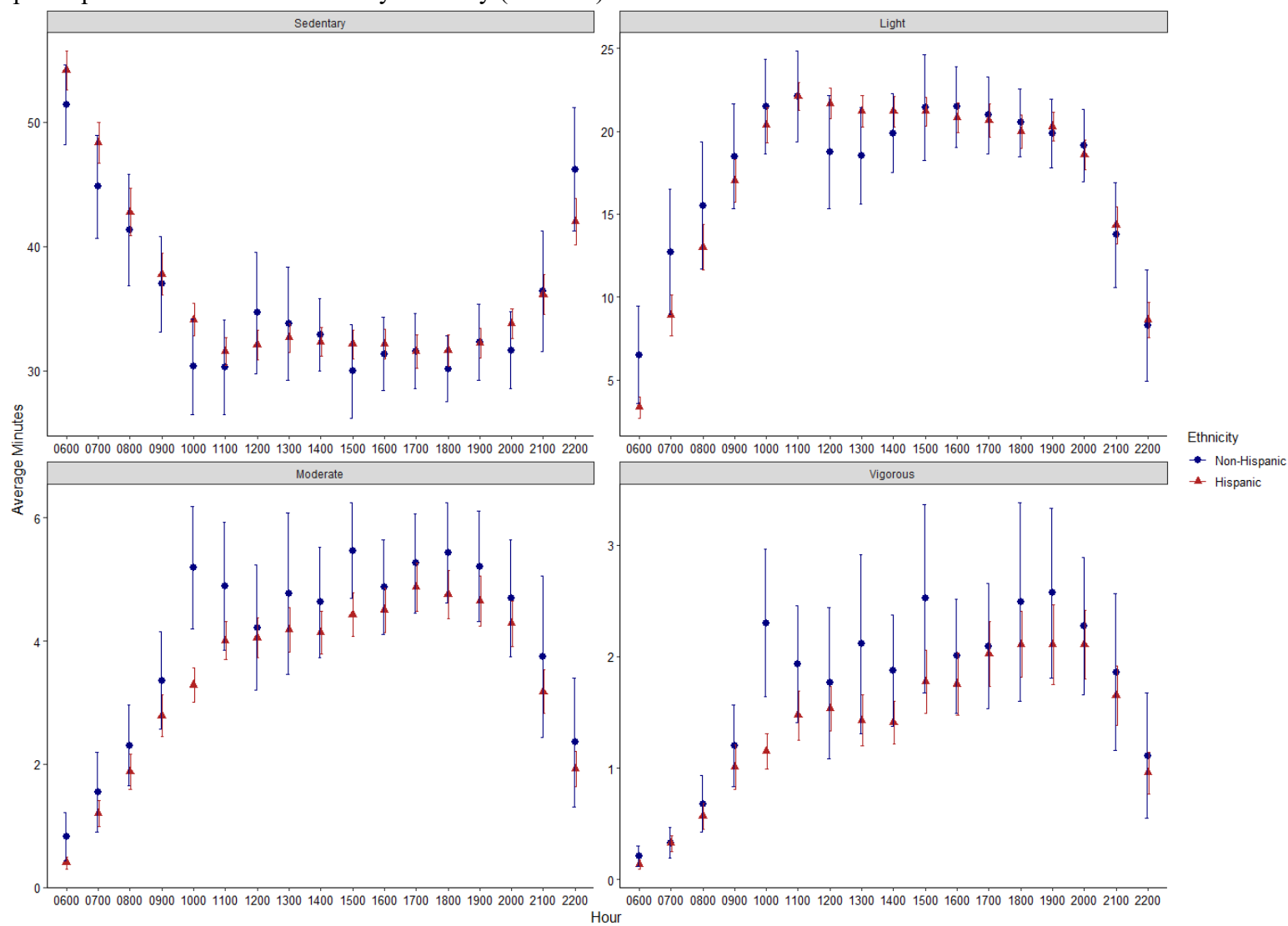
Paper 1 Figure 4. Mean minutes of time spent in activity type by hour of TX CORD Secondary Prevention preschool-aged participants at baseline stratified by sex (N = 131)



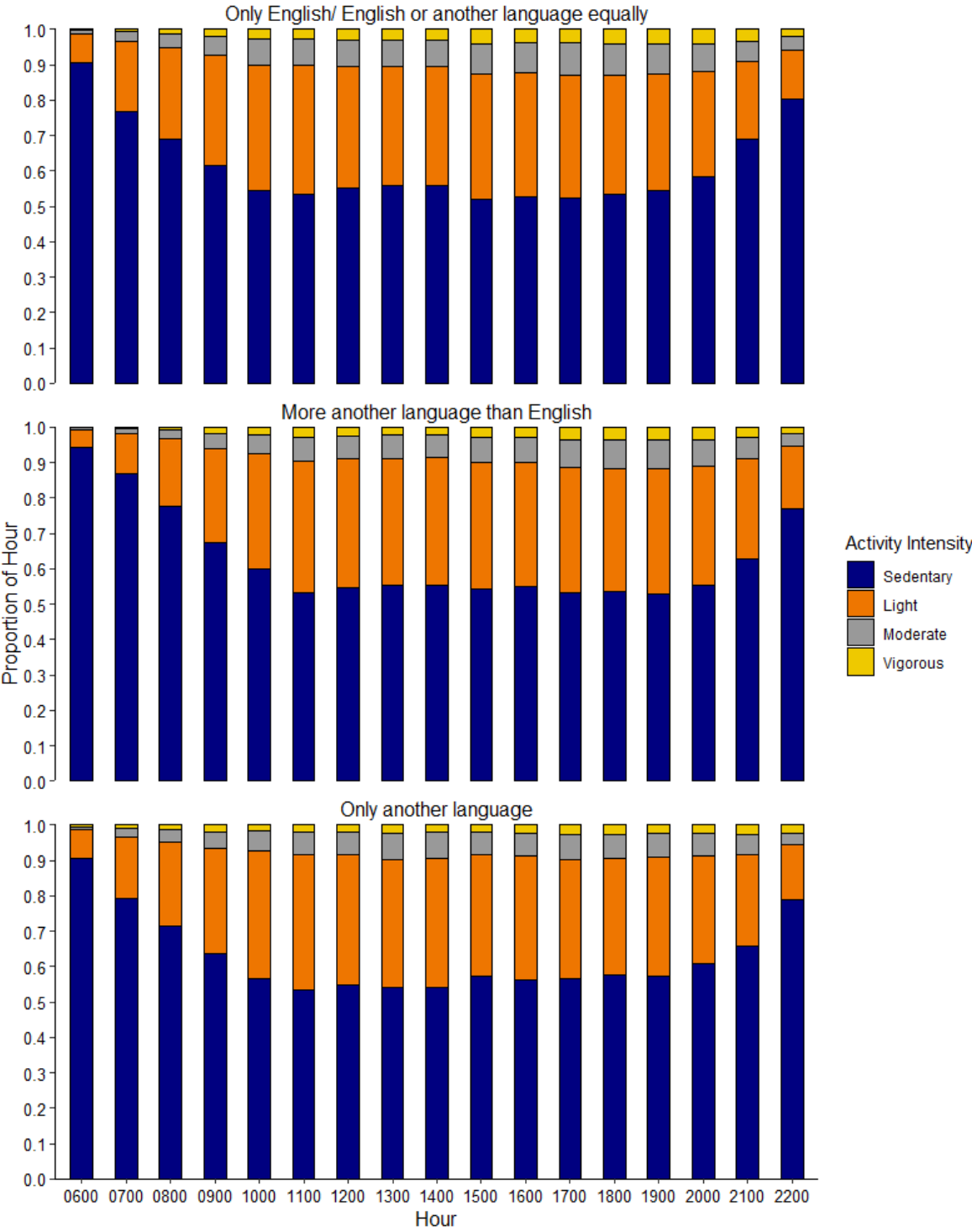
Paper 1 Figure 5. Mean proportion of time spent in activity type by hour of TX CORD Secondary Prevention preschool-aged participants at baseline stratified by ethnicity (N = 131)



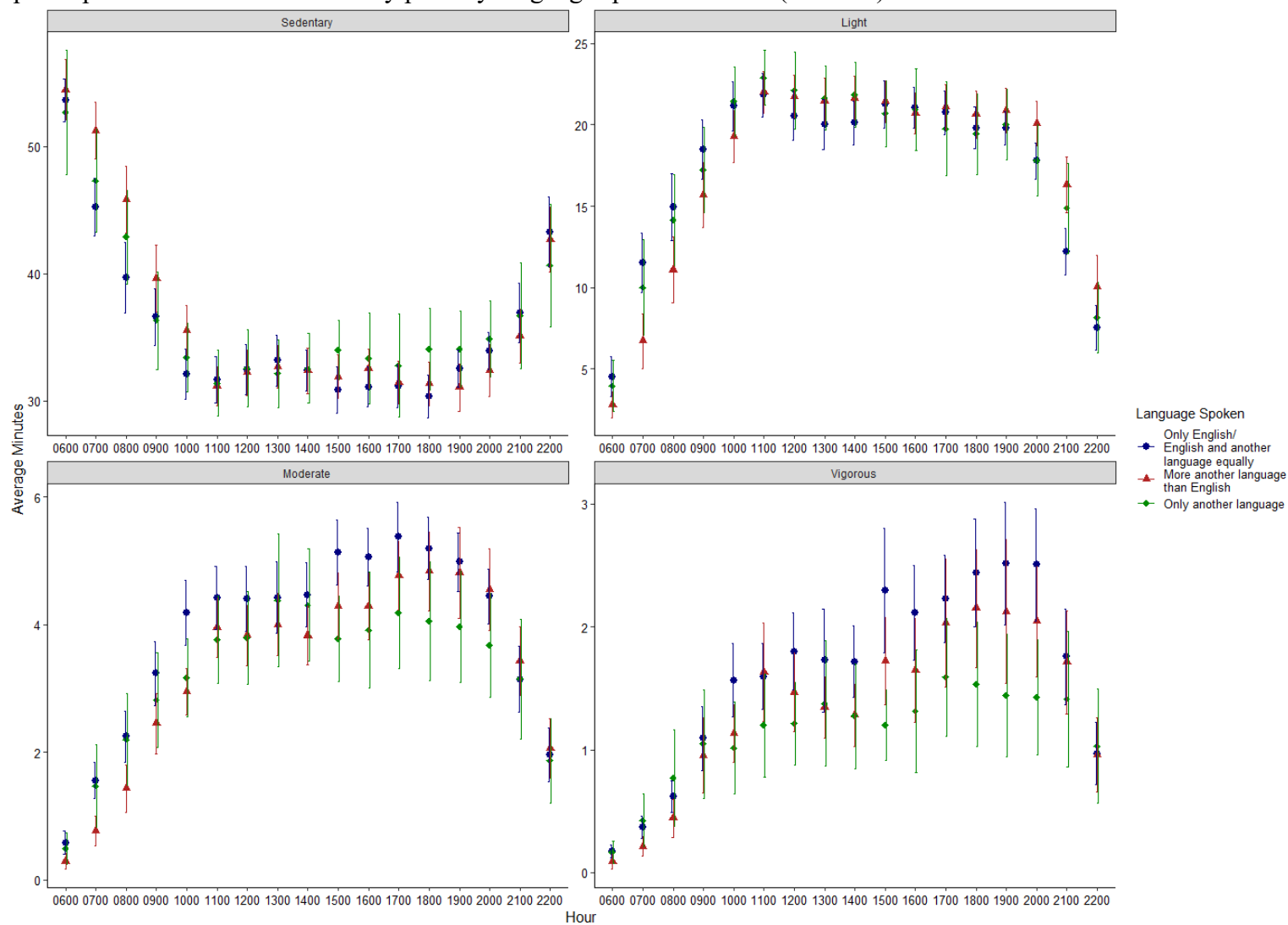
Paper 1 Figure 6. Mean minutes of time spent in activity type by hour of TX CORD Secondary Prevention preschool-aged participants at baseline stratified by ethnicity (N = 131)



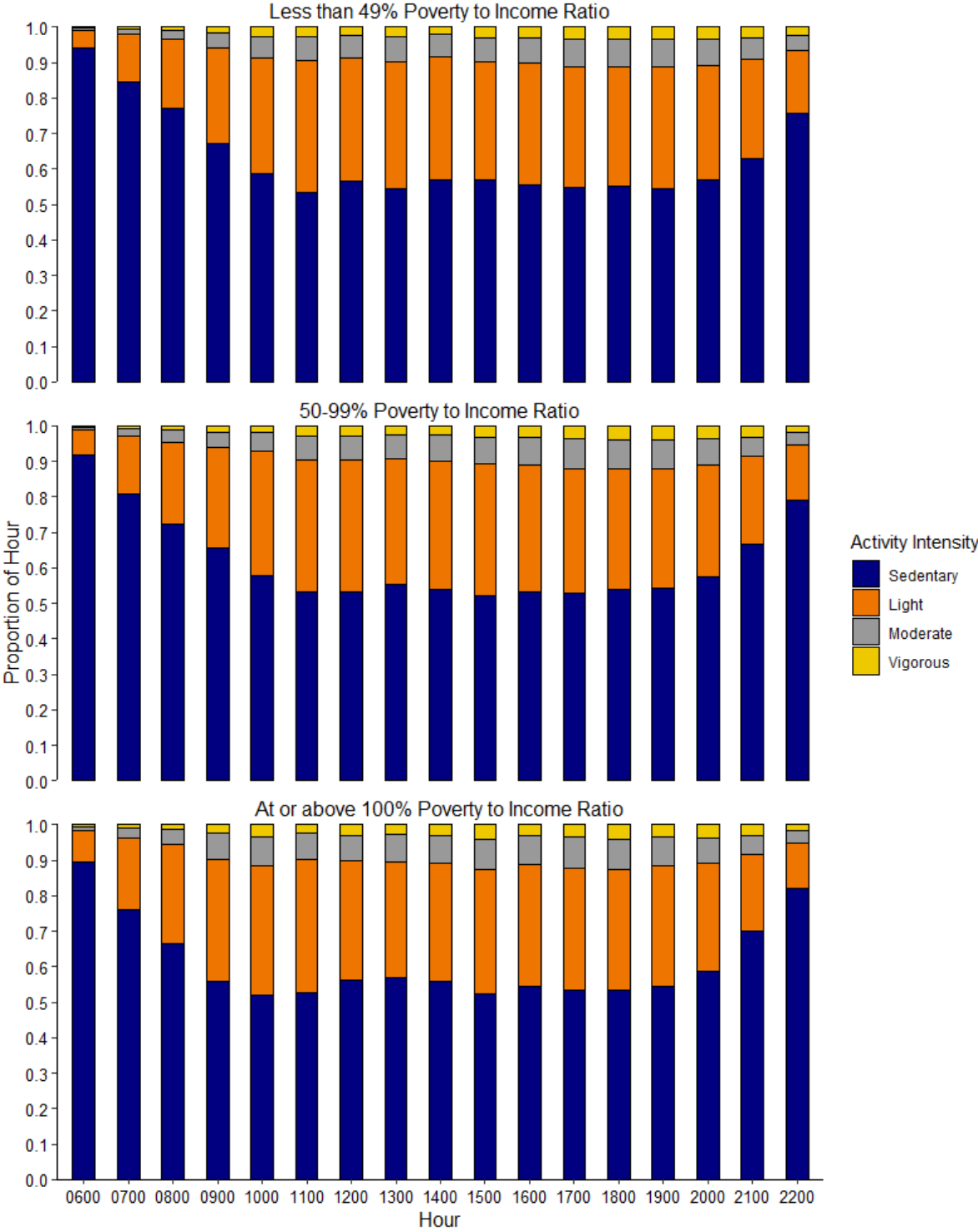
Paper 1 Figure 7. Mean proportion of time spent in activity type by hour of TX CORD Secondary Prevention preschool-aged participants at baseline stratified by primary language spoken at home (N = 131)



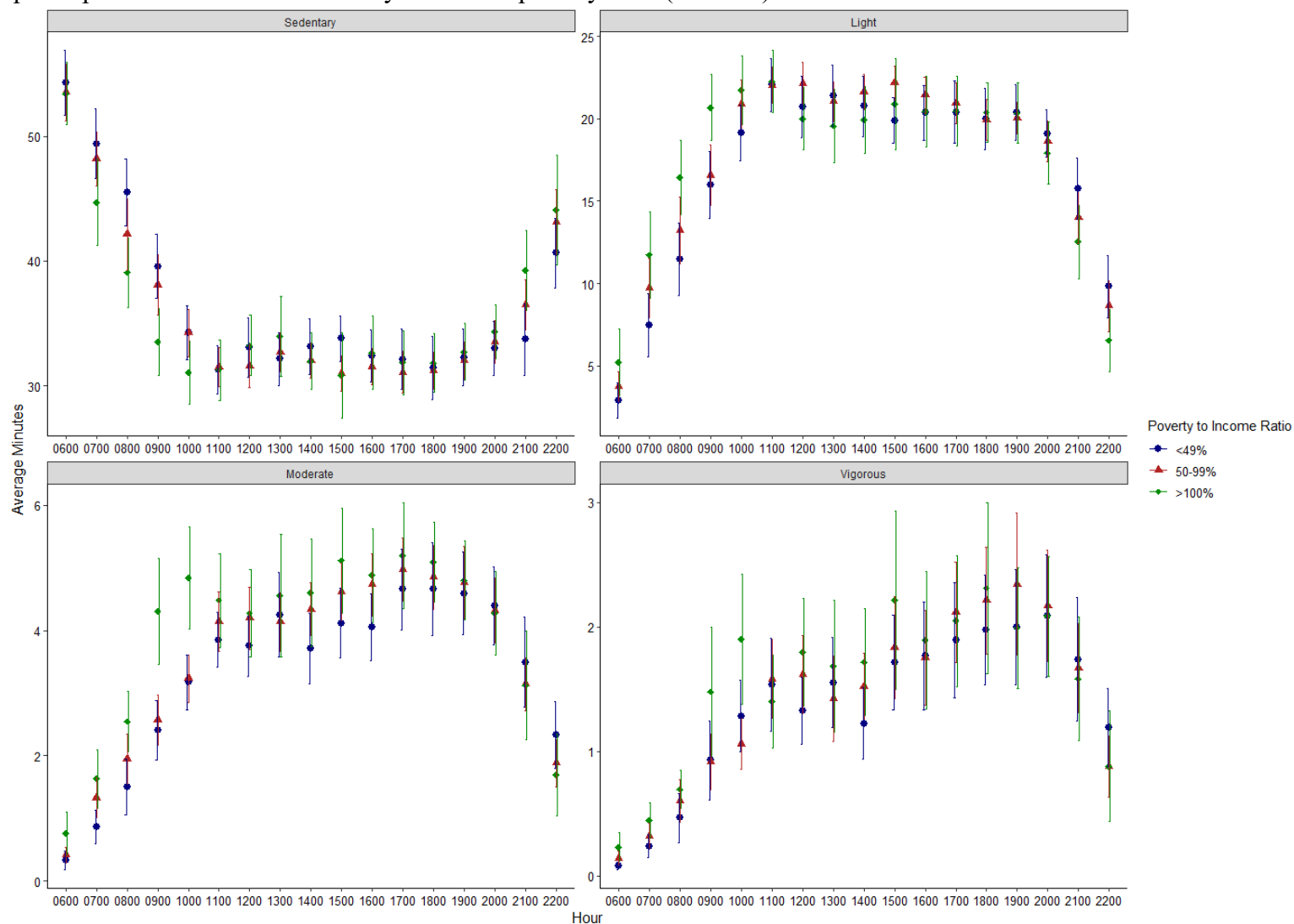
Paper 1 Figure 8. Mean minutes of time spent in activity type by hour of TX CORD Secondary Prevention preschool-aged participants at baseline stratified by primary language spoken at home (N = 131)



Paper 1 Figure 9. Mean proportion of time spent in activity type by hour of TX CORD Secondary Prevention preschool-aged participants at baseline stratified by income to poverty ratio (N = 131)



Paper 1 Figure 10. Mean minutes of time spent in activity type by hour of TX CORD Secondary Prevention preschool-aged participants at baseline stratified by income to poverty ratio (N = 131)



PAPER 2: THE ASSOCIATION BETWEEN WAKING ACTIVITY PATTERNS AND CONTEXT-RELATED FACTORS IN PRESCHOOL CHILDREN WITH OVERWEIGHT AND OBESITY

INTRODUCTION

Promoting physical activity is important for healthy growth and development in the early childhood years (3-5 years) (Carson, Lee, et al., 2017; Timmons et al., 2012), yet few children are meeting physical activity and movement guidelines (Tucker, 2008). Due to young children's reliance on caregivers to provide activity, parents and teachers play pivotal roles in providing opportunities to engage in healthy behaviors. Context-related settings for caregivers to provide opportunities for physical activity has important implications for intervention development (Brown et al., 2009; K. D. Hesketh & Campbell, 2010), yet most studies examine total physical activity volume in children (Tucker, 2008). While these pooled estimates provide a good measure of habitual physical activity (Bingham et al., 2016; Cain et al., 2013), it does not allow for detection of activity patterns of young children across diverse contextual opportunities.

The type of day context (weekday, weekend) can affect activity patterns in young children (Dias et al., 2019; Verbestel et al., 2011). Children have been found to be more physically active and meet physical activity guidelines at greater levels on weekdays alone than weekends (Dias et al., 2019). Hour-by-hour analysis indicates that weekend days, often with more discretionary time, are more flexible to engage in physical activity than weekdays (Van Cauwenberghe, Jones, Hinkley, Crawford, & Okely, 2012). These differences may be due to preschool enrollment status and the structured nature of school and child care settings. Children who attend non-parental care are more active and less sedentary than children who do not attend child care (K. R. Hesketh et al., 2015). Additionally, when examining physical

activity patterns throughout the day in children who attend preschool, children have higher activity levels during care hours than at home (Verbestel et al., 2011). With 54% of U.S. preschool-aged children enrolled in full-day child care programs and 81% enrolled in full-day kindergarten (Snyder et al., 2019), early childhood and education (ECE) centers and schools are important settings that can impact healthy behaviors. However, the evidence is primarily limited to non-Hispanic white, normal weight youth (Dias et al., 2019; Verbestel et al., 2011). There is a need to examine the association of day of the week and child care/school enrollment status on physical activity patterns in diverse populations.

Hispanic children have the highest prevalence of obesity among preschool youth in the U.S. (Ogden et al., 2016). While there is evidence for an inverse association between the amount of time in child care and obesity in this population (Innella et al., 2016), daily physical activity patterns are not well understood. Thus, using a majority-minority sample of preschool-aged children with overweight and obesity, the purpose of this paper was to examine context-related correlates of preschool activity patterns by: 1) day of the week and 2) weekday enrollment in school and/or child care. The hypotheses were: 1) children will have significantly more physical activity on the weekday than on the weekend, 2) children enrolled in preschool programs will have significantly more physical activity than children in other care arrangements, and 3) children enrolled in preschool programs will have significantly more physical activity during normal care hours (08:00 – 14:59) than non-school hours.

METHODS

Study Design

The study is a cross-sectional analysis of baseline data of preschool-aged participants (2-5 years of age) from the Texas Childhood Obesity Research Demonstration (TX CORD) secondary prevention study (N = 167). Briefly, the TX CORD secondary prevention study was a 12-month randomized controlled trial (RCT) in which child participants, ages 2-12 years, and their families were randomly assigned to 1) a community-centered program or 2) a primary health care-centered program (Hoelscher et al., 2015). The current study included participants between the ages of 2-5 years, who returned the baseline accelerometer, and had completed parent surveys (N = 141). Exclusion criteria included if the participant wore the accelerometer on days outside of the Houston and Austin Independent School District (ISD) school calendars, i.e. summer break (May 29-August 25), winter break (December 23-January 6), Thanksgiving holiday (November 27-29), or spring break (March 17-21). The analytic sample included only preschool-aged children with valid accelerometer wear time of ≥ 10 hours of data between the hours of 06:00 – 22:59 on ≥ 3 days (≥ 2 weekdays, ≥ 1 weekend) during the school year (N = 114).

Data Collection

Baseline data collection occurred between September 2012 and February 2014. For this study, TX CORD parent surveys and child worn accelerometers were used. Analyses were conducted in October 2019.

Context-related variables

The independent variables are context-related constructs – day of the week and school enrollment status – obtained from the accelerometer and Parent Common CORD Survey.

Type of day was determined by accelerometer date after they were processed. Day of the week was dichotomized into 1) weekday (Monday-Friday) or 2) weekend (Saturday-Sunday). School/ child care enrollment status was determined using two questions on the parent survey: “*What school does your child attend?*” and “*What child care does your child attend?*”. If a response was provided to these questions, school enrollment was coded as attended school or child care. Missing responses were coded as does not attend school or child care.

Accelerometer-derived physical activity

This study used the estimates by each waking hour and the averaged daily estimate described previously in the parent methods. Briefly, ActiGraph GT3X+ devices were used to collect data. In August 2019, accelerometer files were downloaded from a secure server and processed in ActiLife v6.13.4 software using 10-second epoch lengths. Data were examined hourly to parse out waking time and remove activity accumulated during sleep or usual sleep time hours. Waking periods (06:00 – 22:59) were then screened for wear periods using the Choi wear time algorithm (Choi et al., 2011). Valid wear time was set at ≥ 10 hours of data on ≥ 3 days (≥ 2 weekdays, ≥ 1 weekend).

Estimates by each waking hour

In order to examine hourly patterns, accelerometer data were processed at the hour level per valid day. Activity estimates were summed across all valid days for an activity estimate for each individual waking clock-hour between the hours of 06:00 – 22:59 (total = 17 individual clock-hours). Hourly outcomes by each waking hour included 1) sedentary activity (minutes per hour), 2) light intensity activity (minutes per hour), 3) moderate

intensity activity (minutes per hour), and 4) vigorous intensity activity (minutes per hour). Proportion of each hour (out of 60 minutes) spent in sedentary, light, moderate, and vigorous intensity activity were also calculated. Additionally, hourly outcomes were computed for day of the week to include weekday only estimate, and a weekend only estimate for each waking clock-hour.

Averaged daily estimate

The averaged daily estimate was computed by averaging daily estimates. Daily summary estimates were first computed by summing hourly estimates across all waking hours (06:00 – 22:59) per individual day. Daily summary estimates were averaged across all valid days to compute an averaged daily estimate, which included 1) sedentary activity (minutes per day), 2) light intensity activity (minutes per day), 3) moderate intensity activity (minutes per day), 4) vigorous intensity activity (minutes per day), 5) total accumulated MVPA (minutes per day), and 6) total physical activity (light + MVPA) (TPA) (minutes per day). Additionally, averaged daily estimated by type of day were computed for a weekday only daily estimate and a weekend only daily estimate.

In-school and out-of-school hours

Additionally, weekday-only hourly outcomes were used to compute in-school and out-of-school hourly estimates. Estimates between the hours of 08:00 – 14:59 (420 total minutes) were collapsed into in-school hours. Estimates between the hours of 06:00 – 07:59 and 15:00 – 22:59 (600 total minutes) were collapsed into out-of-school hours. Weekday-only in-school and out-of-school hourly estimates included 1) overall minutes and 2) percent of time, computed as (overall minutes / total minutes).

Covariates

Based on paper 1 of this dissertation, the sociodemographics related to physical activity that were explored as possible covariates in these analyses included sex, ethnicity (Hispanic/ Non-Hispanic), income to poverty ratio (<49%, 50-99%, $\geq 100\%$), and language spoken (speaks English, more English than another language, or both English and another language equally/ speaks more of another language than English/ speaks only another language). Potential covariates were examined using regression analyses with interaction effects.

Data Analysis

Statistical analyses were performed using SAS 9.4 (*SAS Institute Inc., Cary, NC*) with figures developed using the RStudio Tidyverse package (*RStudio, Inc.*). Descriptive statistics including frequencies and percentages were conducted for demographic variables and school/ child care status. Physical activity variables were assessed for normality both visually and through the Shapiro-Wilk test. Medians and 25th and 75th percentiles were calculated for 1) average vector magnitude counts (counts per minute per day), 2) sedentary activity (minutes per day), 3) light intensity activity (minutes per day), 4) moderate intensity activity (minutes per day), 5) vigorous intensity activity (minutes per day), 6) total accumulated MVPA (minutes per day), and 7) TPA (minutes per day).

Day of the Week

Wilcoxon signed-rank tests were used to determine statistically significant differences between weekday and weekend averaged daily estimates with an $\alpha = 0.05$. Proportion of the hour spent in sedentary, light, moderate, and vigorous intensity activity and mean minutes

spent in each intensity category were plotted for every hour between waking hours – 06:00 to 22:59 – and stratified by weekday and weekend.

School Enrollment

Differences in activity pattern by school enrollment status were examined for the 1) overall averaged daily, 2) weekday averaged daily estimates, 3) weekend averaged daily estimates, and 4) weekday in-school and out-of-school hours. One-sided Mann-Whitney U tests compared differences across school enrollment status at $\alpha = 0.05$. Proportion of the hour spent in sedentary, light, moderate, and vigorous intensity activity and mean minutes spent in each intensity category were plotted for every hour between waking hours – 06:00 to 22:59 – stratified by school enrollment for weekday estimates and weekend estimates separately.

RESULTS

The overall sample of TX CORD participants between the ages of 2-5 years was 167. A total of 131 participants had valid accelerometer wear time. An additional 17 participants were excluded based on accelerometer school calendar exclusion criteria, leaving a final analytical sample of 114. There were no significant differences between the overall sample and the analytical sample on demographic variables. The analytic sample had a mean age of 4.3 (SD=1.1), was 50.1% female, and 85.1% Hispanic (**Table 1**).

Day of the Week

Participants wore the accelerometer a total of 4.8 ± 0.5 out of 5 days on the weekday and 1.9 ± 0.3 out of a possible 2 days on the weekend. There were no significant differences between weekday and weekend averaged daily estimates for wear time, average vector magnitude counts, sedentary activity, light intensity activity, moderate intensity activity,

vigorous intensity activity, total MVPA, or TPA ($p > 0.05$) (**Table 2**). However, when examining patterns by each waking hour through visual inspection of the error bars, there were significant differences in the mean minutes spent in each intensity differences among the categories of type of day (**Figures 1 & 2**). Participants spent significantly more time in light and moderate intensity activity and less sedentary time during the hours of 06:00 and 07:00 on the weekday than on the weekend. Between the hours 21:00 and 22:00, participants spent significantly less time in light and moderate intensity activity and more sedentary time on the weekday than on the weekend. No significant difference in hourly patterning, by type of day was found for vigorous intensity activity. No significant interaction effects were found for season, sex, ethnicity, language spoken, or income to poverty ratio.

School Enrollment

A total 58.8% ($n = 67$) of participants attended either school or child care (**Table 1**) across 53 different schools/child cares. A total of 15 schools were attended in Austin and 38 schools in Houston, TX. Out of the 67 children attending school/child care, 17 children were located in Austin, TX and 50 children were located in Houston, TX. The chi-square test examining the relation between city and school/ child care attendance was significant, $\chi^2 (1) = 7.92, p = 0.005$), suggesting significantly more participants in Houston were enrolled in school/child care than in the Austin sample. However, there were no significant interaction effects between city and overall daily, weekday daily, or weekend daily physical activity estimates. Additionally, no significant interaction effects were found for season, sex, ethnicity, language spoken, or income to poverty ratio.

Overall averaged daily

There were significant differences in wear time for the overall averaged daily ($p = 0.018$), weekday averaged daily ($p = 0.040$), and weekend averaged daily ($p = 0.041$), with children enrolled in school/child care having significantly higher minutes of daily wear time than children not enrolled in school (**Table 3**). Children attending school/child care had significantly higher overall averaged daily light intensity activity, moderate intensity, vigorous intensity, total MVPA, and TPA estimates than children not enrolled in school/child care ($p < 0.05$). When further examining estimates stratified by weekday and weekend estimates, children enrolled in school/child care had significantly higher averaged weekday daily light intensity (296.8, IQR: 260.3-334.4) and weekday TPA estimates (384.4, IQR: 337.4-427.8) than children not enrolled in school (283.1, IQR: 245.3-315.8) and (354.5, IQR: 306.7-403.0), respectively. On the weekend, children enrolled in school/child care had significantly higher moderate intensity, vigorous intensity, and total MVPA than children not enrolled in school/child care. No significant findings were found for school status for average vector magnitude counts or sedentary activity ($p > 0.05$).

Weekday and weekend averaged daily

When examining patterns by each waking hour on the weekday (**Figures 3 & 4**), visual inspection of the error bars show participants enrolled in school/ child care had significantly more light intensity activity between the hours of 06:00 and 10:00 and significantly more moderate intensity activity between 06:00 and 07:00. Between the weekday hours 12:00 – 13:00 and 20:00 – 21:00, participants in school/child care had significantly less light intensity activity and more sedentary time than children not enrolled in school or child care. No significant difference in weekday patterns were found for vigorous intensity activity, except at 06:00. When examining patterns by each waking hour on the

weekend (**Figures 5 & 6**), children enrolled in school/ child care had less light intensity activity and more sedentary activity. However, children in school/child care had significantly more vigorous intensity activity throughout the day than children with other arrangements.

In-school and out-of-school hours

There were no significant between-group differences between school enrollment status when examining percent of time spent in each physical activity intensity during weekday in-school hours (08:00 – 14:59) or out-of-school hours (06:00 – 07:59, 15:00 – 22:59) (**Table 4**). However, there were statistically significant within-group differences between in-school hours and out-of-school hours. Preschool-aged children spent significantly less time sedentary during in-school hours than non-school hours, and significantly more time in light intensity, vigorous intensity, and total MVPA during school hours. No significant within-group differences were found for moderate intensity activity or TPA.

DISCUSSION

This study examined the association between context-related factors and waking activity patterns among preschool children with overweight and obesity in Texas. This study found that among low-income, primarily Hispanic preschool youth, children are spending greater than 50% sedentary during all hours of waking periods (06:00 – 22:00), regardless of the day of the week and school/ child care enrollment. The significant type of day differences in hourly estimates between 06:00 – 07:00 suggests children are waking up earlier on the weekday, which may be due to school and/or child care enrollment. This study found that preschool children attending school/child care had significantly higher overall averaged daily light intensity activity, moderate intensity, vigorous intensity, total MVPA, and TPA estimates than children not enrolled in school/child care. Sociodemographic factors, such as

sex, ethnicity, and low-income poverty ratio did not significantly affect differences in weekday and weekend waking activity patterns nor do they affect waking activity patterns due to school and child care enrollment status.

While preschool-aged children have been found to have a higher prevalence of meeting the guidelines for 180 minutes of total physical activity and 60 minutes of MVPA guidelines on the weekday than on the weekend (Dias et al., 2019), this study found no difference in averaged daily minutes per day activity estimates. Despite this, significant differences in physical activity levels were found when examining type of day across school enrollment status with children enrolled in child care or school having significantly higher light intensity and TPA on the weekdays and significantly higher MVPA on the weekends. This is similar to findings by Hesketh et al. (2015) that found children who attend non-parental care are more active and less sedentary than children who do not attend child care (K. R. Hesketh et al., 2015). This study found that children in child care spend, on average, 30 more minutes per weekday in light, moderate, and vigorous intensity physical activity. As children spend an average of 30 hours per week in child care (Snyder et al., 2019), this equates to around 150 more minutes of activity per week.

With higher activity levels during the week attributed to school/ child care, there is the concern of compensatory changes, or decreases in activity behaviors on the weekend or during out-of-school hours. This study found no negative compensation behaviors for activity levels on the weekend (i.e. lower activity levels due to higher weekday activity) within this sample as children enrolled in school also had significantly higher MVPA on the weekend. Further, no compensation during at-home activity was found which is similar to previous research (K. R. Hesketh et al., 2015). While children spent a significantly higher percent of

time sedentary after hours, they also spent a significantly higher percent of the time in vigorous intensity and total MVPA during out-of-school hours than in-school hours.

The compensatory changes in waking activity patterns within this sample seem to occur during hours around wake and bedtime. Significant between-day differences in physical activity estimates between 06:00 – 07:00 suggests children are waking up earlier on the weekday possibly to get ready for school/child care. This trend is further seen when examining morning weekday activity patterns stratified by school enrollment. Preschool children enrolled in school and/or child care having significantly higher light and moderate intensity activity in the early morning hours. The differences in activity estimates between the evening hours of 21:00 –22:00, suggests that preschool-aged children are staying up later on the weekend days. While a majority of preschool-children have set bedtimes, it has been found that only two-thirds of families are able to follow these (Hale et al., 2009). Further, non-White families and those of lower socioeconomic status are less likely to report bedtimes and bedtime routines (Hale et al., 2009). Given this sample is low-income and primarily Hispanic, it seems that families have particular difficulty with having and enforcing bedtime routines on the weekend.

Strengths and Limitations

This study has numerous strengths including the use of a low-income, ethnically diverse population. Hispanic youth have highest prevalence of obesity (29.8%) compared to other race/ethnic groups in the U.S. (Ogden et al., 2014). With a large projected population growth (Vespa et al., 2018), studying contexts that impact physical activity in Hispanic preschool youth is needed. Additionally, few studies have examined activity patterns in a population with overweight and obesity. The findings from this study can help develop future

interventions within the child care and at home settings. With over 54% of preschool-aged children enrolled in full-day child care programs and 81% enrolled in full-day kindergarten (Snyder et al., 2019), understanding patterns of activity throughout the day can help inform specific timing where interventions should occur. Additionally, this is one of the few studies that examines differences in activity across type of day. Further strengths include utilization of device-based measure of physical activity and age-specific VM cut-points. Accelerometers are valid measures of activity in preschool children (Pate et al., 2010) and allow for the assessment of specific intensity minutes and reduce recall-bias that limit self-report surveys.

Limitations should be noted. This is a cross-sectional study so it is unable to determine causality. However, with limited research in this population, this study provides the first step in identifying context-related correlates of activity patterns in Hispanic youth with obesity. The variable used to measure school and child care attendance was dichotomous which limits the ability to examine linear associations with number of days or hours spent in care and activity levels. While amount of time spent in child care has been previously found to have a negative association with obesity among this population (Innella et al., 2016), this study was not be able to assess specific hours spent in school/child care. Additionally, this study used a typical school day start and end time for Houston and Austin ISD (08:00 – 14:59) for every day of the week and was unable to determine individual hours in care. The inability to determine individual care hours may have led to misinterpretation of physical activity minutes as “in-school hours” and “out-of-school hours”, especially as children may attend half-day school/child care or attend child care for extended day hours. Additionally, the significant differences in activity levels by school enrollment status may be confounded by other sociodemographic factors. Hispanic children and those of the lowest

socioeconomic status were less likely to attend school/child care. However, mixed results have been found with ethnicity and socioeconomic status on physical activity (De Craemer et al., 2012) and, specifically within this study, no interaction effects were observed for this sample – suggesting school status impacts activity levels among subpopulations similarly.

Conclusions

The study is one of the first studies to examine context-level factors associated with physical activity patterns among low-income, primarily Hispanic preschool-youth with overweight and obesity. School and home are two of the most important settings for children (Britto et al., 2017), as such opportunities for active play within these settings are paramount for good health amongst this age group. As most physical activity interventions for preschoolers have been conducted in the child care setting (Gordon, Tucker, Burke, & Carron, 2013), future research needs to continue to explore waking activity patterns – particularly for children not attending preschool and/or child care. As children in parent care or other types of care have lower daily activity minutes than children attending school and formal child care establishments, interventions should focus on ways in which to increase caregivers' awareness to increase activity levels throughout the day. Finally, future researchers should consider examining how physical activity patterns are impacted by waking and bedtime routines.

Paper 2 Table 1. Characteristics of the TX CORD Secondary Prevention preschool-aged participants at baseline N = 114

Characteristics	Overall (N = 114)	School/ child care (n = 67)	No school/ child care (n = 47)	p
	M ± SD	M ± SD	M ± SD	
Age (y)	4.3 ± 1.1	4.9 ± 0.8	3.6 ± 1.0	<0.0001
BMI z score (kg/m ²)	2.6 ± 1.1	2.3 ± 0.7	2.6 ± 1.1	0.132
Day of the Week				
Weekday days worn	4.8 ± 0.5	4.9 ± 0.4	4.7 ± 0.5	0.080
Weekend days worn	1.9 ± 0.3	1.9 ± 0.2	1.8 ± 0.4	0.082
	% (n)	% (n)	% (n)	
Female	50.9 (58)	47.8 (32)	55.3 (26)	0.427
Hispanic	85.1 (97)	77.6 (52)	95.7 (45)	0.008
Income to Poverty Ratio				
≤49%	30.7 (35)	22.4 (15)	42.6 (20)	0.012
50-99%	46.5 (53)	46.3 (32)	46.8 (22)	
≥100%	22.8 (26)	31.3 (21)	10.6 (5)	
School/ child care Enrollment	58.8 (67)			
Houston	74.6 (50)			
Austin	25.4 (17)			

Abbreviations: y, years; M, mean; SD, standard deviation;
BMI, body mass index; IQR, interquartile range

Paper 2 Table 2. Averaged daily physical activity estimates of the TX CORD Secondary Prevention preschool-aged participants at baseline stratified by type of day (N = 114)

Physical Activity Estimate (min/d)	Overall	Type of day		p
	Weekly	Weekday	Weekend	
	Median (IQR)	Median (IQR)	Median (IQR)	
Wear time	972.1 (926.1-998.0)	982.4 (931.7-1003.2)	988.5 (873.0-1020.0)	0.250
Average Vector Magnitude Counts (ct×min/d)	1140.5 (950.2-1243.8)	1125.1 (951.7-1241.5)	1161.9 (929.1-1323.9)	0.750
Sedentary Activity	579.8 (538.0-625.7)	587.7 (526.8-639.4)	577.2 (495.9-629.4)	0.160
Light Intensity Activity	288.8 (248.8-318.0)	290.8 (256.5-325.6)	279.0 (241.8-322.2)	0.779
Moderate Intensity Activity	59.1 (46.1-69.6)	57.9 (46.2-68.6)	59.2 (44.2-72.6)	0.111
Vigorous Intensity Activity	22.5 (15.0-30.7)	21.1 (14.3-30.1)	21.9 (12.8-34.3)	1.000
Total MVPA	83.2 (63.5-101.0)	80.1 (61.5-99.3)	84.0 (57.5-106.1)	0.303
TPA	367.7 (325.7-417.0)	374.9 (322.9-418.8)	367.4 (318.1-413.8)	0.160

Abbreviations: MVPA, moderate to vigorous intensity physical activity; M, mean; SD, standard deviation; ct, count; min, minutes; d, day

Total MVPA is the accumulated sum of moderate intensity and vigorous intensity combined

TPA is the accumulated sum of light intensity, moderate intensity, and vigorous intensity combined

Paper 2 Table 3. Overall, weekday, and weekend averaged daily physical activity estimates of the TX CORD Secondary Prevention preschool-aged participants at baseline stratified by school enrollment status (N = 114)

Physical Activity Estimate (min/d)	Overall Daily			Weekday			Weekend		
	School status		P	School status		P	School status		P
	School/ child care n = 67	No school/ child care n = 47		School/ child care n = 67	No school/ child care n = 47		School/ child care n = 67	No school/ child care n = 47	
	Median (IQR)	Median (IQR)		Median (IQR)	Median (IQR)		Median (IQR)	Median (IQR)	
Wear time	980.3 (941.7-997.0)	950.0 (890.2-998.9)	0.018	989.2 (945.7-1006.0)	964.6 (878.4-1003.2)	0.040	993.5 (884.0-1020.0)	953.0 (768.5-1020.0)	0.041
Average Vector Magnitude Counts (ct×min/d)	1176.4 (998.3-1271.9)	1105.4 (882.3-1237.6)	0.145	1114.6 (951.7-1266.6)	1100.1 (934.3-1199.7)	0.127	1183.2 (943.6-1356.3)	1130.7 (876.5-1323.9)	0.224
Sedentary Activity	581.5 (546.4-627.2)	567.0 (517.4-622.8)	0.149	586.0 (531.3-643.2)	591.0 (523.0-639.3)	0.369	585.8 (531.3-628.5)	566.3 (467.8-641.0)	0.060
Light Intensity Activity	295.8 (252.6-321.5)	280.1 (246.6-309.7)	0.044	296.8 (260.3-334.4)	283.1 (245.3-315.8)	0.024	275.9 (235.5-315.0)	290.3 (250.9-324.0)	0.145
Moderate Intensity Activity	61.7 (50.2-71.1)	55.3 (40.7-67.0)	0.032	61.3 (48.9-74.8)	56.4 (43.0-67.9)	0.059	62.2 (48.8-73.3)	51.3 (36.3-71.7)	0.037
Vigorous Intensity Activity	23.7 (16.7-31.5)	19.5 (12.8-28.7)	0.029	21.2 (15.3-31.3)	19.2 (13.5-29.5)	0.112	25.0 (14.4-43.1)	17.4 (10.8-26.4)	0.005
Total MVPA	87.4 (69.2-106.4)	74.2 (54.8-97.6)	0.022	83.4 (63.5-104.5)	73.6 (58.2-99.3)	0.050	90.4 (62.5-112.1)	72.6 (46.0-94.7)	0.009
TPA	384.4 (336.5-430.0)	356.3 (305.9-395.6)	0.014	384.4 (337.4-427.8)	354.5 (306.7-403.0)	0.014	367.4 (309.3-420.4)	363.2 (318.8-412.7)	0.399

Abbreviations: MVPA, moderate to vigorous intensity physical activity; TPA, total physical activity, ct, count; min, minutes; d, day; IQR, interquartile range
Total MVPA is the accumulated sum of moderate intensity and vigorous intensity combined
TPA is the accumulated sum of light intensity, moderate intensity, and vigorous intensity combined

Paper 2 Table 4. Differences in percent of time of weekday averaged daily physical activity estimates of the TX CORD Secondary Prevention preschool-aged participants at baseline by school enrollment status stratified by in-school and out-of-school hours (N = 114)

Physical Activity Estimate (%)	In-school hours (08:00-14:59) (420 min)			p	Out-of-school hours (06:00-07:59, 15:00-22:59) (600 min)			p
	Overall (N = 131)	School/ child care n = 67	No school/ child care n = 47		Overall (N = 131)	School/ child care n = 67	No school/ child care n = 47	
	Median (IQR)	Median (IQR)	Median (IQR)		Median (IQR)	Median (IQR)	Median (IQR)	
Sedentary Activity	59.1 (52.6-65.1)	58.5 † (49.6-65.1)	59.9 † (50.8-65.2)	0.100	62.3 (59.5-67.2)	62.2 (59.3-66.7)	62.4 (59.5-67.6)	0.319
Light Intensity Activity	31.1 (27.8-39.3)	34.1 ¥ (28.3-40.0)	32.6 † (27.1-36.9)	0.062	28.5 (24.1-31.0)	28.5 (23.7-30.8)	28.4 (24.1-31.9)	0.339
Moderate Intensity Activity	5.6 (4.3-7.4)	5.6 (4.6-7.4)	5.8 (4.1-7.4)	0.418	6.2 (4.6-7.4)	6.3 (5.3-7.5)	5.9 (4.5-7.2)	0.204
Vigorous Intensity Activity	1.9 (1.3-2.7)	2.0 † (1.3-2.8)	1.6 † (1.1-2.7)	0.142	2.3 (1.6-3.3)	2.3 (1.6-3.3)	2.3 (1.6-3.3)	0.431
Total MVPA	7.6 (5.6-10.1)	7.6 * (6.6-9.6)	7.6 * (5.3-10.4)	0.306	8.9 (6.5-10.4)	8.9 (6.5-10.4)	8.0 (6.4-10.5)	0.292
TPA	40.9 (34.9-48.4)	41.5 (34.9-50.4)	40.1 (34.8-46.2)	0.100	37.7 (32.8-40.5)	37.8 (33.3-40.7)	37.6 (32.4-40.5)	0.319

Abbreviations: MVPA, moderate to vigorous intensity physical activity; TPA, total physical activity, ct, count; min, minutes; d, day; IQR, interquartile range

Total MVPA is the accumulated sum of moderate intensity and vigorous intensity combined

TPA is the accumulated sum of light intensity, moderate intensity, and vigorous intensity combined

NOTE: Within-group differences for in-school and out-of-school hours:

* p < 0.05

† p < 0.01

¥ p < 0.001

Paper 2 Table 5. Minutes of time of weekday averaged daily physical activity estimates of the TX CORD Secondary Prevention preschool-aged participants at baseline stratified by in-school and out-of-school hours (N = 114)

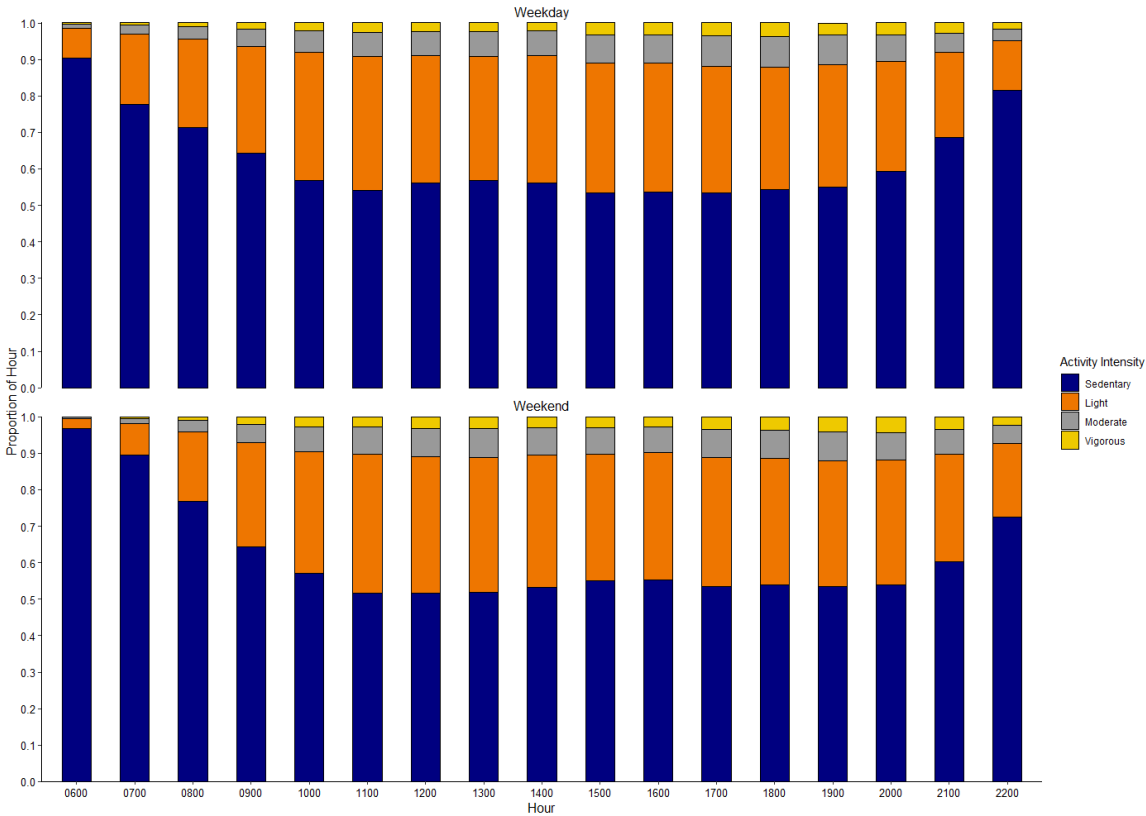
Physical Activity Estimate (min)	In-school hours (08:00-14:59) (420 min)			p	Out-of-school hours (06:00-07:59, 15:00-22:59) (600 min)			p
	Overall (N = 114)	School/ child care n = 67	No school/ child care n = 47		Overall (N = 114)	School/ child care n = 67	No school/ child care n = 47	
	Median (IQR)	Median (IQR)	Median (IQR)		Median (IQR)	Median (IQR)	Median (IQR)	
Sedentary Activity	244.7 (214.0-268.9)	244.8 (208.5-270.5)	244.5 (220.9-265.2)	0.269	361.4 (343.9-396.3)	361.3 (345.0-398.7)	361.4 (337.9-395.2)	0.348
Light Intensity Activity	136.1 (115.1-163.8)	139.9 (117.3-168.1)	133.0 (109.3-152.2)	0.026	161.6 (139.4-177.9)	163.9 (139.4-179.0)	160.3 (138.9-174.0)	0.219
Moderate Intensity Activity	23.3 (17.9-31.0)	23.2 (19.0-31.0)	23.3 (15.8-31.0)	0.273	35.4 (26.8-42.9)	36.4 (29.1-43.5)	33.1 (25.4-40.7)	0.067
Vigorous Intensity Activity	7.8 (5.2-11.4)	8.3 (5.6-11.5)	6.9 (4.5-11.4)	0.104	13.2 (8.7-18.8)	13.9 (8.8-18.8)	12.4 (8.5-19.3)	0.288
Total MVPA	31.7 (23.4-41.3)	31.9 (24.5-40.4)	30.8 (22.3-42.2)	0.189	49.8 (37.0-60.2)	52.0 (38.1-60.4)	43.5 (36.1-60.1)	0.121
TPA	169.5 (141.2-201.7)	174.4 (145.5-211.4)	167.6 (138.5-193.2)	0.042	212.5 (185.9-237.8)	220.2 (186.8-240.2)	205.5 (177.7-227.3)	0.061

Abbreviations: MVPA, moderate to vigorous intensity physical activity; TPA, total physical activity, ct, count; min, minutes; d, day; IQR, interquartile range

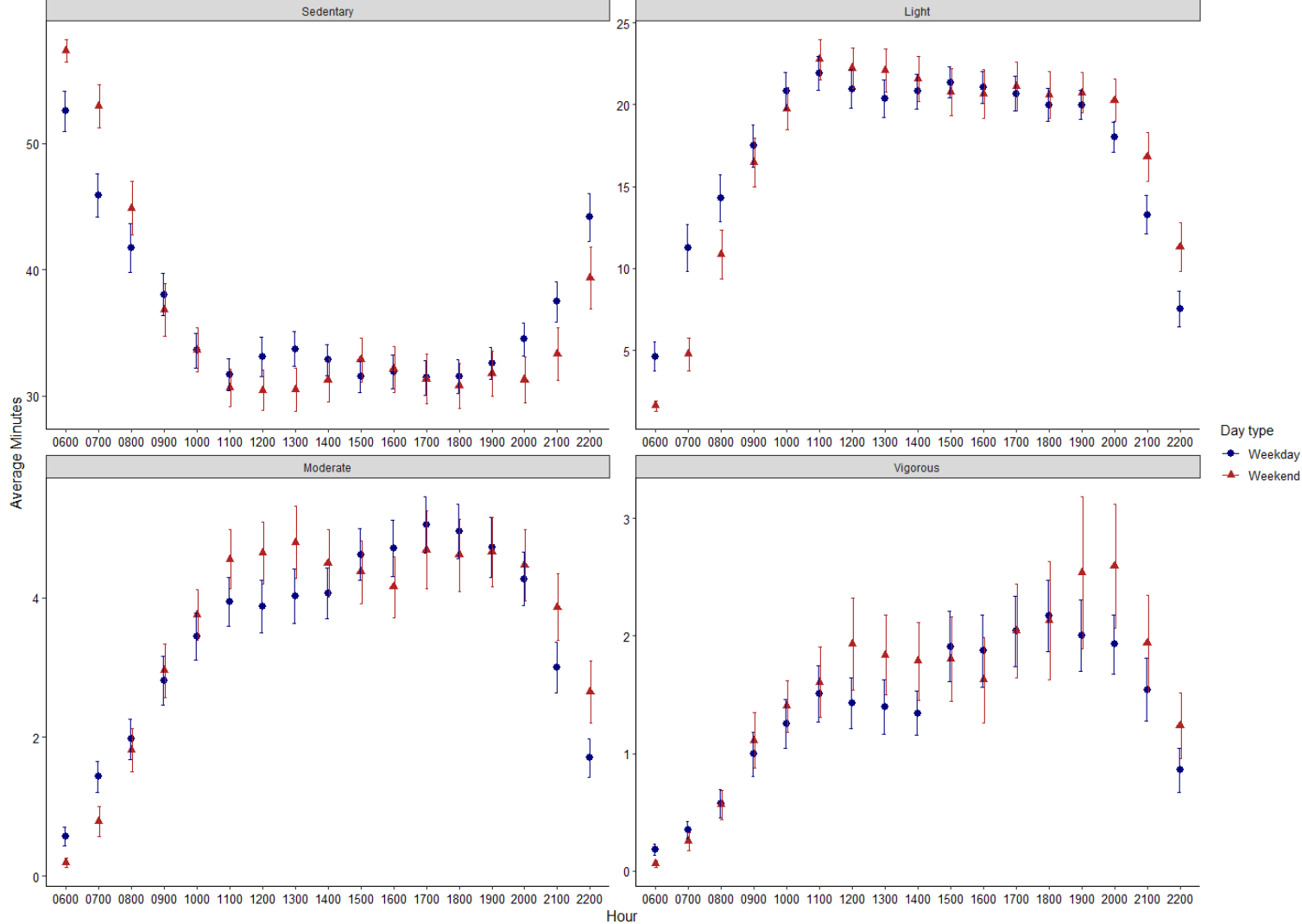
Total MVPA is the accumulated sum of moderate intensity and vigorous intensity combined

TPA is the accumulated sum of light intensity, moderate intensity, and vigorous intensity combined

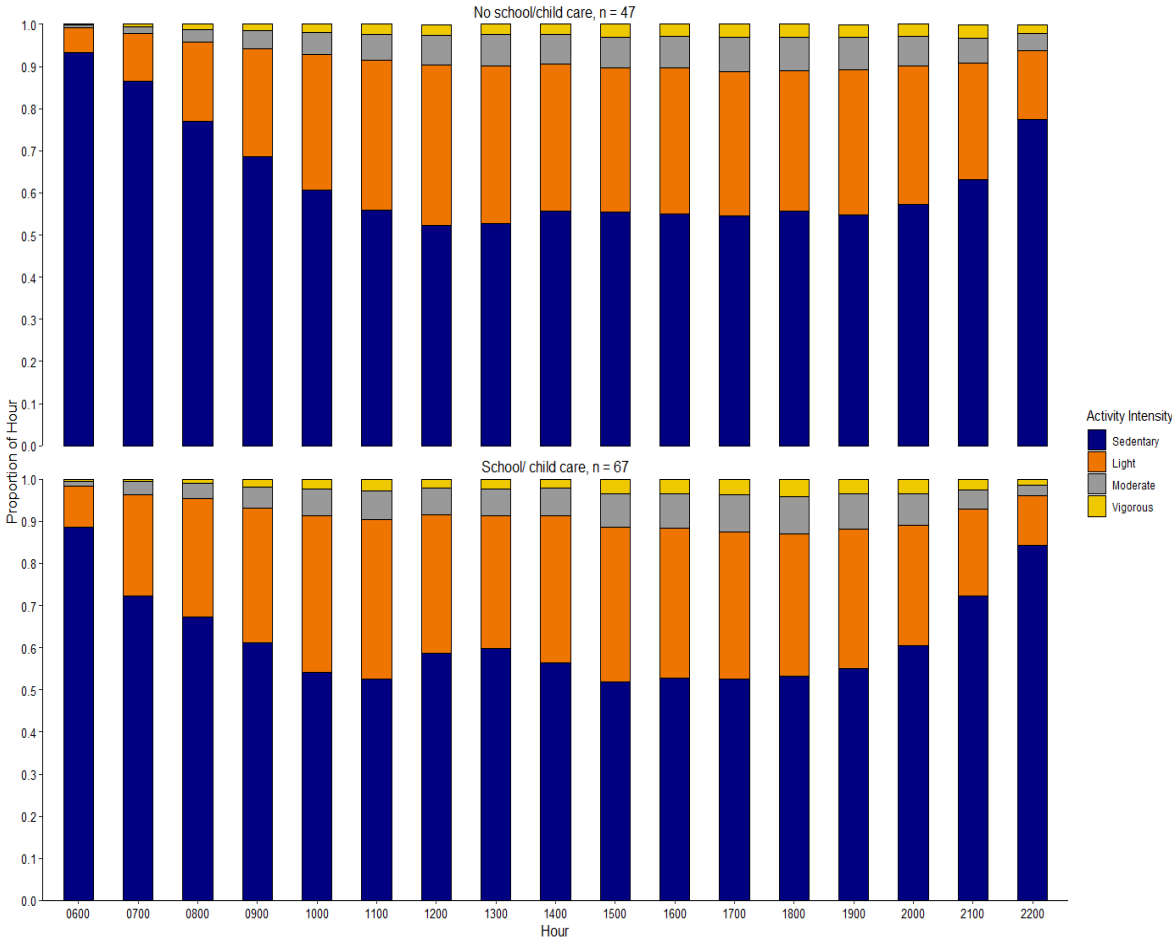
Paper 2 Figure 1. Mean proportion of time spent in activity type for overall sample of TX CORD Secondary Prevention preschool-aged participants at baseline stratified by type of day (N = 114)



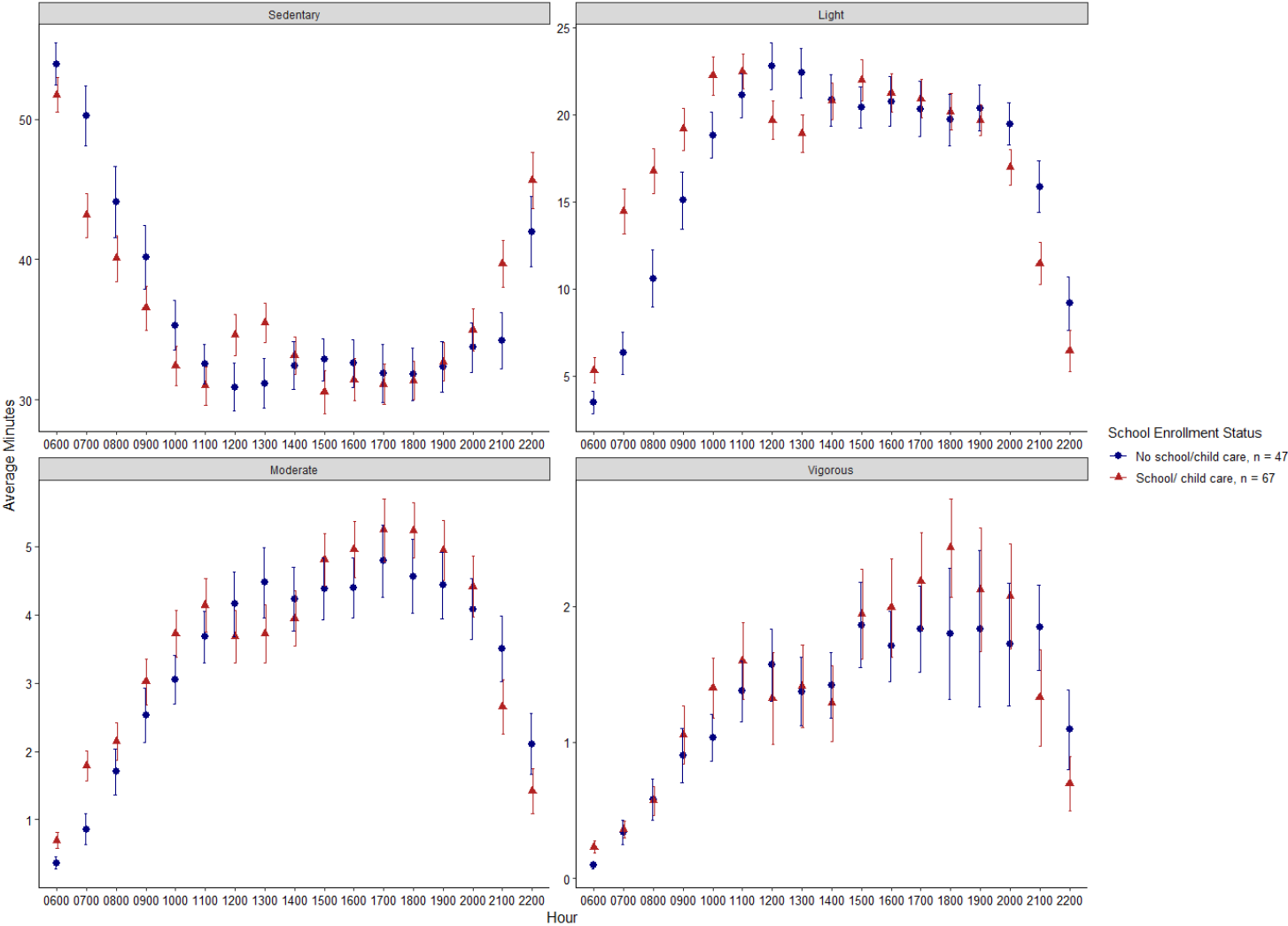
Paper 2 Figure 2. Mean minutes of time spent in activity type by hour of TX CORD Secondary Prevention preschool-aged participants at baseline stratified by type of day (N = 114)



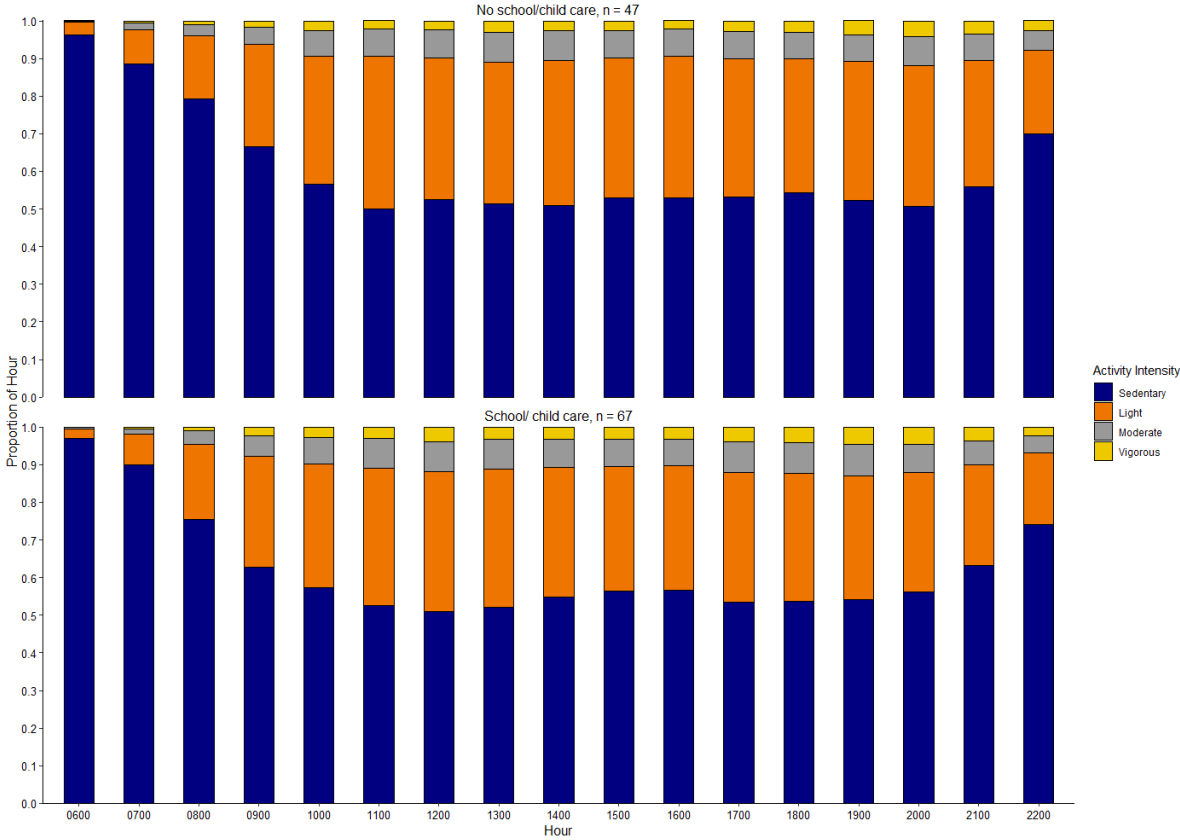
Paper 2 Figure 3. Mean proportion of weekday time spent in activity type of TX CORD Secondary Prevention preschool-aged participants stratified by school enrollment status (N = 114)



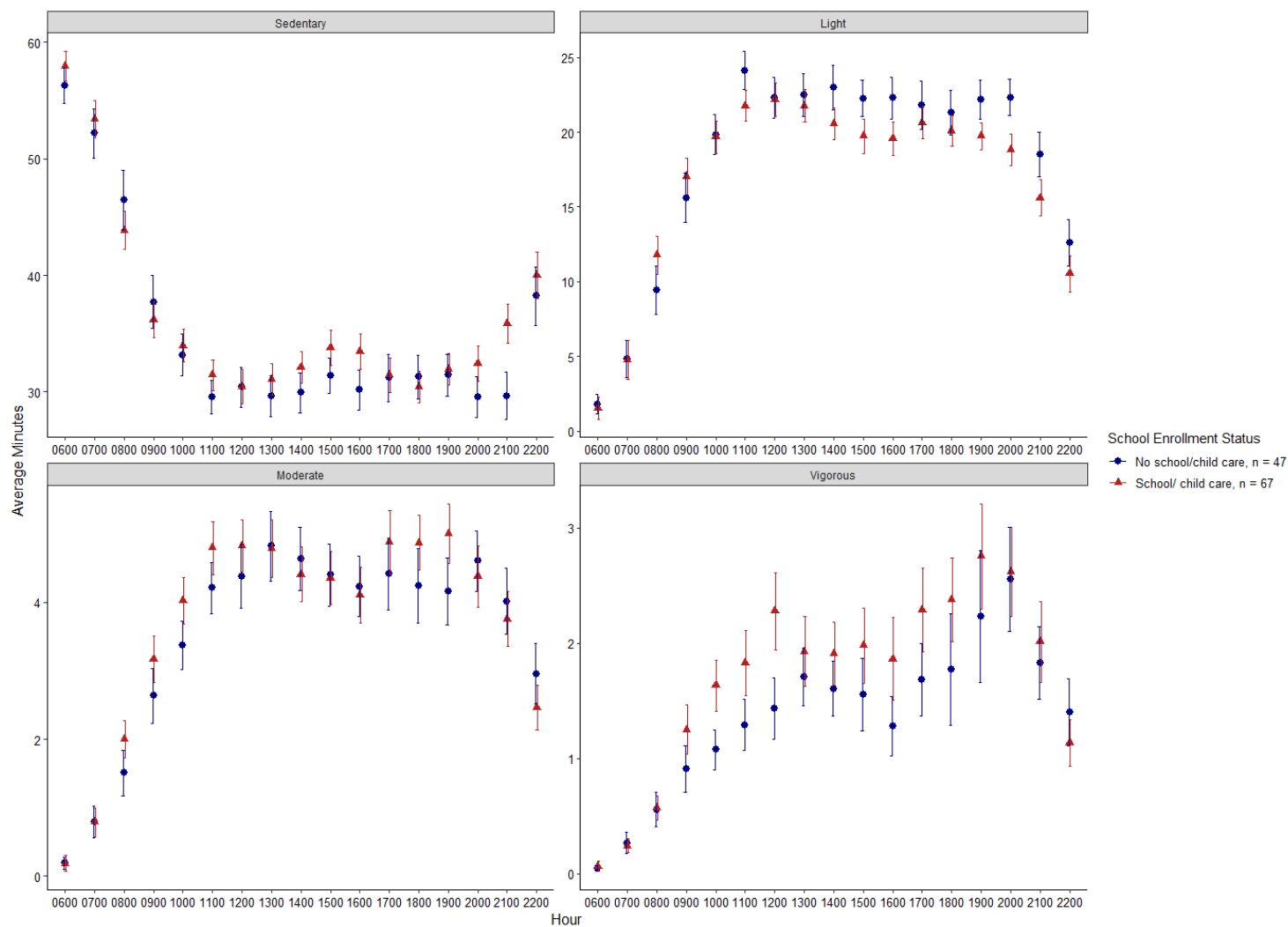
Paper 2 Figure 4. Mean minutes of weekday time spent in activity type by hour of TX CORD Secondary Prevention preschool-aged participants at baseline stratified by school enrollment status (N = 114)



Paper 2 Figure 5. Mean proportion of weekend time spent in activity type of TX CORD Secondary Prevention preschool-aged participants stratified by school enrollment status (N = 114)



Paper 2 Figure 6. Mean minutes of weekend time spent in activity type by hour of TX CORD Secondary Prevention preschool-aged participants at baseline stratified by school enrollment status (N = 114)



PAPER 3: ADIPOSITY, CARDIOVASCULAR, AND QUALITY OF LIFE INDICATORS AND REALLOCATION OF TIME IN PRESCHOOL CHILDREN WITH OVERWEIGHT AND OBESITY: AN ISOTEMPORAL DATA ANALYSIS

INTRODUCTION

The preschool years (ages 3-5 years) are a critical time for development. The 24-hour Activity Cycle (24-HAC) framework is a comprehensive model that includes proportions of a 24-hour period spent sleeping, sedentary, and in light intensity physical activity, or moderate to vigorous intensity physical activity (MVPA) (Rosenberger et al., 2019). The 24-HAC is consistent with whole-day guidelines for young children, which suggests that during waking periods children should be physically active throughout the day for health benefits (Committee, 2018; Okely et al., 2017; Organization, 2019; M. S. Tremblay et al., 2016). With the rising childhood obesity prevalence in the U.S. (Ogden et al., 2014) and globally (De Onis et al., 2010), there is an increasing need to examine how physical activity, sedentary behavior, and sleep, relate to health outcomes in children. The isotemporal substitution approach provides a way to examine the impact on health of specific waking behaviors while taking into account the other movement behaviors that occur within the day. Isotemporal modeling of physical activity has been examined in relation to mental health, adiposity, fitness, and cardiometabolic biomarkers in children and adults (García-Hermoso et al., 2017; Grgic et al., 2018).

Physical activity guidelines for young children focus on obtaining 180 minutes of light, moderate, and vigorous intensity activity throughout the day (Committee, 2018; Okely et al., 2017; Organization, 2019; M. S. Tremblay et al., 2016). Most isotemporal substitution modeling approaches investigate the potential benefits to health when sedentary time is replaced with time spent in other physical activity intensity categories, and the majority of

studies conducted in youth focus on adiposity indicators (García-Hermoso et al., 2017; Grgic et al., 2018). A meta-analysis found that substituting sedentary behavior with MVPA is associated with a 2.5 decrease in body fat percentage (95% CI: -4.2, -0.9) in youth (García-Hermoso et al., 2017). In addition, substituting just five minutes per day of sedentary, light, or moderate intensity activity with vigorous intensity activity has been found to be associated with higher fat free mass and better fitness in preschool youth (Leppänen et al., 2016). However, evidence is still needed for the effects of substituting sedentary behavior with light intensity activity, especially among at-risk and populations with overweight (García-Hermoso et al., 2017), which is a priority area identified by the 2018 Physical Activity Guidelines Scientific Advisory Committee. While studies have found improved cardiovascular indicators and health-related quality of life (HRQOL) when replacing sedentary time with light intensity activity or MVPA in adults, no studies have been conducted among youth or young children (Grgic et al., 2018). The relation of physical activity for the health and well-being of preschool youth is limited to mainly examining relations of MVPA and adiposity indicators. There is a need for examining associations with light intensity activity and the effect of replacing activity behaviors on health, particularly cardiovascular indicators and HRQOL, in this population.

Few isotemporal analyses have been conducted in preschool-aged youth (Collings et al., 2017; Leppänen et al., 2017; Leppänen et al., 2016), with only one study by Collings et al. (2013) examining the impact of race/ethnicity as a potential moderator on these relations (Collings et al., 2013). While the authors found no statistically significant difference between South Asian and White British preschoolers, there is a pressing need to examine physical activity and health in racially/ethnically diverse youth due to the high prevalence of obesity

among the Hispanic and non-Hispanic black U.S. population (Ogden et al., 2014). Thus, the purpose of this paper is to examine the health outcomes related to the activity behaviors among a majority-minority sample of preschool-aged children with overweight and obesity. The study aims are to examine the impact of waking behaviors on 1) adiposity health indicators 2) cardiovascular health indicators, and 3) parent-reported health-related quality of life, in a majority-minority preschool-age population with overweight and obesity.

METHODS

Study Design

The study is a cross-sectional analysis of baseline data of preschool-aged participants (2-5 years of age) from the Texas Childhood Obesity Research Demonstration (TX CORD) secondary prevention study (N = 167). Briefly, the TX CORD secondary prevention study was a 12-month randomized controlled trial (RCT) in which child participants, ages 2-12 years, and their families were randomly assigned to 1) a community-centered program or 2) a primary health care-centered program (Hoelscher et al., 2015). The current study included participants who are in the 2-5 age group, who returned the accelerometer, had completed parent surveys, and completed health measures (N = 141). The analytic sample included only preschool-aged children with valid accelerometer wear time of ≥ 10 hours of data between the hours of 06:00 – 22:59pm on ≥ 3 days (≥ 2 weekdays, ≥ 1 weekend) (N = 131).

Data Collection

Baseline data collection occurred between September 2012 and February 2014. For this study, TX CORD parent surveys, child worn accelerometers, and child health indicators were used. Analyses were conducted in October 2019. The independent variables are

accelerometer-derived physical activity estimates and the outcome variables are health indicators.

Accelerometer-derived physical activity

This study used the averaged daily estimate described previously in the parent methods. Briefly, ActiGraph GT3X+ devices were used to collect data. In August 2019, accelerometer files were downloaded from a secure server and processed in ActiLife v6.13.4 software using 10-second epoch lengths. Data were examined hourly to parse out waking time and remove activity accumulated during sleep or usual sleep time hours. Waking periods (06:00 – 22:59) were then screened for wear periods using the Choi wear time algorithm (Choi et al., 2011). Valid wear time was set at ≥ 10 hours of data on ≥ 3 days (≥ 2 weekdays, ≥ 1 weekend).

Averaged daily estimate

The averaged daily estimate was computed by averaging daily estimates. Daily summary estimates were first computed by summing hourly estimates across all waking hours (06:00 – 22:59) per individual day. Daily summary estimates were averaged across all valid days to compute an averaged daily estimate, which included 1) sedentary activity (minutes per day), 2) light intensity activity (minutes per day), 3) moderate intensity activity (minutes per day), 4) vigorous intensity activity (minutes per day), 5) total accumulated MVPA (minutes per day), and 6) total physical activity (light + MVPA) (TPA) (minutes per day).

Health indicators

Adiposity indicators

Adiposity measures included BMI z-score, %BMI_{p95}, fat mass, and waist circumference, described previously in the parent methods. Briefly, research staff measured height with a stadiometer and weight with a digital scale in light clothes and without shoes. Weight was measured to the nearest 0.1 kg and height was measured to the nearest 0.1 cm. Each participant was measured twice with an optional third measurement if the two measurements differed by 0.1 kg/cm. BMI z-score was computed using *A SAS Program for the 2000 CDC Growth Charts* and the percentage of the 95th percentile (%BMI_{p95}) was calculated as $(100 \times \text{BMI} / \text{BMI } 95^{\text{th}} \text{ percentile for age and sex})$.

Fat mass was measured using bioelectrical impedance analysis (BIA) (*TBF- 410GS, Tanita, Arlington Heights, Illinois*), measured to the nearest 0.1 kg. Mass was measured twice with the final variable equating to the average score between the two trials. Fat mass percent was calculated as fat mass (kg) / total body weight (kg). Fat mass index (FMI) was calculated as total fat mass (kg) / height² (m).

Waist circumference was measured to the nearest 1.0 mm using a measurement tape. Waist circumference was measured twice with the final variable equating to the average score between the two trials. Total waist circumference is provided on a continuous scale (mm). Additionally, a waist to height ratio was calculated as a proportion, from 0-1.

Cardiovascular health indicators

Resting systolic blood pressure (SBP) and diastolic blood pressure (DBP) were measured using an automated monitor to the nearest 1.0 mmHg (*8100T, Dinamap, Berlin, Massachusetts*). Children were instructed to sit quietly for five minutes prior to measurement.

During measurement, children were seated with their feet flat the floor. Resting SBP and DBP were measured twice with the summary variables equating to the average score of both between the two trials. Age, sex, and height determined elevated BP, stage 1 hypertension, and stage 2 hypertension were computed using the simplified BP tables developed by the American Academy of Pediatrics (Flynn et al., 2017).

Resting heart rate was measured at the same time as BP using the automated monitor. The measurements were recorded to the nearest beat per minute (bpm). The final variable equates to the average score between the two trials.

Health-related quality of life

Health-related quality of life (HRQOL) was measured using the PedsQL Measurement Model for the Pediatric Quality of Life Inventory, a 23-item multidimensional scale, measuring 1) Physical functioning (8 items), 2) Emotional functioning (5 items), 3) Social functioning (5 items), and 4) School functioning (5 items). Two items were removed from the School functioning sub-scale for children ages 2-5, for a final survey of 21-items. For children ages 2-5, HRQOL was measured via parent proxy-report, which has been shown to have good reliability (Cronbach's $\alpha = 0.90$) (Varni et al., 2001). Each item has a 5-point response scale of (0 = never a problem; 1 = almost never a problem; 2 = sometimes a problem; 3 = often a problem; 4 = almost always a problem). Items were transformed to a 0-100 scale using (0 = 100, 1 = 75, 2 = 50, 3 = 25, 4 = 0) and divided by the number of items answered for each sub-scale, with higher scores indicating better HRQOL.

Covariates

The included covariates were age (years), sex (male/female), ethnicity (Hispanic/non-Hispanic), and socioeconomic status (income to poverty ratio).

Data Analysis

Statistical analyses were performed using SAS 9.4 (*SAS Institute Inc., Cary, NC*). Descriptive statistics were conducted for demographic, physical activity variables, and health indicators and stratified by sex (**Paper 3 Table 1**). Variables were assessed for normality both visually and through the Shapiro-Wilk test, with medians and interquartile ranges presented for non-normal data and means and standard deviations provided for normally distributed data. Mann-Whitney U test or t-tests, depending on normality, compared differences across sex at $\alpha = 0.05$. Outliers, defined as an observation 1.5 times above or below the interquartile range, were examined for each physical activity variables and health indicators using boxplots.

The isotemporal substitution modeling approach (Mekary, Willett, Hu, & Ding, 2009) was used to examine the hypothetical effect on health when adding and substituting waking activity behaviors. These models use physical activity variables as the explanatory variables and health indicators as the response variable. The analysis uses three multiple linear regression models (single, partition, and substitution). Prior to entering the activity variables into the models, activity variables were divided by 15. This was used so that a one-unit increase was equitable to 15 minutes per day. The selection of 15 minutes resembles the Institute of Medicine (IOM) guidelines that suggests preschoolers have opportunities for light, moderate, and vigorous intensity physical activity for at least 15 minutes per hour.

First, single-variable regression models were run to examine the independent association of each waking behavior (sedentary, light, moderate, vigorous intensity) and also

accumulated MVPA, and TPA, with each health outcome, controlling for demographic covariates. These models were run without adjustment for the other categories of activities.

$$\text{health indicator} = \text{physical activity intensity} + \text{covariates}$$

Second, partition models were run that examine the effect on the health outcome when increasing the activity type variable while holding time in other activity behaviors constant. These models represent the “unique effect” of each intensity category.

Multicollinearity was assessed with variance inflation factor (VIF) index. This model represents the effect of adding 15 minutes spent in each of the activity intensity categories.

$$\text{health indicator} = \text{light intensity} + \text{moderate intensity} + \text{vigorous intensity} + \text{sedentary time} + \text{covariates}$$

Finally, isotemporal substitution models were run to estimate the effect on health when replacing one activity intensity category with another. This model drops the intensity category of interest and includes wear time. These models represent the estimated effect on the health indicator when substituting other activity intensities for the dropped activity intensity for the same amount of time. The equation below is an example of replacing 15 minutes of sedentary activity (dropped variable) with 15 minutes of either light intensity, moderate intensity, or vigorous intensity.

$$\text{health indicator} = \text{light intensity} + \text{moderate intensity} + \text{vigorous intensity} + \text{total wear time} + \text{covariates}$$

These models were run for adiposity health indicators, cardiovascular health indicators, and overall HRQOL and the Physical functioning subscale.

RESULTS

The overall sample of TX CORD participants between the ages of 2-5 years was 167. The final analytical sample included 131 participants with valid accelerometer wear time. The analytic sample had a mean age of 4.3 (SD=1.1), was 52.7% female, 87.0% Hispanic, and had a median income to poverty ratio of 63.0% (**Table 1**).

Single variable, partition, and isotemporal substitution models for each health indicator were run separately. The VIFs were all less than 10, thus determining the partition model could be run. Models were run both with the outliers included and excluded. No changes in effect size were seen when outliers were excluded, thus they were retained for all analyses.

Adiposity Indicators

Single variable, partition, and isotemporal substitution models for adiposity health indicators for the overall sample are presented in **Table 2**. In the overall single models, 15 additional minutes of vigorous intensity physical activity was associated with a 2.0 cm reduction in waist circumference and a 0.02 reduction in waist to height ratio. No significant associations were found for sedentary time, light intensity, or moderate intensity activity.

In the overall partition models, adding 15 minutes of light intensity per day was associated with a 0.1 reduction in BMI z-score. Adding 15 minutes of moderate intensity physical activity was directly associated with increases in all adiposity indicators. Adding 15 minutes of vigorous intensity is inversely associated with all adiposity health indicators (BMI z-score, percentage of the 95th percentile, fat mass percent, FMI, waist circumference and waist to height ratio). No significant associations were found for adding 15 minutes of sedentary time per day when controlling for the other activity behaviors.

Due to the significant differences by sex for adiposity indicators (fat mass percent, FMI, and waist to height ratio), the single variable, partition, and isothermal substitution were run separately for each sex, with models for males ($n = 62$) presented in **Table 3** and **Table 4** for female participants ($n = 69$). The male and female models removed sex as a covariate, controlling for age (years), ethnicity (Hispanic/ non-Hispanic), and socioeconomic status (income to poverty ratio). Partition models and isothermal substitution models were only significant for males.

Replacing sedentary behavior

In the overall sample, replacing 15 minutes of sedentary time with 15 minutes of light intensity activity was associated with a significant reduction in BMI z-score (-0.1) and percentage of the 95th percentile (-1.3%). Replacing sedentary time with moderate intensity physical activity with a significant increase in BMI z-score (0.5), percentage of the 95th percentile (7.9%), fat mass percent (2.70%), FMI (1.03 kg/m^2), waist circumference (4.3 cm), and waist to height ratio (0.03). Replacing sedentary time with vigorous intensity physical activity was associated with a significant reduction in BMI z-score (-0.5), percentage of the 95th percentile (-9.3%), fat mass percent (-3.9%), FMI (-1.4 kg/m^2), waist circumference (-6.2 cm), and waist to height ratio (-0.04). In the accumulated MVPA and TPA models (**Appendix Table 1**), no significant associations were found when sedentary time was replaced with MVPA or when replaced with TPA.

Replacing light intensity

Replacing light intensity with moderate intensity physical activity was associated with a significant increase in BMI z-score (0.6), percentage of the 95th percentile (9.2%), fat mass

percent (3.1%), FMI (1.2), waist circumference (4.7), and waist to height ratio (0.03).

Replacing 15 minutes of light intensity with 15 minutes of vigorous intensity activity was associated with a significant reduction in BMI z-score (-0.4), percentage of the 95th percentile (-8.0%), fat mass percent (-3.5%), FMI (-1.2 kg/m²), waist circumference (-5.8 cm), and waist to height ratio (-0.04). In the accumulated MVPA model, no significant associations were found when light intensity activity was replaced with MVPA.

Replacing moderate intensity

Replacing 15 minutes of moderate intensity with 15 minutes of vigorous intensity activity was associated with a significant reduction in BMI z-score (-1.0), percentage of the 95th percentile (17.2%), fat mass percent (6.6%), FMI (2.4 kg/m²), waist circumference (10.4 cm), and waist to height ratio (0.08).

Replacing vigorous intensity

Replacing 15 minutes of vigorous intensity with 15 minutes of sedentary time, light intensity, or moderate intensity activity was associated with a significant increase in BMI z-score, percentage of the 95th percentile, fat mass percent, FMI, waist circumference, and waist to height ratio.

Cardiovascular Indicators

Single variable, partition, and isothermal substitution models for cardiovascular health indicators are presented in **Table 5**. In the single models, 15 minutes of vigorous intensity physical activity was associated with a 2.8 mmHg reduction in resting SBP and a 2.2 mmHg reduction in DBP. No significant associations were found for sedentary time, light intensity, or moderate intensity activity or between pulse and activity behaviors.

In the partition models, adding 15 minutes of vigorous intensity was associated with a 4.7 mmHg reduction in resting SBP and a 3.6 mmHg reduction in DBP, when controlling for other waking activity behaviors. No significant associations were found for adding 15 minutes of sedentary time, light intensity, or moderate intensity activity when controlling for other activity behaviors. No associations were found between waking activity behaviors and pulse.

Replacing sedentary behavior

Replacing 15 minutes of sedentary time with 15 minutes of vigorous intensity activity was associated with a significant reduction in resting SBP (5.0 mmHg) and DBP (3.7 mmHg), but not resting heart rate. No significant findings were found for replacing sedentary time with light intensity or moderate intensity. In the accumulated MVPA and TPA models (**Appendix Table 2**), no significant associations were found when sedentary time was replaced with MVPA or when replaced with TPA.

Replacing light intensity

Replacing 15 minutes of light intensity physical activity with 15 minutes of vigorous intensity activity was associated with a significant reduction in resting DBP (4.3 mmHg) and DBP (3.2 mmHg), but not resting heart rate. No significant findings were found for replacing light intensity with moderate intensity. In the accumulated MVPA model, no significant associations were found when light intensity activity was replaced with MVPA.

Replacing moderate intensity

Replacing 15 minutes of moderate intensity physical activity with 15 minutes of vigorous intensity activity was associated with a significant reduction in resting SBP (7.3 mmHg) and DBP (5.5 mmHg), but not resting heart rate.

Replacing vigorous intensity

Replacing 15 minutes of vigorous intensity with 15 minutes of sedentary time, light intensity, or moderate intensity activity was associated with a significant increase in resting SBP and DBP, but not resting heart rate.

Health-related Quality of Life

Single variable, partition, and isothermal substitution models for HRQOL are presented in **Table 6**. In the single models, 15 minutes of sedentary time was associated with a 0.8 point increase in physical functioning HRQOL. Findings were not significant between waking activity behaviors and overall HRQOL.

In the partition models, adding 15 minutes of sedentary time was associated with a 0.9 point higher HRQOL score when controlling for other waking activity behaviors.

Replacing sedentary behavior

No significant findings were found when replacing 15 minutes of sedentary time with physical activity intensities. In the accumulated MVPA and TPA models (**Appendix Table 3**), no significant associations were found when sedentary time was replaced with MVPA or when replaced with TPA.

Replacing light intensity

No significant findings were found when replacing 15 minutes of light intensity physical activity with moderate or vigorous intensities. In the accumulated MVPA model, no significant associations were found when light intensity activity was replaced with MVPA.

Replacing moderate intensity

No significant findings were found when replacing 15 minutes of moderate intensity physical activity with 15 minutes of vigorous intensity activity.

Replacing vigorous intensity

No significant findings were found when replacing 15 minutes of vigorous intensity physical activity with the other physical activity intensities or sedentary time.

DISCUSSION

This study examined adiposity, cardiovascular, and health-related quality of life outcomes related to waking activity behaviors among primarily Hispanic preschool children with overweight and obesity in Texas. The principal finding of this paper is that vigorous intensity physical activity is associated with several favorable adiposity and cardiovascular health outcomes among children with overweight and obesity. Replacing waking activity behaviors with 15 minutes of vigorous intensity physical activity per day was associated with a significant reduction in SBP and DBP. Among boys, replacement with vigorous intensity was associated with a significant reduction in BMI z-score, percentage of the 95th percentile, fat mass percent, FMI, waist circumference, and waist to height ratio. Additionally, replacing sedentary time with light intensity physical activity was associated with a significant reduction in adiposity indicators.

This study suggests that vigorous intensity physical activity is the most beneficial activity for body composition among a clinically overweight population. High intensity

exercise training has been found to be effective stimulus in reducing body composition and abdominal fat in adults – which may be due to induced enzyme activity (Irving et al., 2008; A. Tremblay, Simoneau, & Bouchard, 1994). Only one previous study has been conducted in a Hispanic population with clinical overweight, which found that greater accelerometer MVPA was associated with lower BMI z-score (Mendoza et al., 2014). However, Mendoza et al. (2014) did not account for other physical activity intensities that occur throughout the day. Although this study did not find associations with overall MVPA, it did find an inverse association when examining vigorous intensity physical activity separately. These findings are supported by previous studies that found the association between MVPA and adiposity in young children was fully explained by vigorous intensity activity (Collings et al., 2013; Leppänen et al., 2016). Results from Leppänen and colleagues' (2016) isothermal substitution also suggest the strongest associations with adiposity indicators (fat free mass index) when vigorous intensity physical activity replaces sedentary, light, and moderate intensity physical activity. Furthermore, this study supports the findings from Leppänen et al. (2016) that substituting as little as five minutes per day of sedentary, light, or moderate intensity activity with vigorous intensity activity is associated with better health indicators.

The associations between vigorous intensity physical activity and body composition appear stronger amongst an overweight population. While Collings et al. (2017) found no statistically significant findings when substituting 20 minutes of sedentary time with light intensity or MVPA, this study found that among preschoolers with overweight, replacing sedentary time with light intensity or vigorous intensity activity was favorably associated with numerous adiposity indicators. These findings have implications for intervention development as preschool children with overweight have significantly less daily vigorous

intensity and more sedentary time than non-overweight children (Carson, Tremblay, et al., 2017; Metallinos-Katsaras et al., 2007). As most studies have been conducted primarily among populations with low overweight/obesity percentages (8.5% – 16%) (Collings et al., 2013; Leppänen et al., 2016), understanding the unique contributions of vigorous intensity among preschoolers with overweight is needed.

The direct association between adiposity indicators and moderate intensity physical activity was not expected. Further exploring this relation by sex, the association between adiposity indicators was significant only for boys. This study found a direct association in the overall sample (controlling for sex) and the male-only sample that suggests higher moderate intensity physical activity levels is associated with greater adiposity. These findings may be due to the significant differences in daily moderate and vigorous intensity activity between the sexes. Previous studies have found a significant interaction by sex was when examining prolonged sitting time with waist circumference and clustered cardiometabolic risk among older children (Mean age = 11.2 ± 2.7) (Wijndaele et al., 2019). In this study, males had greater variability around the median value and significantly higher daily minutes of moderate and vigorous intensity activity compared to females, although both sexes were relatively active. Further examining patterns hourly by sex (Paper 1 of this dissertation) may provide a potential mechanism as males had higher hourly activity in throughout the day – particularly in the mornings (09:00 – 13:00) and late afternoon (15:00 – 18:00). Physical activity can regulate energy metabolism, sensitivity, and regulation of body homeostasis (A. Tremblay & Therrien, 2006), which may be vital after meal consumption. Future research needs to hourly physical activity patterns, such as diurnal patterns, and the impact on health.

This is one of the first studies to examine isothermal substitution models in regard to cardiovascular indicators among preschool-aged children. Although studies have found improved cardiovascular indicators when replacing sedentary time with light intensity activity or MVPA in adults (Grgic et al., 2018) and more recently children (Wijndaele et al., 2019), no studies have been conducted among only preschool-aged children. Research regarding BP in young children is of the utmost importance as the American Academy of Pediatrics recommends that BP is measured annually in children aged three and older and checked at every health care encounter if they have obesity (Flynn et al., 2017). This study found that among preschool children with overweight, vigorous intensity physical activity is inversely associated with SBP and DBP. Substituting 15 minutes per day of vigorous intensity activity for sedentary, light, and moderate intensity activity was associated with between 4-7 mmHg reduction in SBP and between a 3-5 mmHg reduction in DBP. This is important as 13.2% of the sample had elevated or higher SBP and 26.5% of the sample had elevated or higher DBP. Furthermore, reducing elevated BP is of particular importance as elevated BP tracks from childhood into adulthood (Chen & Wang, 2008; Flynn et al., 2017; Raitakari et al., 2003). Promoting vigorous intensity physical activity during the early childhood years can be important for managing elevated BP levels and, conceivably, reducing the risk of hypertension and heart disease into adulthood.

In regards to quality of life, parents with preschoolers who have overweight and obesity have been found to rate their child's walking, running, ability to lift something heavy, and energy level as lower than parents of normal weight children (Kuhl et al., 2012). Further, compared to non-overweight children, children with clinical obesity are 72% more likely to have additional health care needs (Wake et al., 2008). This is the first study to use

isotemporal substitution models to assess changes in HRQOL when hypothetical substitutions of movement behaviors occur. While studies have found improved HRQOL when replacing sedentary time with physical activity in adults (Grgic et al., 2018) and although this sample has poor adiposity and cardiovascular health indicators, the relatively high scores for overall HRQOL (90.5) and physical functioning (96.9) may have contributed to the lack of association between physical activity and quality of life within this study. Future studies should utilize isotemporal modeling to examine HRQOL and physical functioning in a more diverse population (e.g. race/ethnicity, BMI status).

Strengths and Limitations

This study has a number of strengths including use of a clinical and ethnically diverse population. Hispanic youth have highest prevalence of overweight (29.8%) and obesity (15.6%) compared to other race/ethnic groups in the U.S. (Ogden et al., 2014; Ogden et al., 2016), yet few studies have examined the relation between physical activity and health indicators in Hispanic youth experiencing obesity. The use of a device-based measure of physical activity and age-specific VM cut-points, allows for the assessment of specific intensity minutes. This is especially important as the 24-HAC waking periods include light intensity physical activity, which is not easily captured via self- or parent-proxy report measures. This study is one of the first studies to explore how light intensity physical activity affects health separately from other behaviors and one of the first studies to examine the relation between physical activity and BP using a device-based physical activity measurement. The use of isotemporal data analysis takes into account the nature of time and multicollinearity – a limitation in previous studies that examine independent associations of physical activity and health. This is the first study to use isotemporal analyses with

cardiovascular indicators and HRQOL in preschool-aged youth. Further strengths include the various measures of health indicators. This study used a fat mass measure collected with bioelectrical impedance. A major limitation of the current literature is the use of BMI as the only indicator of adiposity, which may not be the best indicator of adiposity in growing children (Pereira-da-Silva et al., 2016). Few studies use bioelectrical impedance, BodPod, or dual energy x-ray absorptiometry (DXA) as assessment tools (Carson, Lee, et al., 2017).

Limitations should be noted. This is a cross-sectional study so it is unable to determine causality or analyze how this relation affects health over time. However, isotemporal data analysis allows for the evaluation of the “impact” of counterfactual time replacement scenarios, which is an important step for research. Although isotemporal data analyses control for time, they are regression models and thus are not robust to outliers. However, after removing potential outliers from all analyses, effects were similar and thus outliers remained within these data. Additional limitations include the lack of gold-standard measure of adiposity, DXA. While bioelectrical impedance is an improvement over only using BMI for measuring adiposity, there is still error with using this measure for fat mass. Additionally, there were no instructions for participants in order to ensure the most accurate health assessment results. For example, for the most accurate BIA results, children should have fasted for four hours and drank at least one quart of water one hour prior to testing. Further, waist circumference does not have a specific threshold indicator for poor health outcome and therefore this study is only assuming that a larger waist circumference and waist to height ratio is harmful for health. While this population is of importance, generalizability is limited to low-income, primarily Hispanic preschool youth with obesity.

Conclusions

The study is one of the first studies to use isothermal substitution modeling to examine the impact of waking activity behaviors on a variety of health related indicators in a sample of majority-minority preschoolers with overweight and obesity. This study suggests that vigorous intensity physical activity is one of the most advantageous activities for preschoolers to engage in for health. As school and home are two of the most important settings for children (Britto et al., 2017), teaching caregivers (parents and teachers) how to engage children in vigorous intensity is needed, especially since overweight children spend more time sedentary and less time in MVPA than normal weight children. Additionally, the results of this study can help researchers and clinicians develop interventions and counsel families on ways to promote healthy growth during this important stage in development.

Paper 3 Table 1. Characteristics of the TX CORD Secondary Prevention preschool-aged participants at baseline.

Characteristics	Overall (N = 131)		Boys (n = 62)		Girls (N = 69)		p-value
Age (y) M ± SD	4.3 ± 1.1		4.3 ± 1.0		4.2 ± 1.2		0.534
Female, % (n)	52.7	(69)					
Hispanic, % (n)	87.0	(114)	83.9	(52)	89.9	(62)	0.309
Income to Poverty Ratio (%), Median (IQR)	63.0	(45.0-93.4)	64.8	(52.9-95.2)	53.3	(42.3-80.9)	0.066
Adiposity Indicators, Median (IQR)							
BMI z score (kg/m ²)	2.3	(1.7-2.9)	2.1	(1.6-3.2)	2.3	(1.9-2.7)	0.820
%BMI _{p95} (%)	108.8	(100.4-122.6)	105.9	(99.6-122.1)	112.1	(103.4-122.6)	0.198
Fat mass %	31.9	(27.4-36.0)	28.5	(25.7-34.5)	32.9	(29.7-37.0)	0.003
Fat mass index (kg / m ²)	6.3	(5.0-8.2)	5.5	(4.7-7.9)	6.7	(5.5-8.3)	0.005
Waist circumference (cm)	62.5	(56.0-69.0)	59.2	(54.8-67.2)	63.0	(57.3-70.1)	0.078
WHtR	0.6	(0.5-0.6)	0.6	(0.5-0.6)	0.6	(0.6-0.7)	<0.001
Cardiovascular Indicators, M ± SD							
Resting systolic blood pressure (mmHg)	95.4 ± 9.7		96.6 ± 9.2		94.3 ± 10.0		0.186
Resting diastolic blood pressure (mmHg)	59.7 ± 7.6		60.0 ± 7.7		59.5 ± 7.5		0.713
Resting heart rate (bpm)	94.9 ± 13.2		91.5 ± 12.1		97.7 ± 13.6		0.009
Health-related Quality of Life Indicators, Median (IQR)							
Overall HRQOL	90.5	(80.9-96.4)	90.5	(80.0-95.2)	91.7	(83.3-97.2)	0.419
Physical functioning HRQOL	96.9	(86.6-100.0)	93.8	(87.5-100.0)	96.9	(81.3-100.0)	0.689
Accelerometer-derived Physical Activity (min/d), Median (IQR)							
Accelerometer wear time	964.1	(922.3-996.7)	976.6	(939.6-1001.9)	953.7	(907.3-984.0)	0.016
Average Vector Magnitude Counts (ct×min/d)	1125.4	(945.7-1237.6)	1192.7	(1073.0-1325.3)	1050.0	(882.3-1201.6)	<0.001
Sedentary Activity	578.4	(538.0-627.2)	578.0	(538.0-625.7)	578.4	(541.1-630.0)	0.389
Light Intensity Activity	285.6	(248.6-317.0)	288.0	(241.7-318.5)	284.6	(252.0-313.1)	0.450
Moderate Intensity Activity	59.0	(44.5-69.6)	65.8	(56.6-71.9)	50.2	(40.7-61.7)	<0.001
Vigorous Intensity Activity	21.5	(14.0-29.7)	37.0	(20.5-35.1)	16.7	(12.6-24.3)	<0.001

Abbreviations: y, years; M, mean; SD, standard deviation; IQR, interquartile range; BMI, body mass index; FMI, fat mass index; WHtR, Waist to Height Ratio; HRQOL, Health-related quality of life; min, minutes; d, day; ct, count; MVPA, moderate to vigorous intensity physical activity; TPA, total physical activity;

Note: %BMI_{p95} (%) is the percentage of the 95th percentile which is used to classify extreme obesity (Flegal et al., 2009)

Paper 3 Table 2. Associations and isotemporal substitution of waking behaviors with adiposity health indicators in preschool children with overweight and obesity participating in the baseline assessment of the TX CORD Secondary Prevention Study (N = 131)

	BMI z-score β (95% CI) (n=131)	%BMI _{p95} β (95% CI) (n=131)	Fat mass (%) β (95% CI) (n=124)	FMI (kg/m ²) β (95% CI) (n=124)	Waist circumference (cm) β (95% CI) (n=129)	Waist to height ratio β (95% CI) (n=129)
Model 1 – Single Model						
Sedentary time	0.0 (-0.0, 0.0)	0.1 (-0.5, 0.6)	0.0 (-0.2, 0.3)	0.0 (-0.1, 0.1)	-0.0 (-0.326, 0.2)	0.00 (-0.0, 0.00)
LPA	0.1 (-0.2, 0.3)	0.0 (-0.8, 0.9)	0.0 (-0.3, 0.4)	0.0 (-0.1, 0.1)	0.2 (-0.243, 0.7)	0.00 (-0.0, 0.01)
MPA	0.0 (-0.0, 0.0)	1.4 (-1.1, 3.9)	0.2 (-0.8, 1.2)	0.1 (-0.3, 0.5)	0.5 (-0.859, 1.8)	0.00 (-0.01, 0.01)
VPA	-0.0 (-0.2, 0.2)	-1.5 (-5.0, 2.0)	-1.3 (-2.6, 0.1)	-0.4 (-0.9, 0.1)	-2.0 (-3.8, -0.1)	-0.02 (-0.03, -0.00)
Model 2 – Partition Model						
Sedentary time	0.0 (-0.0, 0.1)	0.3 (-0.3, 0.8)	0.1 (-0.1, 0.3)	0.0 (-0.0, 0.2)	0.1 (-0.2, 0.4)	0.00 (-0.00, 0.00)
LPA	-0.1 (-0.1, -0.0)	-1.0 (-2.1, 0.1)	-0.3 (-0.7, 0.1)	-0.1 (-0.0, 0.0)	-0.3 (-0.9, 0.3)	-0.00 (-0.01, 0.00)
MPA	0.5 (0.3, 0.8)	8.2 (3.4, 13.0)	2.8 (1.0, 4.7)	1.1 (0.4, 1.8)	4.3 (-1.8, 6.8)	0.03 (0.01, 0.05)
VPA	-0.6 (-0.8, -0.2)	-9.0 (-14.5, -3.5)	-3.8 (-5.9, -1.7)	-1.4 (-2.2, -0.6)	-6.1 (-9.0, -3.2)	-0.04 (-0.07, -0.02)
Model 3 – Isotemporal Substitution Model						
Sedentary → LPA	0.1 (0.0, 0.2)	1.3 (0.1, 2.5)	0.4 (-0.1, 0.9)	0.2 (-0.0, 0.3)	0.4 (-0.2, 1.0)	0.00 (-0.00, 0.01)
Sedentary → MPA	-0.5 (-0.7, -0.2)	-7.9 (-12.6, -3.3)	-2.7 (-4.5, -0.9)	-1.0 (-1.7, -0.4)	-4.3 (-6.7, -1.8)	-0.03 (-0.05, -0.01)
Sedentary → VPA	0.5 (0.2, 0.8)	9.3 (3.7, 14.9)	3.9 (1.7, 6.1)	1.4 (0.6, 2.2)	6.2 (3.2, 9.1)	0.04 (0.02, 0.07)
LPA → Sedentary	-0.1 (-0.2, -0.0)	-1.3 (-2.5, -0.1)	-0.4 (-0.9, 0.1)	-0.2 (-0.3, 0.0)	-0.4 (-1.0, 0.2)	-0.00 (-0.01, 0.00)
LPA → MPA	-0.6 (-0.9, -0.3)	-9.2 (-12.6, -3.7)	-3.1 (-5.2, -1.0)	-1.2 (-2.0, -0.4)	-4.5 (-7.5, -1.8)	-0.03 (-0.06, -0.01)
LPA → VPA	0.4 (0.1, 0.7)	8.0 (2.8, 13.2)	3.5 (1.5, 5.5)	1.2 (0.5, 2.0)	5.8 (3.1, 8.5)	0.04 (0.02, 0.06)
MPA → Sedentary	0.5 (0.2, 0.7)	7.9 (3.3, 12.6)	2.7 (0.9, 4.5)	1.0 (0.4, 1.7)	4.3 (1.8, 6.7)	0.03 (0.01, 0.05)
MPA → LPA	0.6 (0.3, 0.9)	9.2 (3.7, 14.7)	3.1 (1.0, 5.2)	1.2 (0.4, 2.0)	4.6 (1.8, 7.5)	0.03 (0.01, 0.06)
MPA → VPA	1.0 (0.4, 1.5)	17.2 (7.5, 26.9)	6.6 (2.8, 10.3)	2.4 (1.0, 3.8)	10.4 (5.3, 15.5)	0.08 (0.04, 0.11)
VPA → Sedentary	-0.5 (-0.8, -0.2)	-9.2 (-14.9, -3.7)	-3.9 (-6.1, -1.7)	-1.4 (-2.2, -0.6)	-6.2 (-9.1, -3.2)	-0.04 (-0.07, -0.02)
VPA → LPA	-0.4 (-0.7, -0.1)	-8.0 (-13.2, -2.8)	-3.5 (-5.5, -1.5)	-1.2 (-2.0, -0.5)	-5.8 (-8.5, -3.1)	-0.04 (-0.06, -0.02)
VPA → MPA	-1.0 (-1.5, -0.4)	-17.2 (-26.9, -7.5)	-6.6 (-10.3, -2.8)	-2.4 (-3.8, -1.0)	-10.4 (-15.5, -5.3)	-0.08 (-0.11, -0.04)

Abbreviations: LPA, light intensity physical activity; MPA, moderate intensity physical activity; VPA, vigorous intensity physical activity; CI, confidence interval; cm, centimeter; BMI, body mass index; FMI, fat mass index.

Note: Models are per 15-min change

The arrow symbol (→) indicates “replaces”

Model covariates include: age, sex, ethnicity, and SES

Paper 3 Table 3. Associations and isotemporal substitution of waking behaviors with adiposity health indicators for only the male preschool children with overweight and obesity participating in the baseline assessment of the TX CORD Secondary Prevention Study (N = 62)

	BMI z-score β (95% CI) (n=62)	%BMI _{p95} β (95% CI) (n=62)	Fat mass (%) β (95% CI) (n=56)	FMI (kg/m ²) β (95% CI) (n=56)	Waist circumference (cm) β (95% CI) (n=61)	Waist to height ratio β (95% CI) (n=61)
Model 1 – Single Model						
Sedentary time	0.0 (-0.0, 0.1)	0.7 (-0.1, 1.5)	0.3 (-0.1, 0.6)	0.1 (-0.0, 0.2)	0.3 (-0.1, 0.7)	0.0 (-0.00, 0.01)
LPA	-0.1 (-0.1, 0.0)	-0.9 (-2.2, 0.5)	-0.3 (-0.8, 0.3)	-0.1 (-0.3, 0.1)	-0.3 (-1.0, 0.5)	-0.0 (-0.01, 0.00)
MPA	0.1 (-0.1, 0.4)	0.7 (-3.4, 4.8)	-0.4 (-2.2, 1.4)	-0.1 (-0.8, 0.6)	-0.2 (-2.4, 2.0)	-0.01 (-0.02, 0.01)
VPA	-0.0 (-0.3, 0.3)	-1.9 (-6.5, 2.8)	-1.6 (-3.6, 0.4)	-0.5 (-1.2, 0.2)	-2.3 (-4.7, 0.2)	-0.02 (-0.04, -0.00)
Model 2 – Partition Model						
Sedentary time	0.1 (0.0, 0.1)	0.7 (-0.1, 1.4)	0.3 (-0.1, 0.6)	0.1 (-0.0, 0.2)	0.3 (-0.1, 0.7)	0.00 (-0.00, 0.01)
LPA	-0.1 (-0.2, -0.0)	-2.1 (-3.7, -0.5)	-0.6 (-1.3, 0.1)	-0.3 (-0.5, -0.0)	-0.9 (-1.7, -0.0)	-0.01 (-0.01, 0.00)
MPA	0.8 (0.3, 1.3)	12.5 (5.0, 19.9)	4.1 (0.7, 7.4)	1.6 (0.4, 2.8)	6.4 (2.4, 10.4)	0.04 (0.01, 0.07)
VPA	-0.7 (-1.1, -0.2)	-11.8 (-19.3, -4.2)	-4.7 (-8.0, -1.4)	-1.7 (-2.9, -0.5)	-7.5 (-11.5, -3.4)	-0.05 (-0.08, -0.02)
Model 3 – Isotemporal Substitution Model						
Sedentary → LPA	0.2 (0.1, 0.3)	2.8 (1.2, 4.4)	0.9 (0.1, 1.6)	0.4 (0.1, 0.6)	1.2 (0.3, 2.0)	0.01 (0.00, 0.01)
Sedentary → MPA	-0.8 (-1.2, -0.3)	-11.8 (-19.2, -4.4)	-3.8 (-7.2, -0.5)	-1.5 (-2.7, -0.3)	-6.1 (-10.2, -2.1)	-0.04 (-0.07, -0.01)
Sedentary → VPA	0.7 (0.2, 1.2)	12.4 (4.8, 20.0)	5.0 (1.6, 8.3)	1.8 (0.6, 3.0)	7.7 (3.7, 11.8)	0.05 (0.02, 0.08)
LPA → Sedentary	-0.2 (-0.3, -0.1)	-2.8 (-4.4, -1.2)	-0.9 (-1.6, -0.1)	-0.4 (-0.6, -0.1)	-1.2 (-2.0, -0.3)	-0.01 (-0.01, -0.00)
LPA → MPA	-0.9 (-1.5, -0.4)	-14.6 (-23.0, -6.1)	-4.7 (-8.5, -0.8)	-1.9 (-3.2, -0.5)	-7.3 (-11.9, -2.72)	-0.05 (-0.08, -0.01)
LPA → VPA	0.5 (0.1, 1.0)	9.7 (2.7, 16.6)	4.1 (1.1, 7.1)	1.4 (0.4, 2.5)	6.6 (2.9, 10.3)	0.05 (0.02, 0.07)
MPA → Sedentary	0.8 (0.3, 1.2)	11.8 (4.4, 19.2)	3.8 (0.5, 7.2)	1.5 (0.3, 2.7)	6.1 (2.1, 10.2)	0.04 (0.01, 0.07)
MPA → LPA	0.9 (0.4, 1.5)	14.6 (6.1, 23.0)	4.7 (0.8, 8.5)	1.9 (0.5, 3.2)	7.3 (2.7, 11.9)	0.05 (0.01, 0.08)
MPA → VPA	1.5 (0.6, 2.4)	24.2 (9.9, 38.5)	8.8 (2.4, 15.1)	3.3 (1.0, 5.6)	13.9 (6.2, 21.6)	0.09 (0.04, 0.15)
VPA → Sedentary	-0.7 (-1.2, -0.2)	-12.4 (-20.0, -4.8)	-5.0 (-6.1, -1.7)	-1.8 (-3.0, -0.6)	-7.7 (-11.8, -3.7)	-0.05 (-0.08, -0.02)
VPA → LPA	-0.5 (-1.0, -0.1)	-9.7 (-16.6, -2.7)	-4.1 (-7.2, -1.1)	-1.4 (-2.5, -0.4)	-6.6 (-10.3, -2.9)	-0.05 (-0.07, -0.02)
VPA → MPA	-1.5 (-2.4, -0.6)	-24.2 (-38.5, -9.9)	-8.8 (-15.1, -2.4)	-3.3 (-5.6, -1.0)	-13.9 (-21.6, -6.2)	-0.09 (-0.15, -0.04)

Abbreviations: LPA, light intensity physical activity; MPA, moderate intensity physical activity; VPA, vigorous intensity physical activity; CI, confidence interval; cm, centimeter; BMI, body mass index; FMI, fat mass index.

Note: Models are per 15-min change

The arrow symbol (→) indicates “replaces”

Model covariates include: age, sex, ethnicity, and SES

Paper 3 Table 4. Associations and isotemporal substitution of waking behaviors with adiposity health indicators for only the female preschool children with overweight and obesity participating in the baseline assessment of the TX CORD Secondary Prevention Study (N = 69)

	BMI z-score β (95% CI) (n=69)	%BMI _{p95} β (95% CI) (n=69)	Fat mass (%) β (95% CI) (n=68)	FMI (kg/m ²) β (95% CI) (n=68)	Waist circumference (cm) β (95% CI) (n=68)	Waist to height ratio β (95% CI) (n=68)
Model 1 – Single Model						
Sedentary time	-0.0 (-0.1, 0.0)	-0.5 (-1.2, 0.3)	-0.1 (-0.371, 0.1)	-0.1 (-0.2, 0.1)	-0.3 (-0.6, 0.1)	-0.0 (-0.00, 0.00)
LPA	0.0 (-0.0, 0.1)	0.9 (-0.3, 2.0)	0.3 (-0.134, 0.7)	0.1 (-0.1, 0.3)	0.6 (0.1, 1.2)	0.0 (-0.00, 0.01)
MPA	0.1 (-0.1, 0.2)	1.3 (-1.8, 4.4)	0.3 (-0.816, 1.4)	0.1 (-0.3, 0.6)	0.8 (-0.9, 2.4)	0.01 (-0.01, 0.02)
VPA	-0.0 (-0.3, 0.2)	-0.7 (-6.4, 5.1)	-0.7 (-2.649, 1.4)	-0.2 (-1.0, 0.6)	-0.9 (-3.9, 2.2)	-0.01 (-0.03, 0.02)
Model 2 – Partition Model						
Sedentary time	-0.0 (-0.1, 0.0)	-0.4 (-1.2, 0.5)	-0.1 (-0.402, 0.2)	-0.0 (-0.2, 0.1)	-0.2 (-0.6, 0.3)	-0.00 (-0.0, 0.00)
LPA	0.0 (-0.1, 0.1)	0.6 (-1.0, 2.2)	0.2 (-0.372, 0.7)	0.1 (-0.1, 0.3)	0.5 (-0.3, 1.3)	0.00 (-0.01, 0.01)
MPA	0.1 (-0.2, 0.4)	0.9 (-5.7, 7.4)	0.5 (-1.840, 2.8)	0.1 (-0.8, 1.0)	0.7 (-2.7, 4.1)	0.01 (-0.01, 0.04)
VPA	-0.2 (-0.7, 0.2)	-3.6 (-12.9, -5.7)	-1.7 (-5.019, 1.5)	-0.6 (-1.9, 0.7)	-3.0 (-7.7, 1.8)	-0.03 (-0.06, 0.01)
Model 3 – Isotemporal Substitution Model						
Sedentary → LPA	-0.0 (-0.2, 0.1)	-1.0 (-2.7, 0.8)	-0.3 (-0.892, 0.3)	-0.1 (-0.4, 0.1)	-0.7 (-1.6, 0.2)	-0.00 (-0.01, 0.01)
Sedentary → MPA	-0.1 (-0.4, 0.2)	-1.2 (-7.6, 5.2)	-0.6 (-2.779, 1.7)	-0.2 (-1.0, 0.7)	-0.9 (-4.1, 2.4)	-0.01 (-0.04, 0.01)
Sedentary → VPA	0.2 (-0.2, 0.7)	3.3 (-6.1, 12.7)	1.7 (-1.601, 5.0)	0.6 (-0.7, 1.9)	2.8 (-2.0, 7.6)	0.03 (-0.01, 0.06)
LPA → Sedentary	0.0 (-0.1, 0.1)	1.0 (-0.8, 2.7)	0.3 (-0.334, 0.9)	0.1 (-0.1, 0.4)	0.7 (-0.2, 1.6)	0.00 (-0.01, 0.01)
LPA → MPA	-0.1 (-0.5, 0.3)	-0.2 (-7.9, 7.4)	-0.3 (-2.950, 2.4)	-0.0 (-1.1, 1.0)	-0.2 (-4.1, 3.8)	-0.01 (-0.04, 0.02)
LPA → VPA	0.2 (-0.2, 0.7)	4.3 (-4.5, 13.1)	2.0 (-1.118, 5.0)	0.7 (-0.5, 1.9)	3.5 (-1.0, 8.0)	0.03 (-0.01, 0.06)
MPA → Sedentary	0.1 (-0.2, 0.4)	1.2 (-5.2, 7.6)	0.3 (-2.395, 3.0)	0.2 (-0.7, 1.0)	0.9 (-2.4, 4.1)	0.01 (-0.01, 0.04)
MPA → LPA	0.1 (-0.3, 0.5)	0.2 (-7.4, 7.8)	0.3 (-7.426, 7.8)	0.0 (-1.0, 1.1)	0.2 (-3.8, 4.1)	0.01 (-0.02, 0.04)
MPA → VPA	0.4 (-0.4, 1.1)	4.5 (-10.4, 19.4)	2.2 (-2.962, 7.4)	0.7 (-1.3, 2.8)	3.6 (-4.0, 11.3)	0.04 (-0.02, 0.10)
VPA → Sedentary	-0.2 (-0.7, 0.2)	-3.3 (-12.7, 6.1)	-1.7 (-4.947, 1.6)	-0.6 (-1.9, 0.7)	-2.8 (-7.6, 2.0)	-0.03 (-0.06, 0.01)
VPA → LPA	-0.2 (-0.7, 0.2)	-4.3 (-13.1, 4.5)	-2.0 (-5.023, 1.1)	-0.7 (-1.9, 0.5)	-3.5 (-8.0, 1.0)	-0.03 (-0.06, 0.01)
VPA → MPA	-0.4 (-1.1, 0.4)	-4.5 (-19.4, 10.4)	-2.2 (-7.422, 3.0)	-0.7 (-2.8, 1.3)	-3.6 (-11.3, 4.0)	-0.04 (-0.10, 0.02)

Abbreviations: LPA, light intensity physical activity; MPA, moderate intensity physical activity; VPA, vigorous intensity physical activity; CI, confidence interval; cm, centimeter; BMI, body mass index; FMI, fat mass index.

Note: Models are per 15-min change

The arrow symbol (→) indicates “replaces”

Model covariates include: age, sex, ethnicity, and SES

Paper 3 Table 5. Associations and isothermal substitution of waking behaviors with cardiovascular health indicators in preschool children with overweight and obesity participating in the baseline assessment of the TX CORD Secondary Prevention Study (N = 131)

	Resting Systolic BP β (95% CI) (n=121)	Resting Diastolic BP β (95% CI) (n=121)	Resting Heart Rate (bpm) β (95% CI) (n=122)
Model 1 – Single Model			
Sedentary time	0.4 (-0.0, 0.7)	0.1 (-0.1, 0.4)	0.2 (-0.2, 0.6)
LPA	-0.3 (-0.9, 0.3)	-0.3 (-0.7, 0.2)	-0.2 (-0.9, 0.5)
MPA	-1.2 (-2.9, 0.5)	-1.0 (-2.3, 0.4)	-1.8 (-3.8, 0.3)
VPA	-2.8 (-5.0, -0.5)	-2.2 (-3.9, -0.4)	-2.5 (-5.3, 0.3)
Model 2 – Partition Model			
Sedentary time	0.4 (-0.1, 0.8)	0.1 (-0.2, 0.4)	0.1 (-0.4, 0.6)
LPA	-0.4 (-1.2, 0.4)	-0.4 (-1.0, 0.2)	0.1 (-0.9, 1.1)
MPA	2.7 (-0.7, 6.0)	1.9 (-0.8, 4.5)	-0.9 (-5.1, 3.4)
VPA	-4.7 (-8.3, -1.0)	-3.6 (-6.5, -0.7)	-1.6 (-6.2, 3.1)
Model 3 – Isothermal substitution			
Sedentary → LPA	0.7 (-0.1, 1.6)	0.6 (-0.1, 1.2)	0.0 (-1.0, 1.0)
Sedentary → MPA	-2.3 (-5.6, 0.9)	-1.8 (-4.3, 0.8)	1.0 (-3.2, 5.1)
Sedentary → VPA	5.0 (1.3, 8.7)	3.7 (0.8, 6.6)	1.7 (-3.1, 6.4)
LPA → Sedentary	-0.7 (-1.6, 0.1)	-0.6 (-1.2, 0.1)	-0.0 (-1.0, 1.0)
LPA → MPA	-3.1 (-6.9, 0.8)	-2.3 (-5.3, 0.8)	1.0 (-3.9, 5.9)
LPA → VPA	4.3 (0.9, 7.7)	3.2 (0.5, 5.9)	1.7 (-2.7, 5.9)
MPA → Sedentary	2.3 (-0.9, 5.6)	1.8 (-0.8, 4.3)	-1.0 (-5.1, 3.2)
MPA → LPA	3.1 (-0.8, 6.9)	2.3 (-0.8, 5.3)	-1.0 (-5.9, 3.9)
MPA → VPA	7.3 (0.7, 14.0)	5.5 (0.3, 10.7)	0.7 (-7.7, 9.0)
VPA → Sedentary	-5.0 (-8.7, -1.3)	-3.7 (-6.6, -0.8)	-1.7 (-6.4, 3.1)
VPA → LPA	-4.3 (-7.7, -0.9)	-3.2 (-5.9, -0.5)	-1.7 (-6.0, 2.7)
VPA → MPA	-7.3 (-13.9, -0.7)	-5.5 (-10.7, -0.3)	-0.7 (-9.5, 7.7)

Abbreviations: LPA, light intensity physical activity; MPA, moderate intensity physical activity; VPA, vigorous intensity physical activity; CI, confidence interval; BP, blood pressure

Note: Models are per 15-min change

The arrow symbol (→) indicates “replaces”

Model covariates include: age, sex, ethnicity, and SES

Paper 3 Table 6. Associations and isotemporal substitution of waking behaviors with health-related quality of life in preschool children with overweight and obesity participating in the baseline assessment of the TX CORD Secondary Prevention Study (N = 131)

	Overall HRQOL β (95% CI) (n=124)	Physical Functioning HRQOL β (95% CI) (n=124)
Model 1 – Single Model		
Sedentary time	0.2 (-0.3, 0.6)	0.8 (0.2, 1.3)
LPA	-0.2 (-0.9, 0.5)	-0.2 (-1.2, 0.7)
MPA	-0.2 (-2.2, 1.8)	-0.1 (-2.9, 2.6)
VPA	1.2 (-1.6, 4.0)	1.2 (-2.6, 5.1)
Model 2 – Partition Model		
Sedentary time	0.1 (-0.4, 0.6)	0.9 (0.2, 1.5)
LPA	0.1 (-0.9, 1.0)	0.1 (-1.1, 1.4)
MPA	-1.6 (-5.6, 2.4)	0.3 (-5.1, 5.7)
VPA	3.0 (-1.7, 7.7)	1.9 (-4.4, 8.2)
Model 3 – Isotemporal substitution		
Sedentary → LPA	0.1 (-1.0, 1.1)	0.7 (-0.6, 2.1)
Sedentary → MPA	1.7 (-2.2, 5.6)	0.6 (-4.7, 5.8)
Sedentary → VPA	-2.9 (-7.6, 1.9)	-1.1 (-7.4, 5.3)
LPA → Sedentary	-0.1 (-1.1, 1.0)	-0.7 (-2.1, 0.6)
LPA → MPA	1.7 (-3.0, 6.3)	-0.2 (-6.4, 6.0)
LPA → VPA	-2.9 (-7.3, 1.4)	-1.8 (-7.6, 4.1)
MPA → Sedentary	-1.7 (-5.6, 2.2)	-0.6 (-5.8, 4.7)
MPA → LPA	-1.7 (-6.3, 3.0)	0.2 (-6.0, 6.4)
MPA → VPA	-4.6 (-12.8, 3.6)	-1.6 (-12.6, 9.4)
VPA → Sedentary	2.9 (-1.9, 7.6)	1.1 (-5.3, 7.4)
VPA → LPA	2.9 (-1.4, 7.6)	1.8 (-4.1, 7.6)
VPA → MPA	4.6 (-3.6, 12.8)	1.6 (-9.4, 12.6)

Abbreviations: LPA, light intensity physical activity; MPA, moderate intensity physical activity; VPA, vigorous intensity physical activity; CI, confidence interval; HRQOL, health-related quality of life

Note: Models are per 15-min change

The arrow symbol (→) indicates “replaces”

Model covariates include: age, sex, ethnicity, and SES

Paper 3 Appendix Table 1. Associations and isothermal substitution of waking behaviors with adiposity health indicators in preschool children with overweight and obesity participating in the baseline assessment of the TX CORD Secondary Prevention Study (N = 131)

	BMI z-score β (95% CI) (n=131)	%BMI _{p95} β (95% CI) (n=131)	Fat mass (%) β (95% CI) (n=124)	FMI (kg/m ²) β (95% CI) (n=124)	Waist circumference (cm) β (95% CI) (n=129)	Waist to height ratio β (95% CI) (n=129)
Single Model						
Sedentary time	0.0 (-0.0, 0.0)	0.1 (-0.5, 0.6)	0.0 (-0.2, 0.3)	0.0 (-0.1, 0.1)	-0.0 (-0.3, 0.2)	0.001 (-0.002, 0.002)
LPA	0.1 (-0.0, 0.3)	0.0 (-0.9, 0.9)	0.0 (-0.3, 0.4)	0.0 (-0.1, 0.1)	0.2 (-0.2, 0.7)	0.001 (-0.003, 0.004)
MVPA	0.0 (-0.0, 0.1)	0.2 (-1.3, 1.8)	-0.2 (-0.8, 0.4)	-0.1 (-0.3, 0.2)	-0.2 (-1.0, 0.6)	-0.002 (-0.008, 0.004)
TPA	0.0 (-0.0, 0.0)	0.1 (-0.6, 0.7)	-0.0 (-0.3, 0.2)	-0.0 (-0.1, 0.1)	0.1 (-0.3, 0.4)	-0.001 (-0.003, 0.002)
Partition Model						
Model 1 - MVPA						
Sedentary time	0.0 (-0.0, 0.1)	0.1 (-0.5, 0.7)	0.0 (-0.2, 0.3)	0.0 (-0.3, 0.2)	-0.0 (-0.3, 0.3)	0.001 (-0.002, 0.002)
LPA	-0.0 (-0.1, 0.0)	0.0 (-1.0, 1.0)	0.1 (-0.3, 0.5)	-0.1 (-0.5, 0.3)	0.3 (-0.2, 0.8)	0.001 (-0.003, 0.005)
MVPA	0.1 (-0.0, 0.2)	0.3 (-1.4, 2.1)	-0.2 (-0.9, 0.5)	0.2 (-0.5, 0.9)	-0.5 (-1.4, 0.5)	-0.003 (-0.010, 0.004)
Model 2 - TPA						
Sedentary time	0.0 (-0.0, 0.1)	0.1 (-0.5, 0.7)	0.1 (-0.2, 0.3)	-0.1 (-0.3, 0.2)	-0.0 (-0.3, 0.3)	0.001 (-0.002, 0.003)
TPA	0.0 (-0.0, 0.1)	0.0 (-0.6, 0.8)	0.0 (-0.3, 0.3)	-0.0 (-0.3, 0.3)	0.1 (-0.3, 0.5)	-0.001 (-0.003, 0.003)
Isotemporal Substitution Model						
Model 1 - MVPA						
Sedentary → LPA	0.0 (-0.0, 0.1)	0.0 (-0.9, 1.1)	-0.1 (-0.5, 0.3)	0.1 (-0.3, 0.5)	-0.3 (-0.9, 0.2)	-0.001 (-0.005, 0.003)
Sedentary → MVPA	-0.1 (-0.2, 0.1)	-0.2 (-2.0, 1.5)	0.3 (-0.4, 1.0)	-0.3 (-1.0, 0.4)	0.4 (-0.5, 1.4)	0.003 (-0.004, 0.010)
LPA → Sedentary	-0.0 (-0.1, 0.0)	-0.1 (-1.1, 0.9)	0.1 (-0.3, 0.5)	-0.1 (-0.5, 0.3)	0.3 (-0.2, 0.8)	0.001 (-0.003, 0.005)
LPA → MVPA	-0.1 (-0.2, 0.0)	-0.3 (-2.6, 2.0)	0.3 (-0.6, 1.2)	-0.3 (-1.2, 0.6)	0.8 (-0.5, 2.0)	0.004 (-0.005, 0.013)
MVPA → Sedentary	0.1 (-0.1, 0.2)	0.2 (-1.5, 2.0)	-0.3 (-1.0, 0.4)	0.3 (-0.4, 1.0)	-0.4 (-1.4, 0.5)	-0.003 (-0.010, 0.004)
MVPA → LPA	0.1 (-0.0, 0.2)	0.3 (-2.0, 2.6)	-0.3 (-1.2, 0.6)	0.3 (-0.6, 1.2)	-0.8 (-2.0, 0.5)	-0.004 (-0.013, 0.005)
Model 2 - TPA						
Sedentary → TPA	0.0 (-0.0, 0.1)	-0.0 (-0.7, 0.7)	0.0 (-0.2, 0.3)	-0.0 (-0.3, 0.2)	-0.1 (-0.5, 0.3)	0.001 (-0.002, 0.003)
TPA → Sedentary	-0.0 (-0.1, 0.0)	0.0 (-0.7, 0.7)	-0.0 (-0.3, 0.2)	0.0 (-0.2, 0.3)	0.1 (-0.3, 0.5)	-0.001 (-0.003, 0.002)

Abbreviations: LPA, light intensity physical activity; MVPA, moderate to vigorous physical activity; TPA, total physical activity; CI, confidence interval; cm, centimeter;

Note: Partition and isotemporal substitution models are per 15-min change

The arrow symbol (→) indicates “replaces”

Model covariates include: age, sex, ethnicity, and SES

Paper 3 Appendix Table 2. Associations and isotemporal substitution of waking behaviors with cardiovascular health indicators in preschool children with overweight and obesity participating in the baseline assessment of the TX CORD Secondary Prevention Study (N = 131)

	Resting Systolic BP β (95% CI) (n=121)	Resting Diastolic BP β (95% CI) (n=121)	Resting Heart Rate (bpm) β (95% CI) (n=122)
Single Model			
Sedentary time	0.4 (-0.0, 0.7)	0.1 (-0.1, 0.4)	0.2 (-0.2, 0.6)
LPA	-0.3 (-0.9, 0.3)	-0.3 (-0.7, 0.2)	-0.2 (-0.9, 0.5)
MVPA	-1.0 (-2.1, 0.0)	-0.8 (-1.6, -0.0)	-1.2 (-2.5, 0.1)
TPA	-0.3 (-0.8, 0.1)	-0.3 (-0.6, 0.1)	-0.3 (-0.9, 0.2)
Partition Model			
Model 1 - MVPA			
Sedentary time	0.3 (-0.1, 0.7)	0.0 (-0.3, 0.4)	0.1 (-0.4, 0.6)
LPA	0.1 (-0.6, 0.7)	-0.1 (-0.6, 0.5)	0.1 (-0.7, 1.0)
MVPA	-0.8 (-2.0, 0.4)	-0.7 (-1.6, 0.2)	-1.2 (-2.7, 0.3)
Model 2 - TPA			
Sedentary time	0.3 (-0.1, 0.7)	0.1 (-0.3, 0.4)	0.1 (-0.4, 0.6)
TPA	-0.2 (-0.7, 0.3)	-0.3 (-0.6, 0.1)	-0.2 (-0.9, 1.6)
Isotemporal substitution			
Model 1 - MVPA			
Sedentary → LPA	0.2 (-0.5, 0.8)	0.1 (-0.4, 0.6)	-0.1 (-0.9, 0.8)
Sedentary → MVPA	1.1 (-0.1, 2.2)	0.8 (-0.1, 1.7)	1.3 (-0.1, 2.7)
LPA → Sedentary	-0.2 (-0.8, 0.5)	-0.1 (-0.6, 0.4)	0.1 (-0.8, 0.9)
LPA → MVPA	0.9 (-0.6, 2.4)	0.7 (-0.5, 1.9)	1.3 (-3.2, 0.6)
MVPA → Sedentary	-1.1 (-2.2, 0.1)	-0.8 (-1.7, 0.1)	-1.3 (-2.7, 0.1)
MVPA → LPA	-0.9 (-2.4, 0.6)	-0.7 (-1.9, 0.5)	-1.3 (-3.2, 0.6)
Model 2 - TPA			
Sedentary → TPA	0.5 (-0.0, 0.9)	0.3 (-0.1, 0.7)	0.4 (-0.2, 0.9)
TPA → Sedentary	-0.5 (-0.9, 0.0)	-0.3 (-0.7, 0.1)	-0.4 (-0.9, 0.2)

Abbreviations: LPA, light intensity physical activity; MVPA, moderate to vigorous physical activity; TPA, total physical activity (light + moderate + vigorous); CI, confidence interval; BP, blood pressure

Note: Models are per 15-min change

The arrow symbol (→) indicates “replaces”

Model covariates include: age, sex, ethnicity, and SES

Paper 3 Appendix Table 3. Associations and isotemporal substitution of waking behaviors with health-related quality of life in preschool children with overweight and obesity participating in the baseline assessment of the TX CORD Secondary Prevention Study (N = 131)

	Overall HRQOL β (95% CI) (n=124)	Physical Functioning HRQOL β (95% CI) (n=124)
Single Model		
Sedentary time	0.2 (-0.3, 0.6)	0.8 (0.2, 1.3)
LPA	-0.2 (-0.9, 0.5)	-0.2 (-1.2, 0.7)
MVPA	0.2 (-1.1, 1.4)	0.2 (-1.5, 1.9)
TPA	-0.1 (-0.6, 0.5)	-0.1 (-0.8, 0.6)
Partition Model		
Model 1 - MVPA		
Sedentary time	0.2 (-0.3, 0.7)	0.9 (0.3, 1.5)
LPA	-0.2 (-1.0, 0.6)	0.0 (-1.0, 1.1)
MVPA	0.5 (-0.9, 1.9)	1.0 (-0.9, 2.9)
Model 2 - TPA		
Sedentary time	0.2 (-0.3, 0.6)	0.9 (-0.2, 1.5)
TPA	0.0 (-0.6, 0.6)	0.3 (-0.4, 1.1)
Isotemporal substitution		
Model 1 - MVPA		
Sedentary → LPA	0.4 (-0.4, 1.2)	0.9 (-0.3, 2.0)
Sedentary → MVPA	-0.3 (-1.7, 1.1)	-0.2 (-2.0, 1.7)
LPA → Sedentary	-0.4 (-1.2, 0.4)	-0.9 (-2.0, 0.3)
LPA → MVPA	-0.7 (-2.6, 1.1)	-1.0 (-3.4, 1.4)
MVPA → Sedentary	0.3 (-1.1, 1.7)	0.2 (-1.7, 2.0)
MVPA → LPA	0.7 (-1.1, 2.6)	1.0 (-1.4, 3.4)
Model 2 - TPA		
Sedentary → TPA	0.2 (-0.4, 0.7)	0.5 (-0.3, 1.3)
TPA → Sedentary	-0.2 (-0.7, 0.4)	-0.5 (-1.3, 0.3)

Abbreviations: LPA, light intensity physical activity; MVPA, moderate to vigorous physical activity; TPA, total physical activity (light + moderate + vigorous); VM, vector magnitude; CI, confidence interval; HRQOL, health-related quality of life

Note: Models are per 15-min change

The arrow symbol (→) indicates “replaces”

Model covariates include: age, sex, ethnicity, and SES

CONCLUSION

This dissertation described patterns and examined correlates of waking activity patterns and the relation to health among a majority-minority sample of preschool youth, ages 2 to 5, with overweight and obesity participating in the TX CORD. Paper #1 examined sociodemographic and cultural correlates of waking activity patterns. Using device-based activity measurement, 75% of participants met the 60 minutes of daily MVPA, however there were clear sociodemographic and cultural factors that affect waking activity patterns and meeting physical activity guidelines. Specifically, being male, Non-Hispanic, speaking primarily English or English and another language equally, and living in a family with a higher income to poverty ratio were significantly associated with higher MVPA levels. Paper #2 of this dissertation then explored context-related factors that may influence activity patterns. As young children are reliant on caregivers, parents and teachers have a critical role in providing physical activity opportunities. Results of Paper #2 found that children are spending greater than 50% sedentary during all hours of waking periods with significant pattern differences, particularly in the early morning hours. These pattern differences were further explored by examining enrollment in school and/or child care. Preschool children attending school/ child care had significantly higher overall averaged daily light intensity activity, moderate intensity, vigorous intensity, total MVPA, and TPA estimates than children not enrolled in school/child care. Lastly, Paper #3 explored the relation between waking activity patterns and health. Using an isotemporal substitution modeling approach, and hypothetical time-replacement scenarios, Paper #3 found vigorous intensity physical activity to be the most beneficial intensity category for health. Substituting as little as 15 minutes a day with vigorous intensity activity was beneficial in lowering adiposity and

cardiovascular indicators. This association was particularly important for boys, as girls did not show a significant association with adiposity indicators.

PROGRAM RECOMMENDATIONS

The sociodemographic and cultural correlates found in waking activity cycles during this dissertation work have great implications for the design and development of interventions. Particularly, the primary caregiver's language and acculturation status need consideration when developing programming. Hispanic, Spanish-speaking preschoolers with overweight have been found to have the highest predicted obesity trajectory throughout childhood (Guerrero et al., 2016) and, within this sample, the lowest levels of physical activity. Health promotion interventions need to focus on teaching parents – particularly those with young girls – how to encourage physical activity behaviors. Programming needs to be mindful of ways to effectively address gender roles and norms for activity found within the Latinx community as Latinas may view sports and higher intensity activity as predominately for males (Evenson et al., 2002; Larsen, Pekmezi, Marquez, Benitez, & Marcus, 2013). For girls, dance-based exercises may be most effective for encouraging physical activity (Larsen et al., 2013). Further, to increase program effectiveness among diverse samples, take home materials and health messaging may need to be tailored for each language/ culture differently. For Latinx communities, a focus on family may be most important for encouraging physical activity (Evenson et al., 2002). Personalized, family-centered preschool obesity interventions have been found to be feasible and effective within low-income Latino families (Heerman et al., 2019).

Although a large number of obesity interventions have been conducted in child cares (Ling, Robbins, & Wen, 2016), assisting teachers to encourage activity during school hours

is still needed. This study found that preschool youth achieved a very low proportion of daily MVPA and total physical activity during school hours. Providing opportunities for physical activity has been identified as an area of need among child cares serving this community (Byrd-Williams et al., 2017). In 2019, Texas Senate Bill 952 was passed to align minimum standards for physical activity to standards published in *Caring for Our Children* (American Academy of Pediatrics, 2019), which require 90-120 minutes of indoor MVPA and 60-90 minutes of outdoor play. Environmental improvements to support indoor and outdoor play and providing professional development opportunities for teachers two or more times per year will be ways to encourage meeting these new guidelines (Byrd-Williams, Dooley, Thi, Browning, & Hoelscher, 2019).

This dissertation work can also help with effective health messaging. Tailored health messaging delivered by health practitioners has been found to be feasible and effective to creating behavior change (Wanyonyi, Themessl-Huber, Humphris, & Freeman, 2011) and encouraging physical activity (Brawley & Latimer, 2007; Latimer, Brawley, & Bassett, 2010). This study found the potential for a significant health impact for replacing just 15 minutes of activity behaviors with vigorous intensity activity. Even as little as 5 minutes of substitution was found in this study and previous studies to be beneficial for health (Leppänen et al., 2016). Framing health messages and materials to promote the many positive effects 5-15 minutes of vigorous intensity activity has on adiposity and cardiovascular health (gain-framed messaging) would be beneficial for future interventions. Further, framing activity change as 5-15 minutes per day can help make activity changes achievable rather than the more generic 180-minute guideline messaging. Finally, the use of clinicians to counsel and encourage physical activity for health benefits may increase program

effectiveness. The overall TX CORD Study found the primary care-centered intervention to have the same health effects on preschool-aged youth as the community-centered intervention (Butte et al., 2017). It may be that parents of preschoolers are more sensitive to health messaging delivered by primary care physicians than parents with older children. The findings from this dissertation suggest interventions should develop tailoring messaging based on language and sex of the child to increase program effectiveness. Additionally, more achievable and tailored health messaging may support physical activity promotion.

OVERALL STRENGTHS AND LIMITATIONS

Important strengths of this dissertation include use of an ethnically diverse, clinical sample, use of device-based measurements for physical activity and health, and the unique visualization of activity patterns per hour. Device-based measurements reduce the potential for biases, such as social desirability and recall biases, that limit self-reported measures. The unique visualization of the proportion of time and minutes per hour spent at each activity intensity stratified by sociodemographic and context-related correlates provided novel insight into differences in activity patterns per day. While this study population has a large projected population growth (Vespa et al., 2018), it has been underrepresented in research as most physical activity studies in preschool-aged youth have been conducted in normal weight, White youth.

The limitations to this dissertation should be noted. While this population is a priority population of the *Physical Activity Guidelines for Americans*, generalizability is limited to low-income, primarily Hispanic preschool youth with obesity. Additionally, this dissertation is limited to cross-sectional studies, and therefore the results are unable to determine causality or analyze how these relations change over time. While the isothermal substitution

modeling approach conducted in Paper #3 evaluates counterfactual time replacement scenarios, supporting the development of longitudinal observational studies would be the most advantageous in order to examine the relation between waking activity and health over important life-course transitions. While the use of device-based measurement of physical activity is a strength to this dissertation, devices do not allow for determining context-specific activity – a particular interest in Paper #2. Context-specific information, such as the settings in which activity is occurring, would have provided further understanding for intervention approaches. The use of devices plus domain specific questionnaires, global positioning systems (GPS), wearable cameras, or proximity tagging (Loveday, Sherar, Sanders, Sanderson, & Esliger, 2016) would have provided context-specific locations and reduced limitations of this dissertation. Additionally, the selection of wear time and cut points for classifying intensity categories may have led to unintentional bias. This dissertation work defined wear time equated to ≥ 10 hours of data on ≥ 3 days (≥ 2 weekdays, ≥ 1 weekend) and the Butte VM preschool cut points (2013) to estimate activity intensity (Butte et al., 2014). While the use of ≥ 10 hours of data on ≥ 3 days for wear time has been shown to meet the 0.7 reliability level needed (Hinkley, O'Connell, et al., 2012), more recent analyses suggest ≥ 6 hours of data on ≥ 3 day have been found to have acceptable reliability (Bingham et al., 2016). The use of ≥ 10 hours may have limited the sample size and ultimately, the power to detect associations within this dissertation. Although the selection of the Butte VM was done due to methodological advances and good sensitivity (Butte et al., 2014), the use of vector magnitude cut points (Butte VM) versus cut points developed using vertical axis (Pate) have resulted in 34% less sedentary time, 27% more light intensity physical activity, and 63% more MVPA among preschool-aged children (Leegeer-Aschmann

et al., 2019). This discrepancy in cut point classification may have led to limited results as the sample were determined to be fairly active. Finally, this dissertation was limited to waking activity patterns only. Although participants wore the activity devices for 24-hours per day, data analyses were limited to researcher-defined waking hours (06:00 – 23:00) as sleep algorithms (Cole-Kripke and Sadeh) have not been validated for use in preschool-aged children (Migueles et al., 2017). The use of parent-reported individual-level bedtimes would have been one way to incorporate sleep within this dissertation work, however the data were limited for returned activity logs within the overall TX CORD Study. While activity logs with sleep times were provided to participants, few logs were returned leading to a large amount of missing data and the necessity for default wake and sleep times.

RESEARCH IMPLICATIONS

This dissertation work provides a basis for understanding patterns and correlates of waking activity patterns among Hispanic preschoolers with overweight and obesity and supports the need for an ecological perspective to understand the individual, family, and context-related factors that influence activity and health. The conceptual model of this dissertation (p. 31) provides potential pathways and correlates of waking physical activity and health in preschool-aged children. However, there is the possibility that there are a multitude of factors that were not studied that may also affect these pathways. Future research should consider other levels of the Six-Cs developmental ecological model including community and environmental correlates. As school and home are the most important settings for this age, understanding if and how children react differently to stimuli in these settings may be one way to increase program effectiveness.

This unique sample and visualization has implications for future work. As significant differences in activity were found between sociodemographic, family, and context-level correlates, such as language, sex of the child, and school enrollment, future studies should consider these moderators, test for interactions when possible, and continue to explore the distinct differences in activity and how activity impacts health differently among these sub-populations. However, the ability to do this would require adequate sample size. This unique sample also addresses research needs set forth by the *Physical Activity Guidelines for Americans* Committee suggesting more research should focus on children and adolescents with elevated risk status based on adiposity, cardiometabolic health, and bone health. In this sample of preschool children with overweight and obesity, 13.2% had elevated or higher SBP and 26.5% of the sample had elevated or higher DBP. Future iterations of this dissertation work should examine the correlates and model health effects stratified by elevated cardiometabolic health risk status.

Finally, future studies examining activity patterns should use methodologies for examining all aspects of the 24-HAC (Rosenberger et al., 2019), which includes sleep. While sleep has many beneficial effects on health and development, sleep disorders among preschool-aged youth are more prevalent among racial and ethnic minorities (Smith, Hardy, Hale, & Gazmararian, 2019). The recent development of algorithms for wrist-worn devices to measure activity and sleep tracking or a combination of wrist- and waist-worn devices may be ways in which to accommodate collection of 24-HAC and examine how sleep, sedentary behavior, and physical activity interplay with health amongst minority youth. Future studies should consider replicating the analyses of this dissertation when using a combination of wrist- and waist-worn devices. However, with the challenge of accurately measuring 24-

HAC, consideration of how to promote utilization of activity logs is needed. Finally, the use of methodologies to examine associations between all movement behaviors, such as compositional analyses, or advanced analytics that use the raw output are still needed. Ultimately, funding of observational longitudinal study designs should be encouraged to examine the impact of these correlates on physical activity and health.

OVERALL CONCLUSIONS

The preschool-aged years are a critical time for brain and body development. With nearly 15% of U.S. preschoolers having obesity (Hales et al., 2018), focusing on ways to promote activity among this age group are paramount. Ultimately this dissertation was able to address important research needs set forth by the *Physical Activity Guidelines for Americans* Committee which recommends studies considering social, cultural, and biological factors and the modifying role of race/ethnicity in studies that examine the effects of physical activity on health outcomes. With Hispanic youth having the highest prevalence of obesity compared to other race/ethnic groups in the U.S. (Ogden et al., 2014) and a large projected population growth (Vespa et al., 2018), this dissertation work can help researchers, practitioners, and clinicians to develop tailored interventions for families, child cares, and schools to promote physical activity for healthy Latinx preschoolers.

APPENDICES

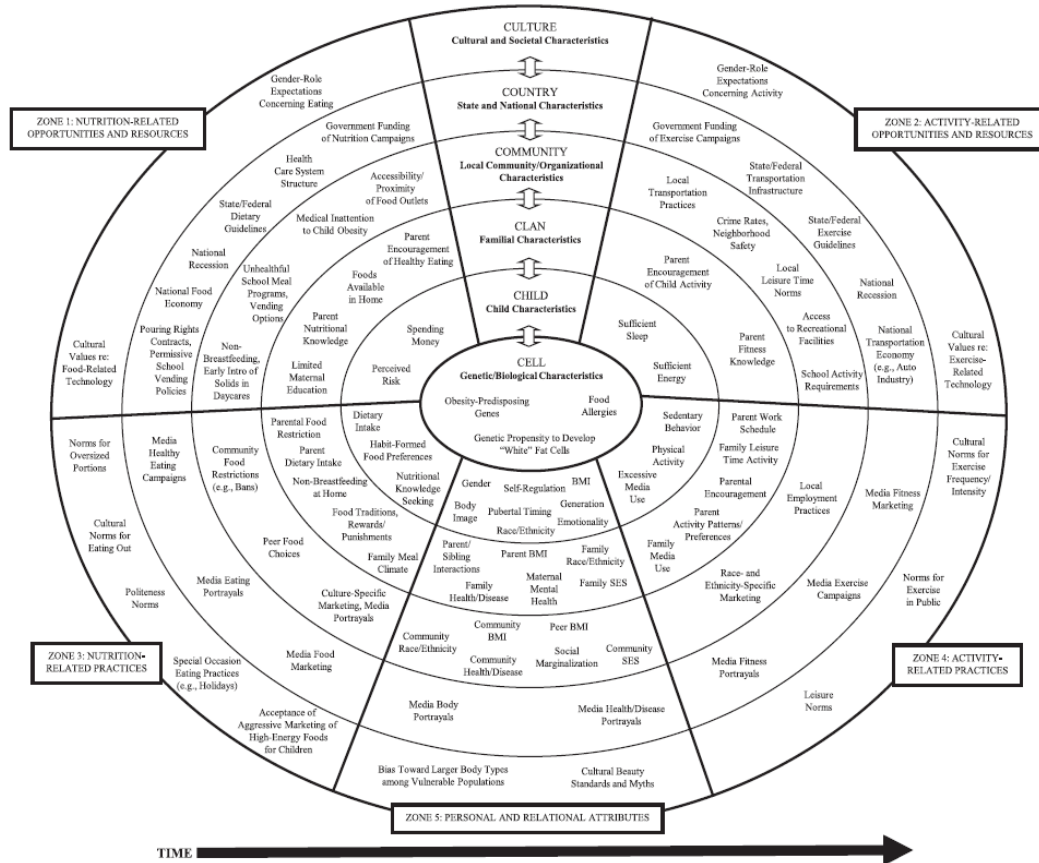
Appendix A: American Academy of Pediatrics Blood Pressure Table for Boys, ages 1-5

Age (y)	BP Percentile	SBP (mm Hg)							DBP (mm Hg)						
		Height Percentile or Measured Height							Height Percentile or Measured Height						
		5%	10%	25%	50%	75%	90%	95%	5%	10%	25%	50%	75%	90%	95%
1	Height (in)	30.4	30.8	31.6	32.4	33.3	34.1	34.6	30.4	30.8	31.6	32.4	33.3	34.1	34.6
	Height (cm)	77.2	78.3	80.2	82.4	84.6	86.7	87.9	77.2	78.3	80.2	82.4	84.6	86.7	87.9
	50th	85	85	86	86	87	88	88	40	40	40	41	41	42	42
	90th	98	99	99	100	100	101	101	52	52	53	53	54	54	54
	95th	102	102	103	103	104	105	105	54	54	55	55	56	57	57
	95th + 12 mm Hg	114	114	115	115	116	117	117	66	66	67	67	68	69	69
2	Height (in)	33.9	34.4	35.3	36.3	37.3	38.2	38.8	33.9	34.4	35.3	36.3	37.3	38.2	38.8
	Height (cm)	86.1	87.4	89.6	92.1	94.7	97.1	98.5	86.1	87.4	89.6	92.1	94.7	97.1	98.5
	50th	87	87	88	89	89	90	91	43	43	44	44	45	46	46
	90th	100	100	101	102	103	103	104	55	55	56	56	57	58	58
	95th	104	105	105	106	107	107	108	57	58	58	59	60	61	61
	95th + 12 mm Hg	116	117	117	118	119	119	120	69	70	70	71	72	73	73
3	Height (in)	36.4	37	37.9	39	40.1	41.1	41.7	36.4	37	37.9	39	40.1	41.1	41.7
	Height (cm)	92.5	93.9	96.3	99	101.8	104.3	105.8	92.5	93.9	96.3	99	101.8	104.3	105.8
	50th	88	89	89	90	91	92	92	45	46	46	47	48	49	49
	90th	101	102	102	103	104	105	105	58	58	59	59	60	61	61
	95th	106	106	107	107	108	109	109	60	61	61	62	63	64	64
	95th + 12 mm Hg	118	118	119	119	120	121	121	72	73	73	74	75	76	76
4	Height (in)	38.8	39.4	40.5	41.7	42.9	43.9	44.5	38.8	39.4	40.5	41.7	42.9	43.9	44.5
	Height (cm)	98.5	100.2	102.9	105.9	108.9	111.5	113.2	98.5	100.2	102.9	105.9	108.9	111.5	113.2
	50th	90	90	91	92	93	94	94	48	49	49	50	51	52	52
	90th	102	103	104	105	105	106	107	60	61	62	62	63	64	64
	95th	107	107	108	108	109	110	110	63	64	65	66	67	67	68
	95th + 12 mm Hg	119	119	120	120	121	122	122	75	76	77	78	79	79	80
5	Height (in)	41.1	41.8	43.0	44.3	45.5	46.7	47.4	41.1	41.8	43.0	44.3	45.5	46.7	47.4
	Height (cm)	104.4	106.2	109.1	112.4	115.7	118.6	120.3	104.4	106.2	109.1	112.4	115.7	118.6	120.3
	50th	91	92	93	94	95	96	96	51	51	52	53	54	55	55
	90th	103	104	105	106	107	108	108	63	64	65	65	66	67	67
	95th	107	108	109	109	110	111	112	66	67	68	69	70	70	71

Appendix B: American Academy of Pediatrics Blood Pressure Table for Girls, ages 1-5

Age (y)	BP Percentile	SBP (mm Hg)							DBP (mm Hg)						
		Height Percentile or Measured Height							Height Percentile or Measured Height						
		5%	10%	25%	50%	75%	90%	95%	5%	10%	25%	50%	75%	90%	95%
1	Height (in)	29.7	30.2	30.9	31.8	32.7	33.4	33.9	29.7	30.2	30.9	31.8	32.7	33.4	33.9
	Height (cm)	75.4	76.6	78.6	80.8	83	84.9	86.1	75.4	76.6	78.6	80.8	83	84.9	86.1
	50th	84	85	86	86	87	88	88	41	42	42	43	44	45	46
	90th	98	99	99	100	101	102	102	54	55	56	56	57	58	58
	95th	101	102	102	103	104	105	105	59	59	60	60	61	62	62
	95th + 12 mm Hg	113	114	114	115	116	117	117	71	71	72	72	73	74	74
2	Height (in)	33.4	34	34.9	35.9	36.9	37.8	38.4	33.4	34	34.9	35.9	36.9	37.8	38.4
	Height (cm)	84.9	86.3	88.6	91.1	93.7	96	97.4	84.9	86.3	88.6	91.1	93.7	96	97.4
	50th	87	87	88	89	90	91	91	45	46	47	48	49	50	51
	90th	101	101	102	103	104	105	106	58	58	59	60	61	62	62
	95th	104	105	106	106	107	108	109	62	63	63	64	65	66	66
	95th + 12 mm Hg	116	117	118	118	119	120	121	74	75	75	76	77	78	78
3	Height (in)	35.8	36.4	37.3	38.4	39.6	40.6	41.2	35.8	36.4	37.3	38.4	39.6	40.6	41.2
	Height (cm)	91	92.4	94.9	97.6	100.5	103.1	104.6	91	92.4	94.9	97.6	100.5	103.1	104.6
	50th	88	89	89	90	91	92	93	48	48	49	50	51	53	53
	90th	102	103	104	104	105	106	107	60	61	61	62	63	64	65
	95th	106	106	107	108	109	110	110	64	65	65	66	67	68	69
	95th + 12 mm Hg	118	118	119	120	121	122	122	76	77	77	78	79	80	81
4	Height (in)	38.3	38.9	39.9	41.1	42.4	43.5	44.2	38.3	38.9	39.9	41.1	42.4	43.5	44.2
	Height (cm)	97.2	98.8	101.4	104.5	107.6	110.5	112.2	97.2	98.8	101.4	104.5	107.6	110.5	112.2
	50th	89	90	91	92	93	94	94	50	51	51	53	54	55	55
	90th	103	104	105	106	107	108	108	62	63	64	65	66	67	67
	95th	107	108	109	109	110	111	112	66	67	68	69	70	70	71
	95th + 12 mm Hg	119	120	121	121	122	123	124	78	79	80	81	82	82	83
5	Height (in)	40.8	41.5	42.6	43.9	45.2	46.5	47.3	40.8	41.5	42.6	43.9	45.2	46.5	47.3
	Height (cm)	103.6	105.3	108.2	111.5	114.9	118.1	120	103.6	105.3	108.2	111.5	114.9	118.1	120
	50th	90	91	92	93	94	95	96	52	52	53	55	56	57	57
	90th	104	105	106	107	108	109	110	64	65	66	67	68	69	70
	95th	108	109	109	110	111	112	113	68	69	70	71	72	73	73
	95th + 12 mm Hg	120	121	121	122	123	124	125	80	81	82	83	84	85	85

Appendix C: The Six-Cs developmental ecological model of contributors to overweight and obesity in childhood



Harrison, K., Bost, K. K., McBride, B. A., Donovan, S. M., Grigsby-Toussaint, D. S., Kim, J., ... & Jacobsohn, G. C. (2011). Toward a developmental conceptualization of contributors to overweight and obesity in childhood: The Six-Cs model. *Child Development Perspectives*, 5(1), 50-58.

Appendix D: Common CORD Parent Secondary Prevention Survey



Common CORD Parent Secondary Prevention Survey - English

For office use only. Do not fill out.

Site:

Community: (Austin or Houston)

Cohort:

Wave:

Research Personnel ID:

Clinic (Select one):

<u>Austin:</u>	<u>Houston:</u>
<input type="radio"/> AK Black Health Center	<input type="radio"/> Gulfgate (AAMA)
<input type="radio"/> East Austin Clinic	<input type="radio"/> Cohan & Masharani
<input type="radio"/> North Central Health Center	<input type="radio"/> Cullen
<input type="radio"/> People's Community Clinic	<input type="radio"/> Fannin
<input type="radio"/> Rosewood-Zaragosa Health Center	<input type="radio"/> Gulfton
<input type="radio"/> Rundberg Health Center	
<input type="radio"/> Seton Topfer Community Health Center	

Family ID:

Relationship to the Child: ☐ Mother (biological-, adopted-, step-, or foster-mother)
☐ Father (biological-, adopted-, step-, or foster-father)
☐ Grandmother
☐ Grandfather
☐ Aunt
☐ Uncle

Date: / /
MM DD YYYY

Please proceed to the 2nd page.

45818

For office use only. Do not fill out.

Site:

Community: (Austin or Houston)

Cohort:

Wave:

Research Personnel ID:

Clinic (Select one): Austin:

☐ AK Black Health Center
☐ East Austin Clinic
☐ North Central Health Center
☐ People's Community Clinic
☐ Rosewood-Zaragoza Health Center
☐ Rundberg Health Center
☐ Seton Topfer Community Health Center

Houston:

☐ Gulfgate (AAMA)
☐ Cohan & Masharani
☐ Cullen
☐ Fannin
☐ Gulfton

Family ID:

Relationship to the Child: ☐ Mother (biological-, adopted-, step-, or foster-mother)
☐ Father (biological-, adopted-, step-, or foster-father)
☐ Grandmother
☐ Grandfather
☐ Aunt
☐ Uncle

Date: / /

MM DD YYYY

Please proceed to the 2nd page.

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