THESIS

SCHOOL-DAY PHYSICAL ACTIVITY IN ELEMENTARY SCHOOL CHILDREN: WHEN AND HOW MUCH?

Submitted by

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ABSTRACT

SCHOOL-DAY PHYSICAL ACTIVITY IN ELEMENTARY SCHOOL CHILDREN: WHEN AND HOW MUCH?

Childhood obesity prevalence has reached an all-time high across the United States. Despite the link between limited physical activity (PA) and increased risk of obesity, current data suggest that few children are meeting PA guidelines. The school day has been targeted for PA interventions; however, with the exception of physical education (PE) and recess, there is little information on when children engage in PA during the school day. Furthermore, few studies have reported school-day PA at epoch lengths (i.e., one-second) that are representative of children's sporadic movement patterns. **PURPOSE:** The purpose of this study was to examine temporal characteristics and inter-child variability of PA accumulation across the elementary school day in an effort to better inform PA intervention approaches. **METHODS:** Using a wrist-mounted GENEActiv accelerometer, we collected six days of accelerometry data from 133 children in first, third, and fifth grades who were participating in the Intervention of PhysicaL Activity in Youth (IPLAY) study. Acceleration data were collected at 75 Hz, filtered, and vector summed over a one-second interval. We then used calibration-derived intensity cutpoints to determine the amount of time spent in moderate-vigorous PA (MVPA). School-day MVPA was quantified during distinct CIs, which included the entire school day, class time, break time (i.e., AM recess, PM recess, and lunch/recess combined), and PE, to determine MVPA accumulation and inter-child variability in the time spent in MVPA. **RESULTS:** Children spent a mean of 30.3% (122 min.) of the entire school day, 27.9% (95 min.) of class time, 42.6% (17 min.) of PE, and 49.3% (18 min.) of break time engaged in MVPA. The maximum percentage of time spent in MVPA across each custom interval was 43.2% (176 min.), 41.7% (152 min.), 69.3% (34 min.), and 72.5% (33 min.) of the entire school day, class time, PE, and break time, respectively. Break time and PE demonstrated the greatest inter-child variability between the minimum and maximum percentage of time spent in MVPA. During the entire school day and class time, first and third graders spent a significantly greater percentage of time in MVPA than did fifth graders. During break time, boys spent a significantly greater percentage of time in MVPA than did girls. Surprisingly, no main effect of weight status was found. **CONCLUSION:** Our results suggest that elementary-aged children, regardless of weight status, are meeting/exceeding recommended amounts of school-day MVPA. Despite these findings, which may be due to the use of acceleration data summed over a very short one second interval, there is still room for increasing mean school-day MVPA, potentially by up to ~50 minutes per day.

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CHAPTER I

INTRODUCTION

Childhood obesity is a leading health concern of modern America, as it is associated with comorbidities including dyslipidemia, hypertension, hyperinsulinemia, sleep apnea, fatty liver disease, and psychological distress (Dietz, 1998). Furthermore, poor diet and physical inactivity, two underlying factors in obesity etiology, are leading causes of death across the United States, accounting for 15.2% of all US mortalities in the year 2000 (Mokdad, Marks, Stroup, & Gerberding, 2004). Because of the increasing prevalence of childhood obesity and its comorbidities, the current generation's children could be the first to live shorter lives than their parents (Olshansky et al., 2005).

Childhood obesity prevalence is on the rise, evidenced by a three-fold increase since 1980 (Ogden & Carroll, 2010). Among American children ages 2 to 19 years, 31.8% are classified as overweight (OW; at or above the 85th percentile for body-mass index (BMI)), and 16.9% are classified as OB (at or above the 95th percentile for BMI); in elementary school children ages 6 to 11 years, obesity prevalence is even higher, with 18% of youth classified as OB (Ogden, Carroll, Kit, & Flegal, 2012a&b). Factors surrounding childhood obesity etiology are central to modern obesity research. Although obesity is a multifactorial disorder comprising genetic, environmental, and behavioral factors, physical inactivity is one modifiable risk factor associated with obesity in childhood.

Several intrapersonal, social, and environmental shifts have led to a culture of reduced physical activity (PA) among children. Some of these shifts include reduced active transport, reduced school time devoted to recess and physical education (PE), reduced active play, and increased reliance on technology and sedentary activities (Fox, 2003). Several studies report a correlation between low levels of PA and childhood obesity (Maffeis, 2000; Molnár & Livingstone, 2000). Notably, OB youth have been shown to spend 16 fewer minutes per day engaged in moderate to vigorous PA (MVPA) compared to normal weight (NW) children (Belcher et al., 2010). Other studies have found a negative dose-response relationship between PA and OW/OB, and still others have shown that aerobic-based PA interventions are effective in decreasing BMI, total fat, and/or abdominal fat in youth (Janssen & LeBlanc, 2010).

Because of the correlation between PA and health, much childhood obesity research focuses on proposing appropriate daily PA guidelines for children as well as developing interventions to increase the number of children meeting proposed recommendations. Current recommendations state that children should engage in a minimum of 60 minutes of daily MVPA (CDC, 2011; Strong et al., 2005). Although it is now widely recognized that more physically active youth maintain healthier weight status and better overall health (Janssen & LeBlanc, 2010), children's activity levels continue to remain below the number of recommended daily minutes. Specifically, only 42% of children ages 6 to 11 years old actually accumulate 60 minutes of daily MVPA (Troiano et al., 2008). Although individual and social factors are implicated in PA participation during childhood, the child's environment, notably the school environment, plays a crucial role in PA participation.

Across the United States, 97% of children ages 5 to 17 years attend school outside of the home (Snyder & Dillow, 2011), and the average child spends about 1300 hours, or 57% of his/her daily waking time, in school during each school year (Anthamatten et al., 2011; Guinhouya et al., 2009). Furthermore, 62% of children ages 9 to 13 years indicate that they do not participate in any organized PA outside of school, and 23% do not participate in any free-time PA (Tudor-Locke, Lee, Morgan, Beighle, & Pangrazi, 2006), signifying the school day as a critical period of PA accumulation. In an attempt to increase children's time spent in PA, school-based interventions focusing on both break time (i.e., recess) and class time have been introduced. Such interventions are capable of increasing school-day PA though curricular and environmental modifications (Brink et al., 2010; Gibson et al., 2008; Pate et al., 2006; Sallis et al., 1997); however, little information on when and how much PA actually occurs across the school day exists to guide these interventions.

Notably, we do not yet have sufficient guidelines surrounding how much PA should be accumulated during specific times of the school day. Although several groups have proposed PA goals for the whole school day as well as its comprising parts (i.e., class time, recess, and PE), little evidence exists to guide the specific amount of school-day PA that is realistically achievable or the best times of the school day for interventions to target. Suggested goals for school-day MVPA have ranged from 20-30 minutes daily (Rush et al., 2012; Nettlefold et al., 2011). Furthermore, it has been proposed that 50% of PE and 40% of recess time be spent in MVPA, respectively (Nettlefold et al., 2011). Guidelines have also been presented for PA achieved during class time; one class time intervention proposed that 90 weekly minutes of MVPA be accumulated during class time alone (Gibson et al., 2008).

Not only is it important to consider that strong evidence for current school-day PA guidelines is lacking, but it is also important to note that such guidelines have been based off of sustained movement patterns that are similar to PA patterns in adults. As the field of PA monitoring in children has become increasingly well-informed, evidence now exists to suggest that children accumulate PA differently than do adults. Specifically, children tend to participate in short, intermittent bouts of MVPA rather than the sustained patterns characteristic of adult PA. Because of this knowledge, the activity monitoring field is moving toward short (i.e., one-second) measurement periods, called epochs, when quantifying PA in children (e.g., Baquet, Stratton, Van Praagh, & Berthoin, 2007; Ekelund, Tomkinson, & Armstrong, 2011). Second-by-second PA measurement, however, is a relatively new practice and, consequently, many of our previous estimates of children's PA accumulation do not reflect such high-resolution monitoring. Accordingly, school-day PA guidelines do not yet reflect data collected at one-second epochs. Because PA accumulation in children has been shown to increase with measurement at shorter epochs (Reilly et al., 2008), it is likely that school-day PA guidelines that reflect measurement at longer epochs are underestimating the true accumulation of and potential for PA across the school day.

Additionally, proposed school-day goals have been presented with little consideration of their plausibility. Without knowing how much activity is currently taking place and when it is taking place across the school day, we do not have a baseline from which we can develop PA interventions. While Nettlefold and colleagues (2011) indicate that greater than 90% of boys and girls meet the 30 minute school day guideline when measured at a 15-second epoch, fewer than 40% of students meet the guidelines for recess and PE when measured through direct observation (Gibson et al., 2008). Based on the low percentage of children meeting proposed guidelines when measured through longer epochs and observational methods, it is crucial to more closely examine PA during the school day and to consider PA accumulation patterns when measured through a one-second epoch.

It is also critical to consider the range of activity between the most and least active children. Without knowing the minimum and maximum PA accumulations across the school day, we have little information on the inter-child variability of PA accumulation. Children demonstrate variability in the amounts of school-day PA they accumulate as well as the times of the day during which they are most active. To gather a complete picture of school-day PA accumulation, it is not only necessary to examine how much school-day PA children accumulate, but also the time periods during which PA occurs. Specifically, we must determine times of the school day when children are the most and least active. In addition, individual differences in PA accumulation during such time periods must also be examined to discern factors potentially implicated in physical inactivity. Insight into children's individual differences in meeting PA goals will help to better tailor PA interventions toward low-PA achievers during specific times of the school day.

Few studies have examined such temporal patterns of PA within the school day. Typical elementary school schedules allot time for classroom lessons, school breaks (i.e., recess), PE, and transition time between classes/breaks. While certain times of the school day are thought to be largely sedentary, thus serving as barriers to PA (i.e., classroom lessons), other times of the day provide movement opportunities that contribute to children's overall daily PA. Studies that have explored temporality of school-day PA have mainly focused on PA during school breaks rather than during class time and PE. Additionally, many of these previous studies have not employed objective PA measurement (e.g., accelerometry) in their efforts. Further insight surrounding the temporality of objectively measured PA during school breaks and non-break periods will provide more information on PA accumulation during the entire school day.

Statement of Problem

This study aims to examine the temporal characteristics and variability of school-day PA through multi-day, free-living accelerometry data from both NW and OW/OB elementary school children. Exploring these factors will allow us to gather an idea of the mean, greatest, and least amounts of PA currently achieved across the school day and during discrete periods of the school day (i.e., class time, break time, and PE). Secondly, exploring variability in school-day PA accumulation across children will allow us to categorize children as either low- or high-PA achievers in relation to their peers and to gather an idea of the characteristics that are common among low- vs. high-PA achievers. Lastly, based on findings from the above aims, we will attempt to provide recommendations for realistic school-day PA goals and suggestions to increase school-day PA in low-physically active children. Such queries surrounding school-day PA temporality and variability will help to develop and support realistic school-day PA guidelines as well as indicate the most appropriate periods of the school day to implement interventions.

Hypotheses

It is hypothesized that school-day PA accumulation will differ by sex, grade, and weight status, such that boys, younger children, and NW children will accumulate significantly greater school-day PA than will girls, older children, and OW/OB children. Secondly, it is hypothesized that temporal characteristics of school-day PA will be identified, such that significant differences in PA accumulation will occur between different times of the school day. Specifically, greatest PA accumulation will occur during school break times, and least PA accumulation will occur during class time (non-PE). Furthermore, it is anticipated that the greatest variability in PA accumulation between children achieving the most and least amounts of school-day PA will occur during school break times, such that high-PA achievers will accumulate significantly greater PA during school breaks than will low-PA achievers.

Delimitations, Limitations, and Assumptions

This study is delimited to first, third, and fifth grade children within the Denver public school system. Seventy-two classrooms from 24 schools within the school district have been previously randomly selected to participate as part of a multi-institutional National Institutes of Health funded intervention. For the present study, a subset of nine classes of control children (one first, third, and fifth grade class from each of three schools) was used for data analysis. The inherent limitation of this study is the use of accelerometers (ACCs) for PA measurement. Although ACCs have been validated as accurate and reliable instruments for PA measurement (Plasqui & Westerterp, 2007), no one tool can capture the idiosyncrasies of children's activity. It is assumed that each participating child will follow instructions for wear and use of the ACC across all study days. It is also assumed that PA measures reported through accelerometry within the six-day sampling period are representative of elementary school children's habitual school-day PA.

CHAPTER II

LITERATURE REVIEW

With childhood obesity affecting 16.9% of American children and adolescents (Ogden et al., 2012a&b), efforts must be taken to reduce the incidence and prevalence of this multifactorial disorder. Obesity etiology is complicated, and causal factors include genetic, behavioral, and environmental components (Hill, 2006). While genetic factors of obesity cannot be easily regulated, behavioral and environmental factors can be modified to reduce obesogenic lifestyles. Specifically, increasing PA is one strategy against childhood obesity. The school environment has been targeted as a focus for PA interventions; however, few studies have examined the temporal aspects of school-day PA. Notably, it is crucial to determine the school periods in which PA occurs at high vs. low quantities and to explore individual differences in PA accumulation during these periods. Furthermore, temporal data will provide reasonable estimates of PA potentials during specific times of the school day, rather than estimates of school-day PA as a whole. Together, this information will serve as the basis for intervention guidelines. This review will begin with an overview of childhood obesity. It will then discuss physical inactivity as a correlate of childhood obesity and the implementation of accelerometry to measure PA behavior. Finally, it will highlight PA in the school environment, ending with a review of current studies assessing the temporal aspect of PA across the school day.

Childhood Obesity Overview

Classification and Prevalence

Child weight status is commonly classified through a BMI percentile chart. This chart graphs a child's calculated BMI (weight in kg/height in meters^2) against his/her current age. The plotted point is then compared to gender-specific norms from a reference population to obtain a percentile score. Cutoff percentile scores have been created to classify children as NW, OW, or OB. While weight status cutoffs for adults are based on increased health risks associated with a certain BMI, cutoffs for children are based on statistical rather than clinical measures (Flegal & Ogden, 2011). Consequently, definitions of these weight classifications and cutoffs for each classification differ across research groups and clinical settings. However, generally accepted definitions of these terms classify children below the 85th percentile for height and weight as NW, children at or above the 85th percentile, but below the 95th percentile as OW, and children at or above the 95th percentile as OB (Barlow, 2007). For the purpose of this paper, the aforementioned cutoffs will be accepted as conventional classifiers.

Childhood obesity prevalence has tripled over the last 30 years (Ogden & Carroll, 2010). In the United States, 31.8% of children and adolescents ages 2 to 19 years are currently at or above the 85th percentile for BMI, and 16.9% are at or above the 95th percentile (Ogden et al., 2012a&b). Alarmingly, 12.3% not only meet the cutoff for obesity, but they lie at or above the 97th percentile for BMI. Among elementary school children ages 6 to 11 years, obesity prevalence is even higher, with 18% classified as OB.

Although childhood obesity is a serious concern across all children, minority children may be at particular risk for excess body fat. Obesity prevalence is significantly greater in Mexican-American boys and non-Hispanic black girls compared to white, non-Hispanic boys and girls, respectively (Ogden & Carroll, 2010). Within the Hispanic and non-Hispanic black populations, obesity prevalence reaches 21.2% and 24.3%, respectively, for children and adolescents ages 2-19 years (Ogden et al., 2012a). Compared to the reference value of 14% among non-Hispanic white children and adolescents, obesity prevalence is 1.5 and 1.7 times greater in Hispanics and non-Hispanic blacks, respectively. These data suggest that obesity intervention efforts may need to specifically or separately target minority populations.

Comorbidities

Childhood obesity is associated with numerous physical comorbidities including, but not limited to, dyslipidemia, hypertension, hyperinsulinemia, sleep apnea, and fatty liver disease (Dietz, 1998). Specifically, OB children are 2.4 times more likely to have hypercholesterolemia, 7.1 times more likely to have high triglycerides, and 12.6 times more likely to have hyperinsulinemia than are NW children (Freedman, Dietz, Srinivasan, & Berenson, 1999). In addition, 70% of OW children ages 11 to 17 years express at least one risk factor for cardiovascular disease (CVD), and 39% express two or more risk factors (Freedman, Mei, Srinivasan, Berenson, & Dietz, 2007). Not only do OB children exhibit medical comorbidities of OW/OB, but they also demonstrate psychological distress. Discrimination against OB children is evident among children as young as 6 to 10 years old; children as young as six years indicate that they would prefer to have a severely handicapped friend than an OB friend (Dietz, 1998).

Importantly, obesity has been shown to track from childhood into adulthood. Individuals who are OB in childhood or adolescence are significantly more likely to become obese adults. In their prospective cohort study tracking body weight and body fat of 932 children into adulthood, Wright, Parker, Lamont, & Craft (2001) found a significant, positive correlation between BMI at age 9 and BMI at age 50. When stratifying children by BMI percentiles, they found that children above the 90th percentile for weight and height at ages 9 or 13 years were five to nine times more likely to be OB at age 50 than those in the bottom 25th percentile for height and weight. A 2008 obesity review of 25 publications drew similar findings, indicating that the risk of OW/OB children becoming OW/OB adults is twice as high as the risk for NW children (Singh, Mulder, Twisk, vanMechelen, & Chinapaw, 2008). Above all, these observations bolster the importance of interventions to reduce obesity prevalence early in life.

Etiology

Childhood obesity is a complex disorder, and many behavioral and genetic factors have been implicated in its causal chain. Physical inactivity is one such factor (Maffeis, 2000; Molnár & Livingstone, 2000). Reduced PA and increased sedentary behavior (SED) decrease an individual's energy expenditure. Using the simplified model of energy balance, which proposes that energy consumed should equal energy expended, reduced energy expenditure without an equal reduction in energy intake precipitates positive energy balance. When positive energy balance is sustained over time, it ultimately leads to weight gain and, in the long term, obesity. Several intrapersonal as well as environmental shifts have led to a culture of reduced physical activity among children. Some of these shifts include reduced active transport, reduced school time devoted to recess and PE, reduced active play, and increased reliance on technology and sedentary activities (Fox, 2003).

Several studies have noted the relationship between PA and body weight in youth. In their systematic review of 31 observational studies surrounding PA and OW/OB, Janssen and LeBlanc (2010) found a significant negative relationship between PA and OW/OB; furthermore, a dose-response relationship was observed, such that greater amounts of PA were associated with lower OW/OB. In addition, of 24 PA-focused intervention studies reviewed, 50% showed significant decreases in BMI, total fat, and/or abdominal fat after an aerobic activity intervention within the pediatric population (Janssen & LeBlanc, 2010). Physical activity in childhood has also been shown to longitudinally correlate with fat mass in adolescence. Riddoch and colleagues (2009) found that a 15-minute increase in PA at age 12 was associated with a significantly lower fat mass at age 14 in both boys and girls (Riddoch et al., 2009).

While physical inactivity is not the only risk factor for OW/OB, it is a modifiable risk factor that is associated with increased body weight and body fat. In contrast, habitual aerobic exercise is linked with lipid improvement, blood pressure reduction, Metabolic Syndrome reduction, obesity reduction, and increased bone health in children (Janssen & LeBlanc, 2010). Based on the positive associations between PA and health, current PA recommendations suggest that children partake in a minimum of 60 minutes of MVPA daily (Barlow, 2007; Janssen & LeBlanc, 2010). However, only 42% of children ages 6 to 11 years currently meet this recommended goal (Troiano et al., 2008).

Physical Inactivity in Childhood

Despite the link between PA, weight status, and overall health in childhood, children's activity levels continue to remain below the number of recommended daily minutes. In children 4 to 11 years old, 37.3% demonstrate low levels of PA, meaning that they engage in sweat-inducing PA fewer than seven days per week; furthermore, 65% of children engage in high levels of SED, classified as two or more hours of screen-time per day (Anderson, Economos, & Must, 2008). In 2002, 62% of children ages 9 to 13 years indicated that they did not participate in any organized PA outside of school, and 23% did not participate in any free-time PA (USDHHS, 2010). Markedly, the disconnect between recommended and achieved daily minutes of MVPA is greater among OW/OB children than among NW children.

Child Weight Status and Physical Inactivity

Several studies have found that OB children spend significantly less time in MVPA than do their NW counterparts (Soric & Misigoj-Durakovic, 2010; Trost, Kerr, Ward, & Pate, 2001). Specifically, OB youth have been shown to spend as much as 16 fewer minutes per day engaged in MVPA compared to NW children (Belcher et al., 2010). Additionally, cross-sectional studies of OB vs. non-OB elementary school children have shown that SED is greater in OB children than in NW children (Hughes, Henderson, Ortiz-Rodrigues, Artinou, & Reilly, 2006; Papandreou, Malindretos, & Pousso, 2010). Thus, not only do OB children spend less time in MVPA than do NW children, but they also spend more time engaged in SED, further decreasing energy expenditure.

OW/OB children have been shown to demonstrate less active personalities compared to NW children, potentially mediating their increased time spent in SED (Deforche, De Bourdeaudhuij, D'hondt, & Cardon, 2009). Specifically, OW/OB children express lower levels of PA self-efficacy than do NW children, suggesting that attempts to improve attitudes and self-efficacy surrounding PA in OW/OB children might decrease SED and increase PA levels. Regardless of the directionality between inactivity and childhood obesity (i.e., are children OW/OB because they are inactive or are children inactive because they are OW/OB?), these findings indicate that PA interventions must be sensitive to differences in PA accumulation by weight status.

Child Sex and Physical Inactivity

Sex differences in PA have also been observed, indicating that boys accumulate significantly greater whole-day PA than do girls (Cox, Schofield, Greasley, & Kolt, 2006; Mota et al., 2005; Nettlefold et al., 2011, Olds et al., 2009; Tudor-Locke, Lee, Morgan, Beighle, & Pangrazi, 2006). Furthermore, while girls accumulate significantly fewer minutes of MVPA than do age-matched boys, they replace this MVPA with SED rather than light PA (LPA) (Nettlefold et al., 2011; Ridgers, Saint-Maurice, Welk, Siahpush, & Huberty, 2011). Thus, displacement of MVPA and LPA with SED leads to decreases in whole-day PA and increases in SED among girls compared to boys.

In addition, differences between boys and girls have been found for specific correlates of SED. Sedentary time in boys is positively correlated with television and video games in the home and negatively correlated with PA equipment in the home; in contrast, girls' SED is positively correlated with BMI and athletic coordination (Byun, Dowda, & Pate, 2011). Additionally, certain aspects of depression (i.e., interpersonal problems and feelings of ineffectiveness) have been shown to correlate with high levels of SED behavior in children (Anton et al., 2006). Once again, regardless of the specific correlates of physical inactivity between boys and girls, sex differences in physical inactivity must be carefully considered and addressed in PA interventions (Belcher et al., 2010).

Accelerometry for Physical Activity Measurement

Accelerometer Function and Validity

Several methods of PA measurement exist, including self-report, direct observation, pedometers, and ACCs. Body-worn ACCs are validated instruments that allow for measurement of various levels of PA and have been shown to correlate with doubly labeled water studies in determining energy expenditure (Plasqui & Westerterp, 2007). Because ACCs provide an objective measurement of the frequency, intensity, and duration of PA, accelerometry is the current best-practice of free-living PA measurement in children.

The majority of ACCs comprise a seismic mass and a piezoelectric element. The seismic mass detects acceleration units (g; 1g=9.8 m/s^2) in one (uniaxial), two (biaxial), or three (triaxial) planes (Chen & Bassett, 2005). This acceleration causes a conformational change on the piezoelectric element, either through bending (i.e., cantilever beam sensor ACCs) or through direct compression of the element (i.e., integrated chip (IC) sensors) (Chen & Bassett, 2005). In response to this conformational change, a build-up of positive or negative charge occurs on one side of the piezoelectric element, which generates a voltage signal that is directly proportional to the acceleration (Chen & Bassett, 2005). These voltage signals are stored over a user-determined measurement period, or epoch (Chen & Bassett, 2005).

The GENEActive ACC (Activinsights Limited, Cambridge, UK) is one device that collects raw (i.e., not processed) acceleration data. The GENEActiv is a triaxial ACC, meaning that it collects acceleration data in three orthogonal directions (x, y, and z). Prior to ACC wear-time, sampling frequency, which must be at least twice the frequency of typical human movement (Chen & Bassett, 2005), is specified. Typical sampling frequencies for the GENEActiv ACC are between 10 and 80 Hz (Esliger et al., 2011). During ACC wear-time, directional accelerations are detected by the seismic mass, transferred to the piezoelectric element, and then stored. To remove gravitational acceleration and to account for detected accelerations that are not physiologically possible for human movement (e.g., aging of the piezoelectric element, temperature-related sensor drifts, electric noise, movement of the monitor relative to the skin), acceleration data are band-pass filtered (Chen & Bassett, 2005). Filtered acceleration magnitudes are then squared and summed over a user-determined epoch (e.g. one second) and the square root of the resultant value, divided by the sampling frequency, is calculated and stored as the signal vector magnitude (SVM). By applying acceleration magnitude cutpoints determined through calibration studies (later discussed in detail), minutes of SED, LPA, MPA, and VPA can be calculated from the SVM values.

Epoch Length

During ACC wear-time, acceleration magnitudes are collected at a specific sampling frequency (10-100 Hz) and can be processed to output data at a user-determined epoch (period of measurement). The epoch is a summary of the accelerations representing movement for a certain period of time (e.g., 2 second epoch, 15 second epoch, 30 second epoch, etc.). Thus, accelerometry output is typically quantified as acceleration values per epoch, per second, or per minute (Baquet et al., 2007). Because children tend to participate in short bouts of movement, with the majority of bouts lasting between 3 and 22 seconds, it has been suggested that shorter epochs (e.g., 1 to 15 seconds) be used in a pediatric population to ensure that sporadic bouts of MVPA are captured (Baquet et al, 2007; Ekelund et al., 2011).

In a study of 6- to 10-year-old boys and girls, the median duration of LPA and moderate PA (MPA) was six seconds, while the median duration of vigorous PA (VPA) was three seconds; 95% of VPA occurred in bursts shorter than 15 seconds (Bailey et al., 1995). These findings indicate that longer epochs could underestimate children's MPA and VPA by diluting short bouts of intense activity across a long epoch. Consequently, epoch lengths of 10 seconds or less are preferred in child populations (Rowlands, Pilgrim, & Eston, 2008). Furthermore, because children's PA varies from day to day, a sampling period of three to seven days is recommended to accurately capture PA; three days of accelerometry measurement predicts 68% of habitual PA and 73% of SED, while the best-practice, seven-day measurement demonstrates 85% reliability (Baquet et al., 2007). However, in first through sixth graders, a four to five day sampling period has demonstrated 80% reliability in a large study of elementary-aged children, suggesting that younger children's PA is fairly consistent across days (Trost, Pate, Freedson, Sallis, & Taylor, 2000).

Because self-report data are often inaccurate and difficult to collect in a child population, and because pedometer data are limited to strict counts of PA rather than frequency, intensity, and duration of movement, accelerometry can provide significantly more detailed and objective information compared to other currently available measures of free-living PA (Troiano et al., 2008; McClain & Tudor-Locke, 2009). From raw, triaxial acceleration data, it is possible to calculate SVM values that, by applying acceleration cutpoints determined through calibration studies, are indicative of the duration and intensity of PA.

Accelerometer Calibration

Accelerometer calibration studies of children varying in age from 3 to 12 years have been used to develop validated cutpoints for PA intensity classification using various ACC devices. Because a variety of ACC makes and models are used in PA measurement, each ACC device must go through a calibration before ACC data can be translated into minutes of activity at various intensities. Such calibrations allow ACC data generated during ACC wear-time to be associated with specific exercise intensities (i.e., SED, LPA, MPA, VPA); from this information, minutes spent in PA of different levels can then be calculated.

Child ACC calibration studies simultaneously collect metabolic rate, typically using a portable metabolic gas analyzer, and accelerometry data while children engage in a variety of age-appropriate laboratory tasks that are representative of typical daily activities (e.g., sitting quietly, coloring, playing video games, walking, jogging). Metabolic Equivalent (MET) values, which provide an indication of activity intensity, are then calculated for each activity by dividing each subject's measured oxygen consumption (VO_2) during each activity by his/her measured or predicted resting VO_2. From the MET values and corresponding ACC output, linear regression or a receiver operating characteristic (ROC) curve is then generated to determine the appropriate ACC cutpoints that correspond with SED, LPA, MPA, and VPA.

Across adult populations, the following MET values are typically associated with the corresponding intensities: SED (<1.5 METs), LPA (1.5-2.99 METs), MPA (3.0-5.99 METs), and VPA (≥6 METs). In the child population, however, there is current debate on the appropriate MET thresholds for MPA and VPA. While some groups use a 3MET and 6MET threshold for MPA and VPA (e.g., Baquet et al., 2007), other groups suggest a 4MET and 7MET threshold to account for a higher resting VO_2 among children compared to adults (e.g., Troiano et al., 2008; Trost et al., 2002). However, studies that measure or predict resting VO_2 values in children rather than using the 3.5 mL/kg/min value suggested for adults account for this difference. Because we estimated each child's predicted VO_2 based on age-, sex-, height-, and weight-specific equations, this paper will report results based on the 3MET and 6MET criteria for MPA and VPA, respectively.

A previous calibration study using the GENEActiv ACC in children resulted in the following ACC cutpoints for data collected at a one-second epoch: 0.190, 0.314, and 0.998 g-s for SED, MPA, and VPA, respectively (Schaefer, Hill, Nigg, Brink, & Browning, in review); the LPA cutpoint is defined by the boundaries of SED and MPA. Once ACC data have been collected, and SVM values have been determined for each epoch across the measurement period, these cutpoints can be applied to determine the amount of time spent in SED, LPA, MPA, and VPA. Such data provide a validated indication of children's activity levels and also serve as a comparison of PA levels across children.

Physical Activity in the Elementary School Setting

Across the United States, 97% of children ages 5 to 17 years attend school outside of the home (Snyder & Dillow, 2011). The average child spends about 1300 hours in school each year (Anthamatten et al., 2011). When considering a 180-day school year and a five-day school week, this amounts to over seven hours a day devoted to school time. Although upwards of 50% of children's daily PA occurs during the school day (Cox et al., 2006), many children still fail to meet school-day PA guidelines.

Role of the Built Environment

A child's environment plays a crucial role in PA adherence. Participation in habitual PA is correlated with individual, demographic, social, and environmental factors; several environmental factors include proximity to safe locations that promote PA, accessibility of PA equipment, and cost of PA (USDHHS, 2010). Through construction of free, safe environments that provide proper equipment to promote PA, communities can reduce barriers to PA. Rodríguez and colleagues (2011) found that the odds of high intensity PA participation are greater in areas with more parks and schools and lower in areas with an abundance of roads and eateries. Willenberg and colleagues (2010) add that playgrounds need to provide access to loose equipment (e.g., balls, jump ropes, etc.) and feature play surfaces with court markings and goals to promote higher levels of PA. Thus, with the proper tools and environmental factors, PA can be successfully promoted to children. The school environment is one such setting in which PA participation can be promoted.

Significance of School-day Physical Activity

Traditionally, periods of substantial PA accumulation within elementary schools have been limited to lunch, recess, and PE periods. While studies evaluating the exact amount of PE and break time PA children accumulate across the school day remain equivocal, it is undeniable that PA accumulated during these periods contributes toward whole-day MVPA goals. Specifically, PA accumulated within the school day has been shown to increase whole-day PA in a magnitude greater than expected from the school-day PA bout alone (Groffik, Sigmund, Frömel, Chmelík, & Nováková Lokvencová, 2012). Thus, these data indicate that active children *do not* necessarily compensate for increased school-day PA by decreasing PA outside of school. For instance, OW and OB children who participated in at least 30 minutes of MVPA during school breaks accumulated significantly greater PA *both* in and out of school than did children not participating in 30 minutes of break time MVPA (Groffik et al., 2012). Furthermore, children encouraged to be physically active during the school day have been shown to be more active after school than children whose PA was restricted during school (Dale, Corbin, and Dale, 2000). In a study of 8- to 11-year-old minority youth, Dauenhauer and Keating (2010) found African American and Hispanic children to be significantly more physically active on school days compared to weekend days. These findings support the role of the school environment in PA promotion, especially in at-risk children.

Similarly, Tudor-Locke and colleagues (2006) examined the effects of PE on whole-day PA accumulation. When examining PE periods within the school day, they found that PA accumulated in PE class was similar between boys and girls (Tudor-Locke et al., 2006; Brusseau et al., 2011). However, when examining whole-day PA, they found that boys accumulated greater whole-day PA on PE days compared to non PE days; in contrast, girls had no significant differences in PA accumulation on PE vs. non-PE days (Tudor-Locke et al., 2006). Among the boys, greater PA accumulation on PE days was attributed not only to PA accumulation during PE class, but also to greater PA during recess and lunch (Tudor-Locke et al., 2006). Thus, PE appears to have a residual effect on increasing whole-day PA in boys, but not girls.

Above all, these findings indicate that PA across the school day is essential, not only to increase PA accumulation during school, but also to enhance PA participation outside of school. Because a limited number of movement opportunities exist across the school day, these opportunities must be maximized in order to promote environments that support physically active lifestyles.

Proposed Guidelines for School-Day Physical Activity

It is undeniable that school-day PA contributes to children's whole-day PA accumulation; however, no consensus has been drawn on discrete guidelines for school-day PA accumulation. Although several groups have proposed PA goals for the whole school day as well as its comprising parts (i.e., class time, lunch, recess, PE), little evidence exists to guide the specific amount of school-day PA realistically achievable or the best times of the school day for interventions to target.

The New Zealand Project Energize recommends that one-third, or 20 minutes, of the daily 60-minute MVPA goal should be achieved during the school day (Rush et al., 2012). In contrast, Nettlefold and colleagues (2011) recommend 30 minutes of school-day MVPA, which amounts to 50% of the daily 60-minute goal. Furthermore, Nettlefold and colleagues (2011) suggest that 40% of recess and lunchtime and 50% of PE be spent in MVPA (Nettlefold et al., 2011). Guidelines have also been proposed for PA achieved during class time. The Physical Activity Across the Curriculum (PAAC) intervention suggests that 90 weekly minutes of MPA should be accumulated during class time alone (Gibson et al., 2008). However, these goals are currently unsubstantiated, as little dose-response evidence surrounding school-day PA guidelines and resultant health outcomes exist. Thus, to provide a greater evidence base for these goals, it is necessary to explore the current range of PA accumulated during the whole school day as well as its comprising parts. Once this information has been gathered, health outcomes in children can begin to be correlated with such activity levels to gather a stronger idea of the relationship between the amount of school-day PA and health outcomes in youth.

While preliminary findings from Nettlefold and colleagues (2011) indicate that greater than 90% of boys and girls meet the 30 minute school day guidelines, fewer students meet the guidelines for recess, lunch, and PE (Gibson et al., 2008). Notably, 15.7% of girls and 34.1% of boys met proposed PA guidelines during recess, 16.7% of girls and 37.4% of boys met proposed PA guidelines during lunch, and 1.8% of girls and 2.9% of boys met proposed PA guidelines during PE. Based on the low success of children meeting proposed guidelines, it is crucial to more closely examine PA during the school day to better direct PA guidelines. In turn, more informed PA guidelines will help lead interventions to increase PA across the school day.

School-Based Interventions to Increase Physical Activity

On one hand, despite opportunities for PA during school breaks and PE, the overall sedentary nature of the school environment poses a significant barrier to school-day PA (Gibson et al., 2008). On the other hand, with the majority of children attending school, including minority children who might otherwise be overlooked, the school environment serves as an ideal setting for PA interventions (Gibson et al., 2008). Notably, enrolled children are required by law to attend school on a consistent basis, daily attendance is recorded, trained teachers and staff can serve to disseminate and model PA interventions, and school environments and policies can be modified to support such interventions. Thus, school-based interventions to increase PA have been implemented in an attempt to increase children's adherence to school-day PA guidelines. Such school-based interventions have focused both on break time and non-break time strategies to increase school-day PA.

Non-Break Time Interventions

Within the traditional classroom setting, the TAKE 10! program strives to increase classroom PA by incorporating movement into the academic curriculum (Pate et al., 2006). Research surrounding the TAKE 10! program indicates that children provided with the TAKE 10! curriculum accumulate significantly greater PA in the classroom than those in traditional classes; while TAKE 10! students spend the majority of their lessons standing, non-TAKE 10! children are seated during the majority of their academic lessons (Gibson et al., 2008). Furthermore, students within TAKE 10! programs demonstrate better ratings of lesson enjoyment, and TAKE 10! teachers indicate that the lessons are more effective in facilitating student learning (Gibson et al., 2008).

Break Time Interventions

Outside of the academic classroom, the SPARK Program (Sports Play and Active Recreation for Kids) provides PE and active recess curricula for elementary schools across the nation. The goal of this program is to increase PA within the school day and to promote regular PA after school (Sallis et al., 1997). Children in SPARK schools have demonstrated increased time spent in PA during the school day as well as twice as much MVPA during PE periods compared to control schools (Sallis et al, 1997).

While the SPARK program provides curricula to increase PA across the school day, it does not typically target PA outside of school hours. Other interventions, like the Intervention of PhysicaL Activity in Youth (IPLAY) study, have begun to target both school-day and out-of-school PA by building renovated play areas for children and the community. When comparing schools with renovated play areas to schools with traditional playgrounds, children attending schools with renovated structures were found to be significantly more active than control children (Brink et al., 2010). Playground markings (e.g., court and goal lines) as well as physical structures within the playground have been shown to mediate this effect (Ridgers, Fairclough, & Stratton, 2010).

In an attempt to increase PA among students within Denver Colorado's Public Elementary Schools, the IPLAY study along with the Learning Landscapes (LL) program at the University of Colorado Denver have built more than 98 culturally tailored schoolyard environments that feature artwork, shade structures, playground markings, play structures, large fields, and walking paths (Anthamatten et al., 2011). Observations following the System for Observing Play and Leisure Activity (SOPLAY) guidelines of PA measurement have found schoolyard utilization of these LL play areas to be significantly greater than playground utilization in control schools (Anthamatten et al., 2011). Additionally, objective PA measurement through accelerometry has shown that LL environments increase children's percentage of recess time spent in MVPA compared to control environments (Schaefer, 2011). Furthermore, children with access to LL participate in greater amounts of MVPA across the entire school day than do children in control schools (Schaefer, 2011).

While both break-time and non-break time interventions across the school day have shown success in increasing children's school-day PA, little information exists to guide these interventions. Without information regarding the temporality of PA across the school day, we have little knowledge of when the most PA occurs, when the least PA occurs, and when the greatest improvement in PA accumulation would be possible during the school day. Such information will help to better guide school-based PA interventions to target increased PA during specific times of the school day.

Temporality of Physical Activity

Temporality Overview

Addressing temporality in PA research allows us to look at not only *how much* PA occurs but also *when* it occurs and the *pattern* through which it occurs. For instance, ACC data might provide total minutes of SED, LPA, MPA, and VPA achieved within a school day, but without a temporal lens, it is impossible to determine when that activity occurred. Furthermore, temporal analyses help to distinguish patterns of activity that indicate whether an individual is highly active for an extended, yet discrete period of time, or whether he/she accumulates activity at intermittent bouts throughout the day.

In the context of the school day, temporal analyses indicate periods of the school day that are highly active vs. highly sedentary. They also indicate when, within certain time periods, PA occurs. For instance, temporal analyses indicate whether the majority of activity occurs during the beginning of recess, during the end of recess, or interspersed throughout. Lastly, temporal data allow us to determine differences in patterns of PA accumulation based on child activity level, sex, etc. For instance, some children might accumulate PA in short, sporadic bursts of vigorous intensity while other children might accumulate PA in longer, more frequent bursts of moderate intensity. Each of these levels of temporal data is crucial in shaping the story of PA accumulation across children.

Temporality of Whole-Day Physical Activity

Children demonstrate variability in the amounts of whole-day PA they accumulate as well as the times of the day during which they are most active. To gather a complete picture of whole-day PA accumulation, it is not only crucial to examine how much whole-day PA children accumulate, but it is also necessary to examine the time periods during which PA occurs. McGall, McGuigan, & Nottle (2011) found activity counts among seven- to nine-year-old boys and girls to be greatest during school free-time compared to afterschool and weekend time. In contrast, Steele and colleagues (2010) found that nine- and ten-year-old boys and girls accumulate more VPA outside of school than during school. These contrasting findings may, in part, be explained by individual differences in the temporality of PA accumulation. Consequently, individual differences must be further considered to evaluate whether certain intrapersonal characteristics are correlated with greater or lower PA at certain times of the day. Specifically, temporal patterns of whole-day PA accumulation have been shown to differ by activity level and sex.

Several studies have classified children as high- or low-PA achievers in their examination of activity patterns (Fairclough, Beighle, Erwin, & Ridgers, 2012; Brusseau et al., 2011). Fairclough and colleagues (2012) have found high-PA achievers (defined as those meeting $\geq$60 minutes of daily MVPA) to accumulate 12.5 and 5.1 minutes more MVPA during the whole day and school day, respectively, than low PA achievers (defined as children not meeting 60 minutes of daily MVPA). Furthermore, the greatest differences in high- versus low-PA achievers occurred before and after school, during class time, and at lunchtime, with high-PA achievers accumulating more PA during those periods than low-PA achievers. In a separate study, Cox and colleagues (2006) discovered a significant difference in PA accumulation outside of school. Specifically, among the most active tertile of boys and girls, 55.1% of daily PA occurred outside of school, compared to 46.7% among the least active tertile, indicating that the most active children accumulate greater out-of-school PA than do the least active children.

Mota, Santos, Guerra, Ribeiro, & Duarte (2003) divided the day into four discrete time periods including morning, noon, late afternoon, and evening. While no significant temporal patterns or sex differences were found, girls tended to be more active in the morning and during school periods than other times of the day; boys tended to be more active in the afterschool and evening periods (Mota et al., 2003). These findings suggest that, although current studies of temporal characteristics of whole-day PA remain equivocal, temporal patterns likely differ by sex and activity level.

Temporality of School Day Physical Activity

Because the school day is a significant focus of childhood PA interventions, temporal characteristics of school-day PA must be considered separately from whole-day PA. The typical elementary school day includes classroom lessons, break time (i.e., recess and lunch), PE, and transition time between classes/breaks. While students have the opportunity for active time throughout the day, the majority of the school day is sedentary in nature (Gibson et al., 2008). Furthermore, active periods throughout the day (i.e., recess and PE) do not always promote sufficient time or opportunities for PA across all children. Because the school day is a unique mix of time spent in SED and time allotted for PA, temporal analyses aid in better-understanding the school-day PA environment, notably *when* PA occurs and *where* opportunities for increased PA exist.

Break-time and Physical Education Physical Activity Accumulation

Several studies of PA across the school day have focused on PA accumulation during school breaks and PE. Although 78.4% of states require elementary schools to provide PE, only 8% of elementary schools provide daily PE classes (Pate et al., 2006). Previous work examining PA during PE indicates that 8% to 33% of PE class-time is spent in MVPA (Tudor-Locke et al., 2006). Estimates of MVPA during school breaks are slightly higher, with approximations ranging from 20% to 50% of recess time spent in MVPA (Mota et al., 2005; Ridgers, Stratton, & Fairclough, 2005; Verstraete, Cardon, Clercq, & De Bourdeaudhuij, 2006). In some studies, recess PA has shown to elicit the most intense PA of the school day (Rush et al., 2012), contributing 15.6% and 17.9% of girls' and boys' school-day MVPA, respectively, despite the recess period accounting for only 4% of the school day (Ridgers et al., 2011). Guinhouya et al. (2009) cite even higher estimates, with greater than 70% of children's daily MVPA coming from recess PA. However, Brusseau and colleagues (2011) have noted a significant interaction between sex and school-day time period, such that recess may not be the greatest PA contributor in all children. Notably, among boys, the greatest percentage of school-day PA was accumulated during lunch, followed by PE and recess; among girls, the greatest percentage of school-day PA was accumulated during PE, followed by lunch and recess. Thus, individual differences in school-day PA accumulation must be considered.

Individual Differences in School-Day Physical Activity Accumulation

Individual differences in school-day PA accumulation primarily have been explored during school break times. During school breaks, sex, socioeconomic status, teacher supervision, and access to equipment have been identified as correlates of PA accumulation (Stanley, Ridley, & Dollman, 2012); however, sex has been the principal construct of focus when examining individual differences during break-time. Looking specifically at the recess period, Mota and colleagues (2005) have shown that boys and girls spend 31% and 38% of recess time in MVPA, respectively. In contrast, Ridgers et al. (2005) indicate these numbers to be 32.9% and 23% for boys and girls, respectively, and Stratton, Ridgers, Fairclough, and Richardson (2006) have found that children can spend as much as 40% to 50% of recess time in MVPA, with boys accumulating greater recess MVPA than girls. Fairclough et al. (2012) have also found that recess PA is significantly greater in boys than girls. Thus, not only do the percentages of time spent in MVPA differ across studies, but variation in sex differences relating to recess PA accumulation is also indicated. While Ridgers et al. (2005), Stratton et al. (2006), and Fairclough et al. (2012) found boys to accumulate significantly greater PA during recess than girls, Mota and colleagues (2005) claim the opposite relationship.

Recess PA can also be evaluated by the number of children meeting a pre-set PA goal for that time period. When examining recess PA among six- to ten-year-old boys and girls, Stratton and colleagues (2006) proposed the goal of 40-50% of recess time spent in PA. They found that, while few children met the 50% goal, more than 40% of NW boys, 30% of OW boys and girls, and 20% of NW girls met the 40% goal. Thus, 40% of recess spent in MVPA is a potentially realistic goal. However, success in achieving this goal varied by child weight status, underscoring the need to not only consider gender, but to also consider weight status when setting PA goals and structuring school-based PA interventions.

Additional interactions have been found for break-time PA accumulation based on children's activity level. Rush and colleagues (2012) classified children within two elementary school classes by activity level (i.e., top 10 percent and bottom 10 percent for PA accumulation). Significant differences between the most and least active children were not seen during class time; however, PA accumulation between these children was significantly different during school breaks, with the most active children accumulating significantly more break-time PA than the least active children.

In contrast, Fairclough et al. (2012) present opposing findings, such that high vs. low achievers were significantly different in accumulated MVPA during class time and lunch time (including an optional outdoor recess period after lunch), but not during morning or afternoon recess. Findings may have been affected by high vs. low classification strategies; while Rush et al. (2012) stratified by activity percentile, Fairclough et al., (2012) classified children reaching 60 minutes of daily PA as high achievers and all others as low achievers.

Apparent from the presented literature, findings remain equivocal surrounding the temporal patterns and individual variability in school-day PA accumulation. It is undeniable that the school setting provides opportunities for PA among children. What remains unexplored is the exact potential for PA accumulation during the whole school day as well as PA goals during specific times of the school day, including class time, break time, and PE. Additionally, little information exists on the temporal pattern through which PA is accumulated during these specific time periods as well as individual differences and variability in these patterns based on child sex, child weight status, and low- vs. high-PA achievers. Objective study of school-day PA accumulation and its temporal patterns across the school day will help to clarify many of these questions.

Conclusion

Physical inactivity among children has been reported as a causal factor in childhood obesity etiology. Despite interventions to increase PA throughout the school day, levels of PA in elementary school children appear to remain inadequate compared to the currently recommended 60 minutes of whole-day MVPA. Thus, interventions to increase PA within the school day must be carefully developed and implemented. The current study aims to employ objective measures of PA (i.e., accelerometry) in evaluating the temporal aspects of PA within the elementary school day. Specifically, we attempt to quantify the mean, minimum, and maximum amounts of PA accumulated during the school day and to describe the current patterns of PA across the school day, thus elucidating time periods that present the greatest opportunity for increased PA. We also attempt to explore individual differences in school-day PA accumulation between children and to identify which time periods demonstrate the greatest differences in PA accumulation between the most and least active children.

Few studies have answered these questions, and those that have explored the temporal aspect of PA during the school day have used less objective measures (i.e., pedometers, observation) or focused solely on school breaks to examine such temporal associations. Increased objectivity through accelerometry and a closer look at PA throughout the entire school day will help to better guide implementation of PA interventions within the schools.

CHAPTER III

METHODS

Human Subjects Approval

This investigation was approved by the Institutional Review Board for Human Subjects Research at Colorado State University. All children and parents/guardians provided written informed assent and consent, respectively, before commencement of participation.

Subjects

Study participants were a subset of 6- to 12-year-old children from three control schools participating in The Intervention of PhysicaL Activity in Youth (IPLAY) study. IPLAY is a multi-school intervention which assesses the effects of LL and PA-based curricula on PA in elementary-aged children attending 24 public schools across metropolitan Denver, Colorado. Each participating first, third, and fifth grade classroom was randomly selected for participation. The 6- to12-year-old age range was chosen to ensure that a representative sample from each elementary age group was included and to provide a study population that encompassed a characteristic age range from previously documented literature surrounding PA and childhood obesity. Only data from control schools were included in the present analyses. Participants were 165 boys and girls ages 6 to 12 years. After cleaning collected data for non-wear or ACC malfunction (details to follow), 32 children were removed, and 133 children were included in the final analyses.

Experimental Procedures

Data collection occurred during April and May of 2011 and 2012. Prior to activity measurement, participants' height to the nearest 0.001 meters (standard tape measurer) and weight to the nearest 0.2 kilogram (Health o meter professional scale, Model 349KLX) were measured by a trained member of the research team. From these measurements, BMI was calculated as kg/m^2, children's BMI percentiles were determined from a Centers for Disease Control and Prevention (CDC) macro, and children were dichotomized as NW vs. OW/OB. Weight status was classified in concordance with current CDC guidelines (i.e., NW $<85^{th}$ percentile; OW/OB $\geq 85^{th}$ percentile).

Participants were provided a waterproof GENEActiv (Activinsights Limited, Cambridge, UK) ACC, which was fitted to the wrist of their non-dominant hand. They were asked to wear the ACC for six consecutive days and were instructed to wear the device at all times. Parents and teachers were provided instructions for children's ACC use, notably, that children should not tamper with the device nor remove it during the six-day assessment period. Children were then asked to engage in their typical daily activities while wearing the ACC. Teachers provided a daily class schedule for the week of ACC wear, including school start and end times, lunch and recess times, and PE periods. Children, parents, and teachers were also asked to take note of any atypical behaviors or situations encountered during the six-day study period (e.g., illness, absence from school, vacations/class trips). At the end of the six-day period, study personnel returned to each classroom to collect ACCs from participants. At this point, children received gift cards as remuneration for their participation.

Accelerometry

Body-worn ACCs are validated instruments that allow for measurement of PA duration and intensity (i.e., SED, LPA, MPA, and VPA) and have been shown to correlate with doubly labeled water studies in determining energy expenditure (Plasqui & Westerterp, 2007). The GENEActiv ACC is a light-weight (16g), waterproof, triaxial ACC that has been validated for wear on the wrist in both adults and children (Esliger et al., 2011; Phillips, Parfitt, & Rowlands, 2013). Notably, it demonstrates strong intra- and inter-device reliability, strong criterion validity against a Multi-Axis Shaking Table, and strong concurrent validity against the hip-mounted ActiGraph GTIM (Esliger et al., 2011).

We collected acceleration data at 75 Hz and summed the values over a one-second epoch. Because children tend to participate in short bouts of movement, it has been suggested that shorter epochs (i.e., less than 15 seconds) be used in a pediatric population to capture sporadic bouts of MVPA (Baquet et al., 2007). Using longer epochs in a child population has been shown to dilute short bouts of PA across a long sampling period, thus underestimating true MVPA accumulation (Baquet et al, 2007; Chen & Bassett, 2005; Ekelund et al., 2011). Acceleration data were downloaded from ACCs with the GENEActiv software (Version 2.1), and a customized Matlab program (Matlab v 12.0, Mathworks, Natick, MA) was used to filter the data (band pass with cutoff frequencies of 0.2 and 15 Hz) and calculate an SVM (units are gravity*seconds (g*s)) for each second (Equation 1). Using previously determined GENEActiv cutpoints (Table 1) from a calibration study using a similar child population (Schaefer et al., in review), the resultant filtered and processed files were then processed with another custom Matlab program, which calculated minutes of SED, LPA, MPA, VPA, and MVPA (sum of MPA and VPA) during pre-determined custom intervals (CI; details to follow). Percentage of time spent in activity of each intensity level was also calculated for each CI.

Equation 1. SVM Calculation.

$$\text{SVM (g*s)} = \sum \left| \sqrt{x^2+y^2+z^2} \right| / (f)$$

Table 1. GENEActiv Cutpoints.

	Cutpoint* (1-sec. epoch)
Sedentary (SED)	0.190
Light (LPA)	NA*
Moderate (MPA)	0.314
Vigorous (VPA)	0.998

*Cutpoints refer to SVM values (g*s) for a particular second. The LPA boundaries are defined by the cutpoints listed for SED and MPA.

Custom Intervals

Custom intervals were chosen to represent the general periods of the elementary school day. These intervals included whole school day, morning class time, afternoon class time, lunch/recess combined, morning recess, afternoon recess, and PE. When initially processed, morning class time and afternoon class time included PE and morning/afternoon recess CI data for several classes. To better ensure that the class time CI truly represents time spent in the academic classroom, any PE and morning/afternoon recess CI data that coincided with class time were subtracted from the morning and afternoon class time data. Additionally, data for morning class time and afternoon class time were summed to create a single class time CI; similarly, data for lunch/recess combined, morning recess, and afternoon recess were summed to create a single break time CI. The four resultant CIs were: whole school day, class time, break time, and PE. Notably, the whole school day, although discussed as a discrete CI in the present analyses, comprises the CIs of class time, break time, and PE.

When multiple valid school days of ACC data were available for a particular child, data were averaged for each CI to present mean activity data (i.e., across multiple days) for each CI. The average values were used in the present analyses so that all CI data represent an average of each child's valid measurement days across the sampling period. For instance, if a child had three valid days of school day ACC data, CIs for those three days were averaged to create a single mean value for each CI. Valid measurement days ranged from one to three school days depending on the particular child.

Non-wear

Post processing, data were manually examined and cleaned based on evidence of non-wear. Non-wear was defined as any CI that did not include the full number of minutes for that CI (likely ACC failure), any CI that was indicated as 100 percent sedentary, or any CI that registered as having 10 or more minutes of consecutive SVM values <0.013g*s. Custom intervals demonstrating any of the aforementioned non-wear characteristics were removed, and averages of each CI were re-calculated to reflect only the valid measurement days. Furthermore, to avoid changes in PA that might have been caused by the novelty of wearing the ACC device, the first day of ACC measurement (i.e., ACC drop-off day) was removed from analyses. The final day of ACC measurement (i.e., ACC pick-up day) was also removed from analyses because it did not allow for a full day of measurement. Lastly, weekend days were not included in analyses, as the current study considers only school day PA. Children with at least one valid school day of ACC data were included in analyses.

Statistical Analyses

All data were analyzed in SPSS (IBM SPSS Statistics 20, Somers, NY), and significance was set at $p<0.05$. Physical activity analyses used the dependent variable of percent of time spent in MVPA during each CI. Descriptive statistics were run for participant demographics and for percent of time spent in MVPA during each CI. Paired samples t-tests were used to test for significant differences in the percentage of time spent in MVPA between CIs. Chi-square analyses were conducted to assess significant differences in weight status distribution across grade levels.

Three-way univariate ANOVAs (3x2x2) were used to examine differences in percent of time spent in MVPA during the school day, class time, break time, and PE. Fixed factors were grade (three levels; first, third, and fifth), sex (two levels; boy, girl), and weight status (two levels; NW, OW/OB). When main effects were significant, Tukey's honestly significant difference (HSD) post hoc analyses were carried out to determine the levels and directions of the main effects. To assess differences in percentage of time spent in MVPA during each CI by high- vs. low-PA achievers, data were stratified into quartiles based on percent of the school-day spent in MVPA. To test for differences in demographics between PA quartiles (i.e., grade, sex, weight status), chi square analyses were run. One-way ANOVA was then conducted using percent of time spent in MVPA as the dependent variable and school-day quartile ranking as the fixed factor to determine the CIs during which low vs. high quartiles (i.e., Quartile 1 vs. Quartile 4, respectively) were significantly different. To further examine these differences, children were also dichotomized as low- vs. high-PA achievers (i.e., top and bottom 50th percentiles, respectively) for percent of school day spent in MVPA, and similar analyses were run.

CHAPTER IV

RESULTS

Demographics

Consent rate across all IPLAY study participants during 2011 and 2012 was 85-90%. For the present analyses, subject characteristics for the whole sample (N=165) and the valid sample (N=133) are presented in Table 2. A total of 32 children were removed from the initial data set; of the excluded children, 28 were excluded because of missing ACC data. For these 28 children, data files were either completely missing (i.e., the ACC was not received back from the child) or faulty (i.e., the device failed to communicate with software upon receipt, the files only partially downloaded, or the files failed to filter). In addition, 4 files were removed due to ACC processing error, such that extraneous values were recorded on a non-wear day. Each of the remaining 133 children had valid ACC data for at least one school day during the measurement period, so no children were completely excluded due to non-wear. Fourteen children (10.5%) demonstrated some non-wear during the sampling period, and their data were processed as explained previously (see Methods).

Table 2. Subject demographics by grade level.

	Full Sample (n=165)	Valid Sample (n=133)
First Grade	(n=47)	(n=32)
% Male	63.8	53.1
% NW	78.7	71.9
Age (years)	6.7 (0.6)	6.7 (0.6)
BMI Percentile	57.1 (29.8)	62.6 (29.9)
Third Grade	(n=54)	(n=44)
% Male	48.1	52.3
% NW	66.7	68.2
Age (years)	8.7 (0.5)	8.7 (0.5)
BMI Percentile	59.0 (31.2)	59.0 (31.4)
Fifth Grade	(n=64)	(n=57)
% Male	48.4	49.1
% NW	53.1*	50.9
Age (years)	10.6 (0.6)	10.6 (0.6)
BMI Percentile	70.8 (27.5)	72.0 (27.3)
Total		
% Male	52.7	51.1
% NW	64.8	61.7
Age (years)	8.9 (1.7)	9.0 (1.7)
BMI Percentile	63.0 (29.9)	65.4 (29.7)

Data are presented as frequencies and means (SD). NW is defined as $<85^{th}$ percentile for BMI. No significant differences were found between the samples. *Indicates a significant difference compared to first graders at p<0.05.

Although 50% of the excluded children were NW boys, and 28% were NW girls, no significant differences in subject characteristics were found between the whole vs. valid sample. Because findings did not differ when examining OW and OB children separately, they are discussed together as OW/OB. Chi square analyses indicated that weight status (NW vs. OW/OB) did not differ by sex in the whole sample (p=0.264) or the valid sample (p=0.079), nor did it differ by MVPA quartile in the valid sample (p=0.789). In the whole sample, weight status was significantly different across grade level, (p=0.019; Figure 1), such that first grade comprised a significantly greater percentage of NW children (78.7%) and a significantly lower percentage of OW/OB children (21.3%) than did fifth grade (53.1% and 46.9%, respectively); a similar but non-significant trend (p=0.082) was found for the valid sample. The following analyses refer to the valid sample only; unless otherwise noted, data are presented as mean (standard error).

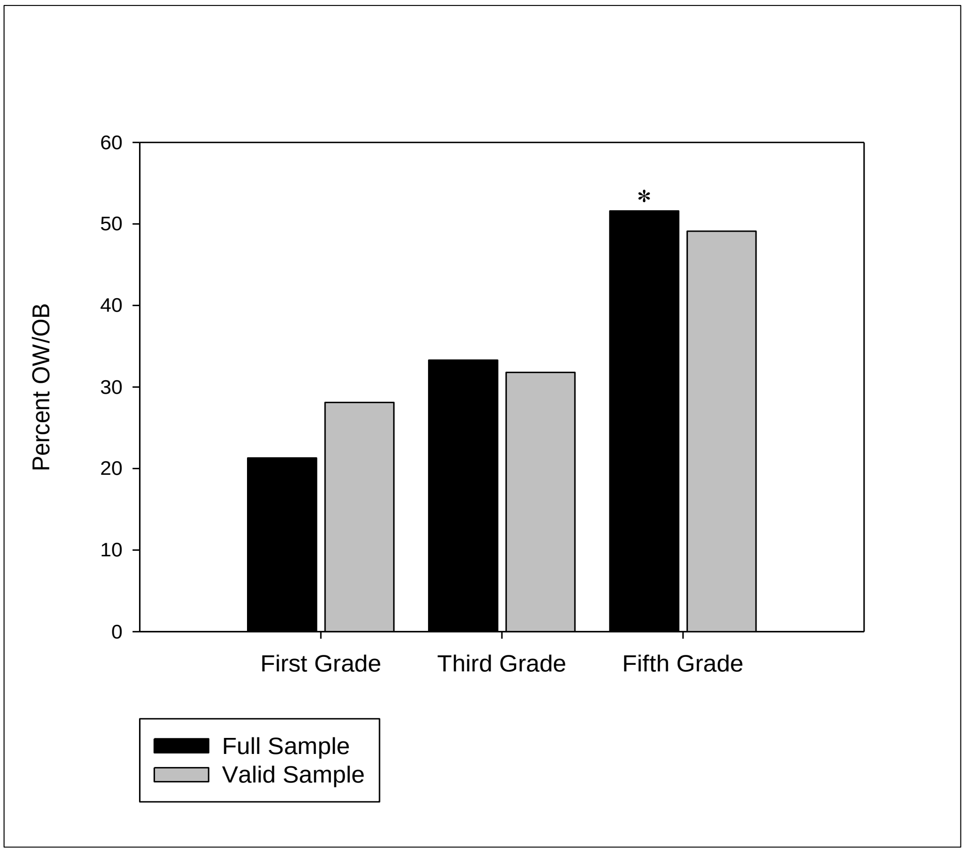

Figure 1. Percent of children classified as OW/OB by grade level for the full and valid samples. OW/OB is defined as $\geq 85^{th}$ percentile for BMI. *Indicates a significant difference compared to first graders at p<0.05.

Custom Intervals

Four CIs were assessed, including the whole school day (which comprises class time, break time, and PE), class time, break time, and PE. Because AM and PM class time were not significantly different across analyses, class time is presented as a combination of both AM and PM class. The percentage of time spent in MVPA was significantly different across each CI ($p<0.001$), with break time yielding the greatest percentage of time in MVPA, followed by PE, school day, and class time (Table 3).

Table 3. Minimum, maximum, and mean (SE) percent of time and minutes spent in MVPA during each custom interval across the school day.

	Minimum	Maximum	Mean
School Day			
Percent	11.0	43.2	30.3 (0.5)
Minutes	44.0	176.0	122.0 (2.0)
Class Time			
Percent	10.6	41.7	27.9 (0.5)
Minutes	37.5	151.7	94.9 (1.7)
Break Time			
Percent	18.2	72.5	49.3 (0.9)
Minutes	5.5	32.6	18.09 (0.48)
PE (n=79)			
Percent	10.1	69.3	42.6 (1.4)
Minutes	4.0	33.7	17.4 (0.9)

School Day

The school day ranged in minutes from 400 to 410; within-child school day length was consistent across study days but varied across schools, such that inter-subject school day length differed, and thus, resulted in varying school day lengths for the overall sample. All 133 children accumulated at least 30 minutes of MVPA, and 132 of the 133 children accumulated at least 60 minutes of MVPA throughout the school day. Across the sample, 73 children (54.9%)

accumulated upwards of 120 minutes of MVPA during school. A main effect of grade ($p<0.001$) was found between children who achieved $\geq$120 minutes of school-day MVPA and those who did not; specifically, first (71.9%) and third graders (72.7%) were more likely to achieve 120 minutes of school-day MVPA than were fifth graders (31.6%). Across the sample, 74% of children spent between 26% and 37% of the school day engaged in MVPA.

No main effects of sex (F (1,131) = 1.40, P = 0.239) or weight status (F (1,131) = 0.03, P = 0.862) were found for percentage of the school day spent in MVPA. There was a main effect of grade (F (2,130) = 12.396, P < 0.001), such that first (32.2% (0.99)) and third (32.3% (0.65)) graders spent a significantly greater percentage of the school day in MVPA than did fifth graders (27.6% (0.74)). No significant interactions were found.

Class Time

The average total class time ranged from 320 to 380 minutes. Differences in class time were observed both within subjects, depending on the day of the week, and between subjects. The main variables altering the number of minutes spent in class time were whether PE and/or extra break time were scheduled for a single day. On days when PE or extra recess was offered, fewer minutes were spent in class compared to days when no PE or extra recess was offered. A main effect of grade was found for minutes spent in class (F (2, 130) =7.904, P=0.001), such that first grade spent a greater number of minutes in class time (354.5 (3.3)) than did third grade (336.7 (2.8)) or fifth grade (335.1 (3.8)).

No main effects of sex (F (1,131) = 1.10, P = 0.30) or weight status (F (1,131) = 0.005, P = 0.95) were found for percentage of class time spent in MVPA. There was a main effect of grade (F (2,130) = 10.95, P = <0.001), such that first (29.32 (1.0)) and third (30.1 (0.7)) graders spent a significantly greater percentage of class time in MVPA than did fifth graders (25.4 (0.7)). No significant interactions were found.

Break Time

Total break time (including AM recess (n=12), PM recess (n=66), and lunch/recess combined (n=133)) ranged in minutes from 30 to 60. Break time varied by grade and class, such that only one first grade class received an AM recess, and only four classes (two first grade, one third grade, and one fifth grade) received a PM recess; break time also varied by day, such that certain classes only received extra break time (i.e., AM and PM recess) on certain days of the week (e.g., Friday), while other classes received extra break time daily.

No main effect of weight status (F (1,131) = 0.13, P = 0.719) or grade (F (2,130) = 2.80, P = 0.065) was found for percentage of break time spent in MVPA. There was a main effect of sex (F (1,131) = 8.75, P = 0.004), such that boys (52.8 (1.1)) spent a significantly greater percentage of break time in MVPA than did girls (45.5 (1.2)) (Figure 2). No significant interactions were found. Of the 133 children, 108 (81.2%) spent at least 40% of break time engaged in MVPA. A main effect of sex (p=0.003) was found between children who spent $\geq$40% of break time in MVPA and those who did not; specifically, boys (91.2%) were more likely to meet this goal than were girls (70.8%).

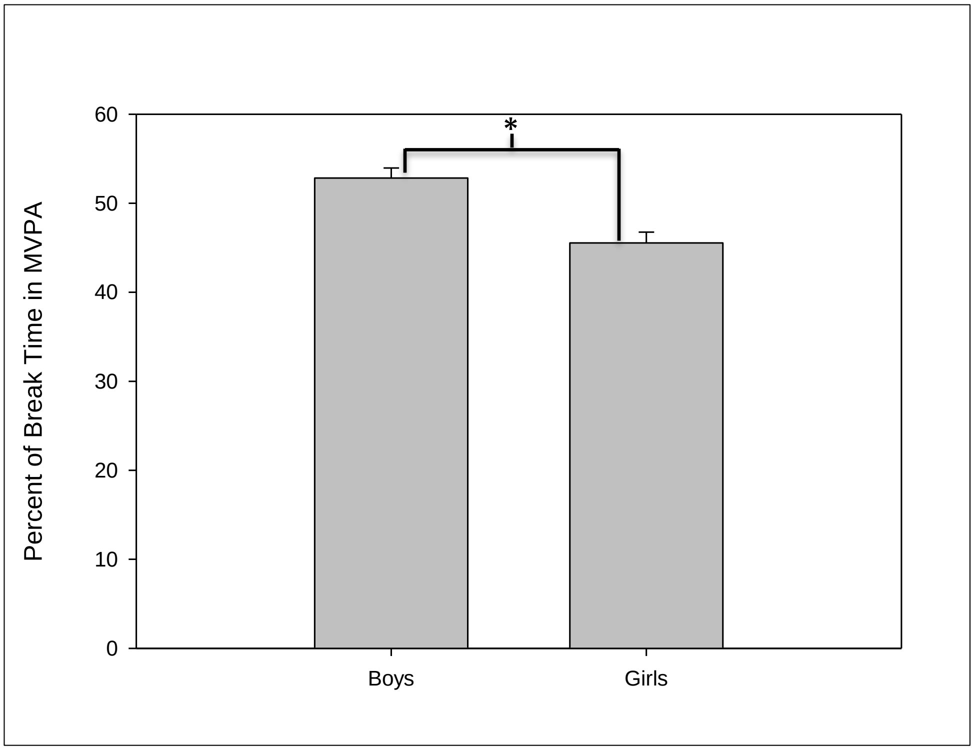

Figure 2. Average percentage of break time spent in MVPA by sex. Values are reported as mean percent, with error bars representing standard error of the mean (SEM). During break time, boys spent a significantly greater percentage of time in MVPA (M = 52.8 (1.1)) than did girls (M=45.5 (1.2)). *Values are significantly different from each other at p<0.05.

PE

Total PE time ranged in minutes from 20 to 55, depending on the school and class. Of the 133 subjects, 79 participated in a PE period during the sampling days; children who did not have a scheduled PE class during the specific sampling days likely received PE during a non-sampling day. No main effects were found for sex (F (1,130) = 0.76, P = 0.385), weight status (F (1,130) = 0.15, P = 0.697), or grade (F (2,131) = 2.79, P = 0.068) on the percentage of PE class spent in MVPA. A grade-by-sex-by-weight status interaction was found. However, because PE classes across the particular sample varied by school, grade, and PE teacher, this interaction was likely an effect of those constructs and, thus, further analyses were not explored. Of the 79 children, 24 (30.4%) spent at least 50% of PE engaged in MVPA.

PA Quartiles

Demographics for each PA quartile are presented in Table 4.

Table 4. Subject demographics by school-day MVPA quartile.

	Quartile 1 (n=33)	Quartile 2 (n=33)	Quartile 3 (n=34)	Quartile 4 (n=34)
Grade				
First	9.1%	21.2%	26.5%	39.4%
Third	18.2%	24.2%	50.0%	39.4%
Fifth	72.7%	54.5%	23.5%	21.1%
Sex				
Male	45.5%	36.4%	52.9%	69.7%
Female	54.5%	63.6%	47.1%	30.3%
Weight Status				
NW	57.6%	54.5%	76.5%	57.6%
OW/OB	42.4%	45.5%	23.5%	42.4%

Data are reported as frequencies (%). School-day MVPA quartiles were created by stratifying subjects according to the average percentage of the school day spent in MVPA. Quartiles are listed by increasing percentages of the school day spent in MVPA, such that Quartile 1 includes children with the lowest percentage of the school day spent in MVPA, while Quartile 4 includes children with the greatest percentage of the school day spent in MVPA.

No significant differences in weight status were found between quartiles. A main effect of sex was found ($p<0.05$), such that quartiles 1 and 2 comprised a significantly lower percentage of boys (45.0% and 36.4%, respectively) than did quartile 4 (69.7%). Similarly, a main effect of grade ($p<0.001$) was found between quartiles 1 and 3, 1 and 4, 2 and 3, and 2 and 4. To further examine these relationships, children were dichotomized by quartile, such that children in quartiles 1 and 2 were classified as “low active,” whereas children in quartiles 3 and 4 were classified as “high active.” Low active children comprised a greater percentage of fifth graders (63.6%) and girls (59.1%) than did high active children, of which 22.4% were fifth graders and 38.8% were girls. 68.7% of first graders, 68.1% of third graders, and 26.3% of fifth graders were dichotomized as high active (Figure 3a). Furthermore, 60.3% of boys were dichotomized as high active, compared to 40.0% of girls (Figure 3b).

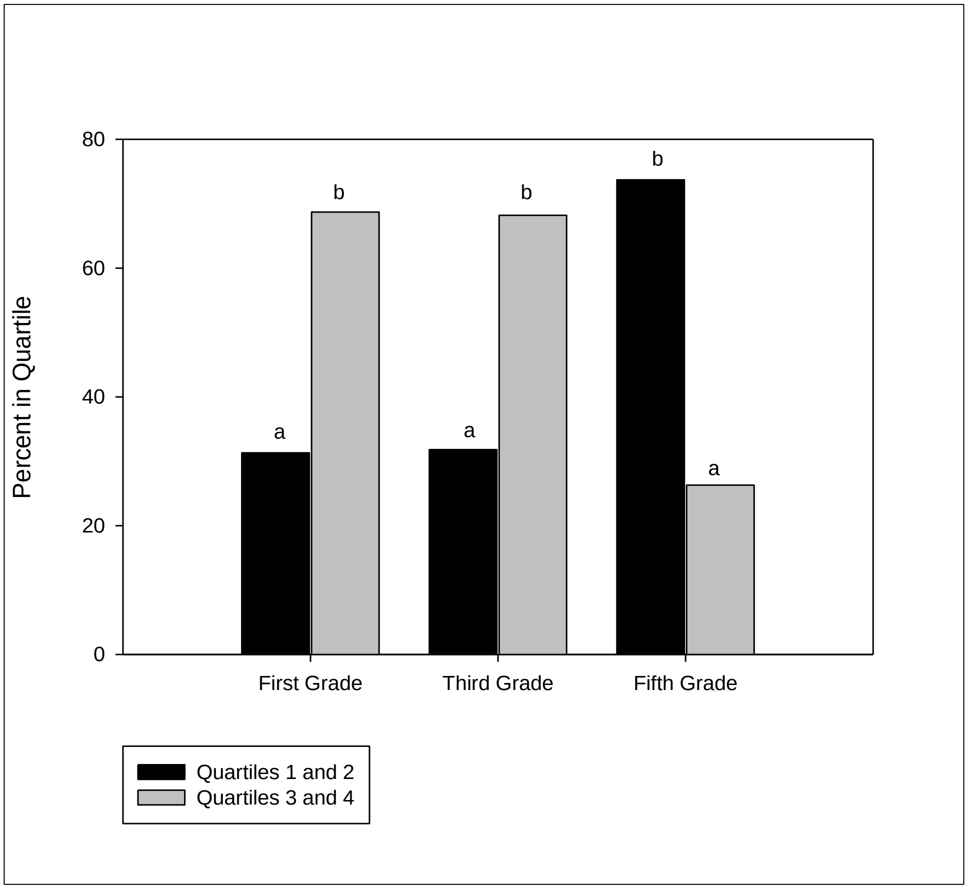

Figure 3a. Percentage of children classified as high- vs. low- PA achievers by grade. Data represent the percentage of children in each grade classified as low- vs. high-PA achievers. A significantly greater percentage of first (68.7%) and third graders (68.1%) were classified as high-PA achievers than were fifth graders (26.3%). Values with different letters are significantly different from each other at $p<0.05$.

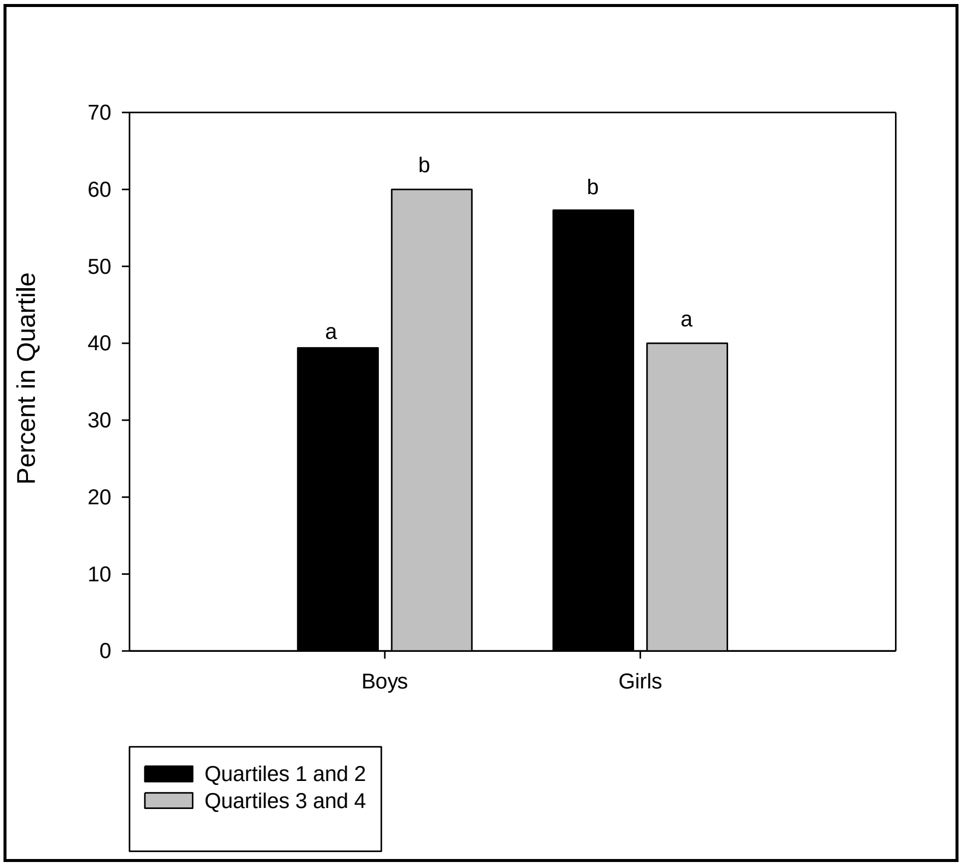

Figure 3b. Percentage of children classified as high- vs. low-PA achievers by sex. Data represent the percent of males vs. females classified as low- vs. high-PA achievers. A significantly greater percentage of males (60.3%) were classified as high-PA achievers than were females (40.0%). Values with different letters are significantly different from each other at p<0.05.

When considering the percentage of each CI spent in MVPA by school-day MVPA quartile, each quartile was significantly different (p<0.001) from other quartiles across the school day, class time, and break time, such that high-PA achievers spent a significantly greater percent of time in MVPA than did low-PA achievers (Table 5; Figure 4). For PE, however, significant differences were found only between quartiles 1 and 3, 1 and 4, and 2 and 4 (p<0.05).

Table 5. Mean percentage of each CI spent in MVPA by school day MVPA quartile.

	Quartile 1 (n=33)	Quartile 2 (n=33)	Quartile 3 (n=34)	Quartile 4 (n=33)
School Day	23.1 (0.7)[a]	28.5 (0.2)[b]	32.3 (0.2)[c]	37.2 (0.4)[d]
Class Time	21.6 (0.7)[a]	26.1 (0.3)[b]	29.5 (0.3)[c]	34.3 (0.5)[d]
Break Time	39.9 (1.6)[a]	46.6 (1.3)[b]	52.0 (1.1)[c]	58.6 (1.2)[d]
PE	32.8 (2.0)[a]	38.7 (2.2)[a, b]	45.8 (2.4)[b, c]	50.1 (2.9)[c]

Data are reported as mean percent (SE). During the school day, class time, and break time, children in increasing quartiles spent a significantly greater percentage of time in MVPA than did children in each of the lower quartiles. *For each CI, values with different letters are significantly different at $p<0.05$

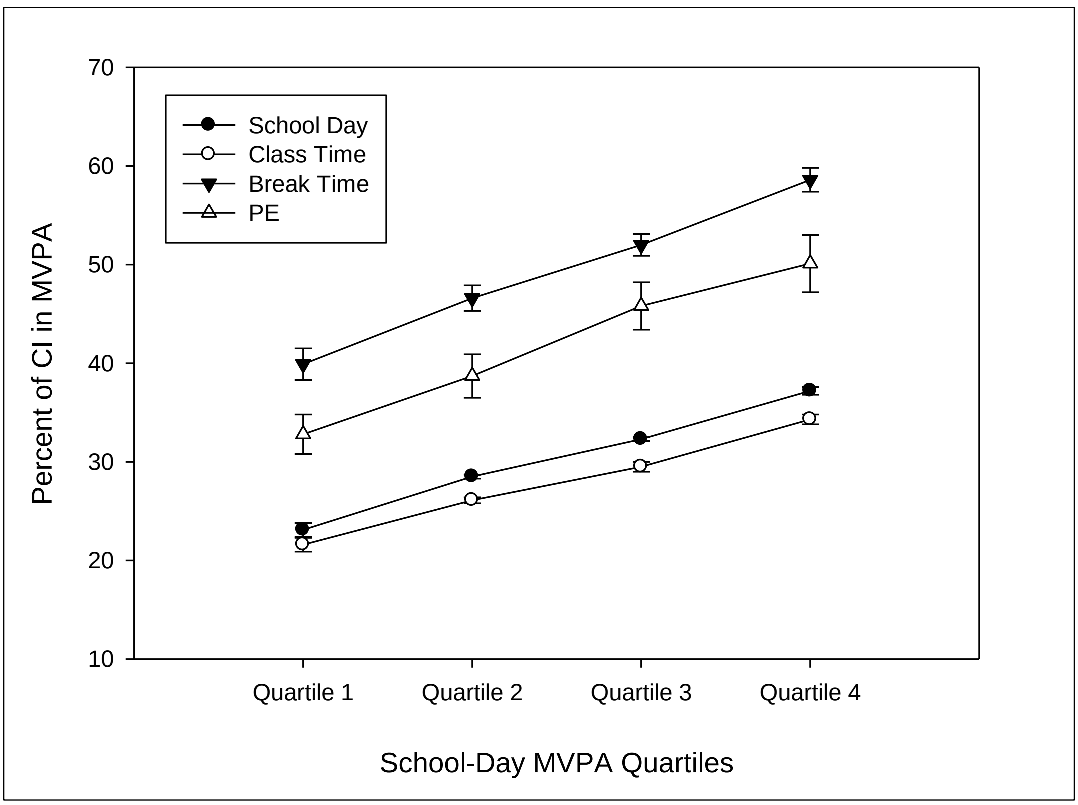

Figure 4. Mean percentage of each CI spent in MVPA by school-day MVPA quartile. Data are reported as mean percent (SE). During the school day, class time, and break time, children in increasing quartiles spent a significantly greater percentage of time in MVPA than did children in each of the lower quartiles. A similar trend followed for PE, but significant differences were seen only between Quartiles 1 and 3, 1 and 4, and 2 and 4.

CHAPTER V

DISCUSSION

The primary aim of this study was to objectively quantify, using a short epoch, the mean, greatest, and least amounts of PA accumulated across different CIs of the elementary school day and to explore variability in PA accumulation between children during these CIs. Our first hypothesis proposed that school-day PA accumulation would differ by sex, grade, and weight status. This hypothesis was partially supported, in that first and third graders accumulated significantly greater MVPA during the entire school day and class time than did fifth graders. Additionally, boys accumulated significantly greater MVPA during break time than did girls. However, no differences in MVPA accumulation by weight status were found for any CI. Our second hypothesis proposed that the greatest PA accumulation would occur during school break time and the least PA accumulation would occur during class time (non-PE). This hypothesis was also supported, as the greatest percentage of time spent in MVPA occurred during break time, followed by PE, and class time; because of this pattern, the percentage of the entire school day spent in MVPA fell between that of break time/PE and class time. Finally, our third hypothesis proposed that the greatest variability between high- and low-PA achievers would occur during break time. This final hypothesis was partially supported. MVPA quartiles were significantly different from each other across all CIs (i.e., class time, break time, and PE), indicating significant variability between high- and low-PA achievers throughout all CIs of the school day; however, the greatest range in percentage of time spent in MVPA occurred during break time and PE.

Using a wrist-mounted ACC and a one-second epoch measurement period, we found a greater prevalence of MVPA across the entire school day and its comprising parts than what has been previously reported. Earlier studies using longer epochs (i.e., five-second to one-minute epochs) have reported averages of 33 to 63 minutes and 25 to 53 minutes of MVPA across the whole school day for boys and girls, respectively (Fairclough, Butcher, & Stratton, 2007; Mota et al., 2003; Nettlefold et al., 2011), as well as averages of 28.4 minutes and 23.3 minutes of school-day MVPA for high- vs. low-PA achievers, respectively (Fairclough et al., 2012). Previous break time estimates have ranged from 9% to 43% of break time spent in MVPA for boys and girls (McGall et al., 2011; Mota et al., 2005; Ridgers et al., 2011), and previous PE estimates have suggested that 9-33% of PE time is spent in MVPA for both sexes combined (Nettlefold et al., 2011; Tudor-Locke et al., 2006).

Notably, in this sample, all children met the 30-minute MVPA goal across the school day, which was similar to Nettlefold et al.'s (2011) finding of 91% in girls and 96% in boys. Additionally, 81.2% of children spent at least 40% of break time engaged in MVPA, and 30.4% met the goal of 50% of PE spent in MVPA. Although our school-day minutes of MVPA are higher than previously reported, several studies that examined whole-day PA in youth found numbers similar to our school-day PA values. Using accelerometry at a one-minute epoch in 8- to 10-year-olds, Mota et al. (2005) found whole-day MVPA values of 137 and 142 minutes per day for girls and boys, respectively. Also using a one-minute epoch, Riddoch et al. (2004) quantified whole-day MVPA in nine-year-olds as 160 and 192 minutes per day for boys and girls, respectively. These high values for whole-day MVPA, along with the observation that a significant amount of children's activity occurs during school, suggest that our school-day values, as measured using a one-second epoch, are plausible (Mota et al., 2005; Steele et al., 2010).

Remarkably, few studies have described school-day MVPA using a one-second epoch. Because children tend to participate in multiple sporadic, short bursts of movement, using a longer epoch length is likely to underreport true PA in children, as the longer sampling interval dilutes these bursts across a long epoch (Baquet et al, 2007; Chen & Bassett, 2005; Ekelund et al., 2011). Although little objective data exists for MVPA accumulation across short epochs, direct observation studies can provide insight into PA potential when measured at a high-resolution. Sleap and Warburton (1996) conducted continuous direct observation across a three-second sampling period to quantify MVPA in 5- to 11-year old boys and girls during school playtime (i.e., recess, lunch, and PE) and the afterschool period. Across a 418-minute observation period, they detected an average of 122 minutes of MVPA and an average of 50% of school playtime spent in MVPA. These numbers are strikingly comparable to our findings of 122 minutes of school-day MVPA (across a 400-410 minute sampling period) and 49% of break time engaged in MVPA.

To further explore our data, we considered bout length data from the present study as well as evidence from McClain, Abraham, Brusseau, and Tudor-Locke (2008) regarding differences in MVPA estimates by varying epoch length. In our data, moving from a one-second to a five-second bout of MVPA decreases MVPA estimates by 39%; furthermore, as demonstrated by McClain et al. (2008), moving from a five-second to a 15-second epoch decreases MVPA estimates by an additional 10%. When applying these corrections to our data, school-day MVPA estimates decrease from 122 minutes to 67 minutes (122-(122*.39) =74.4 minutes; 74.4-(74.4*.1)=67 minutes). Thus, our data, as viewed comparably to data collected at a 15-second epoch, is very similar to Nettlefold et al.'s finding of 64 minutes of school-day MVPA when quantified by a 15-second epoch. Thus, we are confident that the large amount of school-day MVPA presently reported is a function of the one-second measurement period.

Challenges also exist in ACC placement and ACC processing procedures. Although current studies are moving toward the use of wrist-mounted ACCs, few report PA data obtained from wrist-mounted devices. Moving from a hip-mounted to a wrist-mounted protocol has shown to increase compliance in adults and children, resulting in more data being available to researchers (Phillips et al., 2013; Rosenberger et al., 2012; Schaefer, 2011). Furthermore, lack of standardization in ACC processing also influences PA data. Specifically, there is little consensus on definitions of non-wear and appropriate PA intensity cutpoints. Using a hip-mounted ActiGraph ACC collecting at a one-minute epoch, Reilly et al. (2008) analyzed seven days of free-living data in 172 children (mean age 5.8 years) by applying three different published cutpoints. Cutpoint development in these studies ranged from free-living calibration studies in children to extrapolation from treadmill-based calibration studies in adults. Notably, time spent in MVPA ranged from 28 to 266 minutes per day depending on cutpoints applied. Overall, they concluded that based on biological plausibility and robustness of calibration procedures, cutpoints indicating 28 minutes to 41 minutes of MVPA across the day are more conceivable than those indicating higher amounts (Reilly et al., 2008). However, no universal consensus has been drawn to support any particular set of cutpoints over another.

Because of these differences in ACC protocols and lack of standardization across researchers, large variation in the absolute number of minutes of PA accumulated as well as the percentage of children meeting guidelines exists (Ekelund et al., 2011). Our data suggest that, based on ACC data collected at the wrist and quantified by a one-second epoch, children may be getting more movement throughout the school day than previously estimated. Despite this finding, children are still likely to benefit from increased school-day PA. It is important to note that there is currently little concrete evidence to support the 30-minute guideline for school-day MVPA or the guidelines for each CI (Carlson et al., 2013; Twisk, 2001). Furthermore, currently proposed guidelines are based on minutes of sustained, consecutive movement, which we now know is not characteristic of how children move. It is likely that guidelines based on children's typical movement patterns will be different from those originally proposed.

As critically reviewed by Twisk (2001), similar challenges exist for the 60-minute MVPA recommendation across the whole day. Notably, no longitudinal dose-response studies in children have reported the nature of the relationship between increased MVPA in childhood and both youth and adult health (Strong et al., 2005; Twisk, 2001). Thus, we do not yet know the optimal amount of school-day or whole-day MVPA for youth, as no data currently suggest a threshold at which health benefits from increased PA plateau in youth. Given the unsubstantiated nature of the current guidelines and the lack of a clear MVPA threshold in youth, children are likely to experience increased health benefits as they participate in increased school-day PA, even above the proposed guidelines.

Although these data indicate that 100% of the sample met the goal of 30 minutes of MVPA during the school day, which was similar to Nettlefold and colleagues' (2011) finding of about 90%, significant variability in school day PA did exist. While the average percentage of the school day spent in MVPA was 30%, the range between high- and low-PA achievers was 32%, or 132 minutes per school day. Additionally, based on current findings as well as those reported previously (Nettlefold et al., 2011), older children, particularly those between third and fifth grade, are critical targets for increasing overall school-day PA. Specifically, efforts should be made to increase school-day MVPA in low-PA achievers, such that the current school day mean for MVPA can be raised from 30% (122 minutes). Examples of strategies to increase MVPA accumulation include active academic lessons, peer-led active recess periods, recess before lunch, and organized, structured PE curricula. Additionally, to promote school-day PA across the entire school, a school-wide culture of PA promotion must be adopted. Notably, PA should not be taken away as punishment for bad behavior or poor academic performance; conversely, PA should not be assigned as punishment during break time or PE periods.

Based on the maximum school day values observed in this sample, this investigation suggests that it is possible for children to engage in MVPA for up to 43% (176 minutes) of the entire school day. While it is understood that not all children will reach the maximum values found in this study, these findings indicate that in the absence of any external school-based PA interventions there is potential to increase school day PA by up to ~50 minutes per day. Notably, because almost 75% of the sample spent between 26% and 37% of the school-day in MVPA, it is likely that an appropriate school-day MVPA goal lies between 26% and 43% of the time spent in MVPA. Again, it is critical to note that this goal reflects wrist-mounted PA data collected at a one-second epoch; goals for ACC data collected through different methods may vary significantly. For instance, recommendations based off of a 15-second epoch or greater would be significantly lower than the numbers currently presented. As Reilly et al. (2008) moved from a 15-second to a 60-second epoch using a hip-mounted ACC, estimates of daily MVPA decreased by 40%, suggesting that MVPA goals would change by a similar amount. However, best-practices in accelerometry measurement in a child population suggest that a one-second epoch is most representative of children's movement and that wrist-mounted devices are valid and accurate while promoting increased compliance (Baquet et al., 2007; Esliger, 2011; Phillips et al., 2013; Rosenberger et al., 2012; Schaefer, 2011). Thus, the school-day MVPA reported in the current investigation is potentially a more accurate representation of children's school-day movement than what has been previously reported.

Each CI exhibited variability in the percentage of time children spent in MVPA. On average, children spent about 95 minutes of class time engaged in MVPA per day, which is more than five times higher than the previously suggested 90-minutes of weekly class-time MVPA (Gibson et al., 2008), indicating that class-time goals can be increased substantially. Although we do not have direct observation data to provide an exact account of the activities that elicited MVPA during class time, it is likely that much of this activity was accumulated in short bursts of movement from activities that included moving across the room to sharpen a pencil or fidgeting at one's desk; however, with non-traditional learning strategies becoming more prominent across elementary schools, it is also likely that the nature of such lessons elicited significant class-time MVPA. Notably, increasing PA during class time does not imply decreasing time that is allotted for academic lessons; on the contrary, PA can be incorporated into active academic lessons. With new teaching techniques that promote PA (e.g., TAKE 10!, classroom activity breaks/"brain breaks", active lessons, and FitSticks), it is becoming more feasible to introduce activity into the academic setting. A 2011 review of the TAKE 10! program found that teachers were both willing and able to incorporate active lessons into their curriculum, and that children receiving such lessons spent ~13% more time in PA during class time compared to those who did not (Kibbe et al., 2011).

Similar to school-day MVPA analyses, first and third graders spent a significantly greater percentage of class time in MVPA than did fifth graders, again suggesting the period between third and fifth grades as a critical time for PA interventions. Notably, teachers at these grade levels must continue to strive to incorporate PA into their classrooms. To do so, however, feedback surrounding the class' overall PA levels throughout the day is necessary. Future innovations surrounding PA monitoring should explore potential devices and programs that would allow teachers to quickly and accurately monitor their efforts to increase PA in the classroom. Without such information, teachers have little knowledge surrounding how active their classes truly are or the effectiveness of their PA-efforts.

Finally, children also demonstrated significant variability during traditionally active periods of the school day, including break time and PE. Notably, these CIs presented the greatest variability between high-and low-PA achievers. Break time offers the greatest opportunity for individual freedom in PA participation across the school day, and it is also likely to provide an environment that promotes PA, probably to a greater extent in some children than others. During break time, children spent an average of 49% of the CI engaged in MVPA. This mean is higher than the 40% goal set by Nettlefold and colleagues (2011), indicating that the potential exists to increase break time PA goals across children. For example, 81.2% of children in this sample spent at least 40% of break time engaged in MVPA, which was significantly greater than the approximately 45% suggested by Stratton and colleagues (2006). However, Stratton et al. (2006) reported break time MVPA using data collected through hip-mounted devices at a five-second epoch; thus, variation in measurement protocols may explain the difference between samples. Furthermore, the maximum percentage of break time spent in MVPA was 72%, indicating that an appropriate break time goal is likely between 50% and 70%.

It is critical to note that during break time, boys spent a greater percentage of time engaged in MVPA than did girls and were more likely to meet the goal of 40% of break time engaged in MVPA. Thus, while older grades must be targeted for increased activity during class time and the entire school day, girls must be targeted during break time. These findings are consistent with earlier work that indicates that boys accumulate significantly greater PA than do girls, particularly during school break times (Cox et al., 2006; Mota et al., 2005; Nettlefold et al., 2011; Olds et al., 2009; & Tudor-Locke et al., 2006). Previous studies that have demonstrated gender differences during recess propose that boys thrive during unstructured periods of PA (i.e., break time), whereas girls tend to accumulate greater MVPA during periods of structured activity (Bailey et al., 2012). Thus, active recess interventions that provide structured, female-specific activities during break time are warranted.

During PE, children spent an average of 42% of the CI in MVPA. Additionally, only 30.4% of children met the current 50% PE goal, which was significantly higher than the <5% cited by Tudor-Locke et al. (2006). While it may seem counterintuitive that children would accumulate more MVPA during a shorter and unstructured break period than during a longer, structured PE period, several studies suggest that children, and particularly boys, are more active during unstructured vs. structured play (Bailey et al., 2012; Trost, Rosenkranz, & Dzewaltowski, 2007). Additionally, PE class requires time at the beginning and end of class for organizational tasks including lesson instructions and classroom management, thus decreasing the percentage of time left for MVPA. Based on our findings, the average percentage of PE time spent in MVPA is lower than the currently recommended 50%; however, the maximum value of 69% indicates that a 50% goal is realistic. PE teachers could promote the attainment of this goal by providing activities that keep all children active during a majority of the PE period. Providing organized, standards-based PE curricula, which is not currently required across the majority of states (Carlson et al., 2013), is one strategy to improve the quality of PE and, consequently, increase the percentage of PE time children spend in MVPA. Notably, PE should be restructured to focus on motor skills (particularly in the younger grades) and life-long fitness, rather than sports-based activities that are likely to exclude low-active children or leave a large majority of the class inactive while a select few are playing. SPARK PE is one example of a PE curriculum that promotes these goals (Sallis et al., 1997).

On one hand, break time and PE demonstrated the greatest range in percentage of time spent in MVPA; on the other hand, these CIs represent only a small fraction of the school day. Thus, interventions during these periods might be successful in significantly increasing the percentage of time spent in MVPA for the particular CI, but such increases would likely only amount to a few minute increase in daily MVPA. In contrast, while class time interventions might not be as successful in drastically increasing the percentage of time spent in MVPA, smaller increases during this longer time period would likely amount to a greater number of additional daily minutes engaged in MVPA. These findings present the need for PA interventions that center on the entire school day, and not just those that focus on break time and PE. One possible strategy to achieve this goal is to promote longer bouts of sustained MVPA during break time and PE, while encouraging short and sporadic bouts of MVPA (i.e., movement typical of child PA) during class time. This combination of prolonged and sustained movement along with short, sporadic bursts of activity is likely to improve both health status and functional capacity in children compared to either strategy alone.

Notably, we found that high- and low-PA achievers differed significantly in the percentage of time spent in MVPA across all CIs. Figure 5 graphically represents the SVM values (indicative of PA intensity) calculated for both a high-PA achieving first grader and a low-PA achieving first grader. This figure visually depicts the findings from our statistical analyses, particularly, that the magnitude of PA accumulation is significantly greater in high-compared to low-PA achievers across the entire school day, and predominantly during AM recess, lunch/recess combined, and PE.

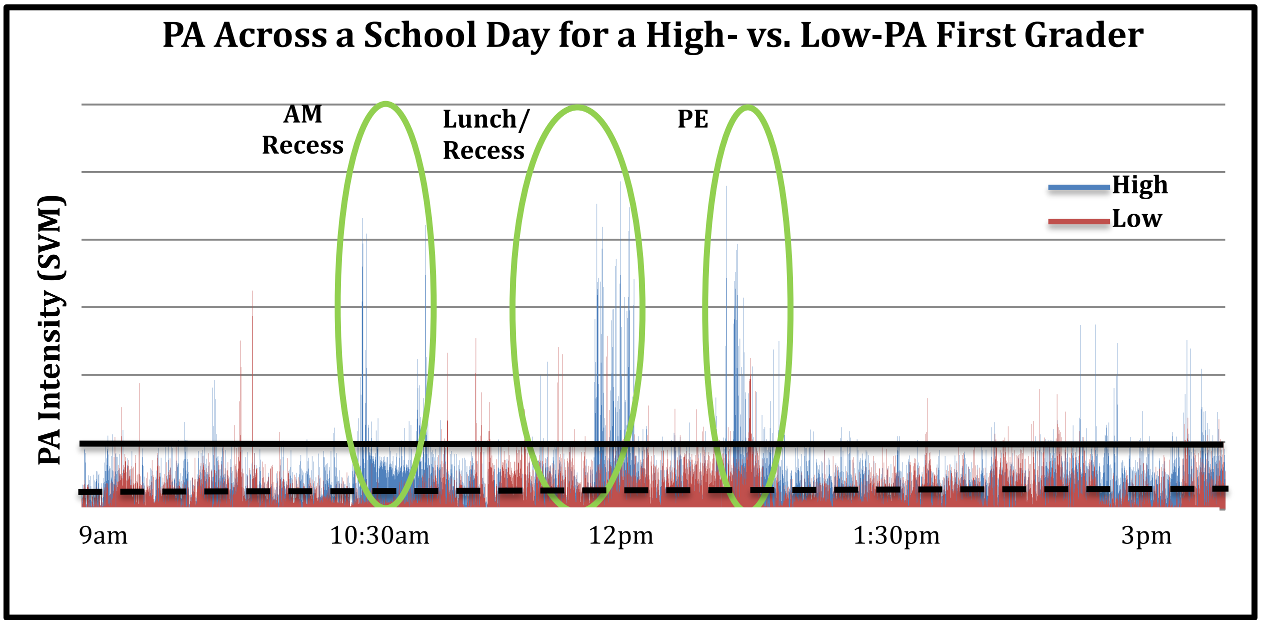

Figure 5. SVM values (representing PA intensity) plotted by time (seconds) for a full school day. The highly active child (School-day PA Quartile 4; Male, NW, 7yrs. old, 34% of the school day in MVPA) appears in blue. The low active child appears in red (School-day PA Quartile 1; Male, OB, 7yrs. old, 24% of the school day in MVPA). Horizontal lines represent MPA (dashed line) and VPA (solid line) thresholds.

Based on these findings, we did not identify a particular time of the day during which interventions should target low-PA achievers. Rather, on average, low-PA achievers accumulate less MVPA across all CIs. Such conclusions are similar to those of Fairclough and colleagues (2012) who found that high- and low-PA achievers accumulated significantly different amounts of MVPA during all school day periods, but that greatest differences actually occurred after school.

Interestingly, when looking at differences in weight status by grade, we found a significantly greater percentage of OW/OB children among fifth graders than among first graders in the whole sample and a similar trend in the valid sample. Additionally, a main effect of grade was found for the whole school day and class time, such that first graders spent a significantly greater percentage of time in MVPA than did fifth graders. These findings potentially indicate that a decreased percentage of time spent in MVPA may be correlated with an increase in OW/OB prevalence in older grades (i.e., fifth grade). However, in contrast to previous findings (Soric et al., 2010; Trost et al., 2001), we did not find a main effect of weight status on percentage of the school day or CIs spent in MVPA.

It is important to consider accelerometry methodology when interpreting these findings. Specifically, we used a one-second epoch, which is capable of picking up short bouts of movement but is not necessarily indicative of sustained movement. It may be that sustained movement, which is measured in analyses of longer PA bouts, is more strongly correlated with weight status than are short bursts of motion. Future analyses should explore these data in longer bouts (i.e., 2-sec, 3-sec, 5-sec, 10-sec, 15-sec) to see if sustained activity is, in fact, associated with weight status across this dataset. Secondly, the present analyses centered on MVPA and did not consider MPA and VPA separately. As seen in Trost et al. (2007), it may also be that MVPA is similar across children of all weight status, but that VPA makes up a greater proportion of time spent in MVPA in NW compared to OW/OB children. This finding would suggest greater energy expenditure in NW children, regardless of the similar amount of time spent in MVPA. Preliminary analyses of our data set do not suggest that either of these explanations is valid, as the presented findings remained when exploring further analyses of bout length and PA intensity.

Overall, these data suggest that MVPA accumulation across the school day is independent of weight status. Thus, it is likely that factors other than school-day PA are implicated in childhood OB etiology. Notably, diet is one factor that varies considerably across children. Several studies have explored the association between PA and diet in adults (Charlot &

Chapelot, 2013; Lluch, King, & Blundell, 2000; Hagobian et al., 2013), but few have looked at this relationship in children. Much debate exists over whether PA precipitates increased caloric intake due to increased appetitive signals or whether it suppresses appetite post-exercise, leading to caloric deficit. It may be that OW/OB children engage in comparable amounts of PA to NW children but are consuming a larger number of calories, either from hedonic pathways that differ between NW and OW/OB, from an overcompensation of food intake post PA-participation, or from a home environment that promotes consumption of low-nutrient, high-energy dense foods.

Additionally, it is possible that high-active OW/OB children compensate for increased school-day PA by decreasing activity in the after school and evening periods, while high-active NW children do not. Preliminary analyses across this sample did not suggest compensation to be the case in high-PA achievers; when looking solely at high PA achievers (i.e., Quartiles 3 and 4), no differences in after-school and evening MVPA were seen by weight status. However, when considering low-PA achievers (i.e., Quartiles 1 and 2), NW children spent a greater percentage of the after school and evening period in MVPA than did OW/OB children. Future analyses should continue to explore the constructs of both diet and PA compensation in children to determine whether they are possible risk factors for obesity.

Despite these findings between PA and weight status, we must acknowledge that PA provides countless benefits independent of its effects on weight status. Not only does PA provide positive physical and psychological benefits (Janssen & LeBlanc, 2010), but it has also shown to improve both behavior and performance in the academic setting (Caterino & Polak, 1999; Fedewa & Ahn, 2011). Physical fitness in children, but not weight status, has shown to positively predict performance on standardized Math and Reading Exams in children from fourth to eighth grades (Rauner, Walters, Avery, & Wanser, 2013). These findings emphasize the importance of PA, and particularly school-day PA, independent of child weight status.

An exciting implication of these findings is the application of social network theory to increase PA across the school day. Social network theory suggests that both obesity and PA are connected to an individual's social group, both the immediate social group and more distant social groups (Christakis & Fowler, 2007; Macdonald-Wallis, Jago, Page, Brockman, & Thompson, 2011; Voorhees et al., 2005). Thus, PA levels are likely to increase among members of a social group if one of the members is or becomes a high-PA achiever; notably, these relationships appear to be causational, and not merely a function of individuals who share certain characteristics becoming friends. Because high- and low-PA achievers did not differ by weight status, it does not appear that children are discouraged from PA by weight status. Thus, it is possible to engage high-PA achievers (both NW and OW/OB) as role models to help increase school-day PA among low-PA achievers. With a diverse mix of children of both weight statuses in the high-PA quartiles, it is more likely that these role models will reach the similarly diverse low-PA achievers than if the groups differed significantly by weight status. Future school-day PA interventions should explore the possibility of enrolling high-PA achievers as student PA ambassadors to lead active recess periods and implement school-based PA programs.

The primary strengths of this study were its temporal lens in examining PA and PA variability across the school day as well as its high statistical power (0.99) at $p<0.05$. It also used a one-second epoch, which is better able to capture sporadic movement characteristic of the pediatric population and a wrist-mounted design, which promotes increased compliance. However, a one-second epoch presents challenges in interpreting the data, as it is not yet known what bout length of activity is physiologically meaningful and potentially indicative of health benefits in children. Future studies must begin to explore the optimal PA bout length in children as it relates to numerous health benefits. In addition, while field-based research is more representative of real-world application than are lab-based studies, we must acknowledge a lesser amount of control in community work. For instance, while we attempted to clean our data for non-wear or ACC malfunction, it is impossible to know the nuances of children's ACC wear. Additionally, while we collected school day schedules from teachers to indicate times corresponding to each CI, it is likely that daily schedules varied slightly from the times provided. Similarly, we were unable to control for the effects of the individual teacher across each of the nine classrooms examined.

Despite these limitations, this study provides an objective view of the temporality and variability of school-day PA. Overall, we see that younger children spend a greater percentage of time in MVPA across the entire school day and during class time than do older children; boys spend a greater percentage of break time in MVPA than do girls; and school-day MVPA accumulation does not appear to vary by weight status. Furthermore, low-PA achieving children spend a consistently smaller percentage of time in MVPA during the entire school day and during each CI than do low-PA achieving children, suggesting that low-active children need to be targeted for increased PA during all times of the day. However, break time and PE presented the greatest ranges in the percentage of time spent in MVPA across children, indicating a significant potential for increased PA in low-PA achievers during these times, particularly focusing on girls during the break time period. Based on the largest percentages of time spent in MVPA across the whole school day and each CI, it is possible for 43% of the school day, 41% of class time, 72% of break time, and 69% of PE to be spent in MVPA in the absence of any targeted school-day PA interventions. While we do not suggest that every child is capable of reaching these goals on a daily basis, we do know that a greater potential for school-day PA, as a whole, exists.

Our data suggest that a significantly greater percentage of the school-day is being spent in MVPA than was previously thought. However, these goals are reflective of one-second epochs, which denote movement, and not necessarily sustained activity. Thus, further research surrounding meaningful bout lengths in children is needed before goals are set for PA interventions. Additionally, a strong call for standardization across research groups exists before PA data can be confidently compared across groups and universal school-day PA recommendations can be formed. Such standardization is most critically needed for epoch length and ACC placement. If best-practices continue to move toward wrist-mounted devices collecting at one-second epochs, school day PA goals will need to be increased and will likely resemble the data present in the current paper. Future considerations must also examine whether children who are more active during the school day compensate for higher school day activity by reducing activity outside of school. It may be that differences in MVPA between NW and OW/OB children exist for activity outside of school and for activity across the whole day, but not for school day activity.

Conclusion

The school day is a critical period of MVPA accumulation, with as much as 43% of the school day spent in MVPA. Our results suggest that elementary-aged children, regardless of weight status, are meeting/exceeding recommended amounts of school-day MVPA. Despite these findings, and because of the numerous health and academic benefits stemming from PA, efforts must still be made to increase school-day PA across all children. However, older children are significantly less active across the school day than are younger children, and girls are less active during break time than are boys. These individual differences in school day MVPA accumulation indicate that older children and girls must be targeted to increase the average percentage of time spent in MVPA across the school day. Thus, even in the absence of school-based intervention efforts, there is still room for increasing mean school-day MVPA, potentially by up to ~50 minutes per day. Based on significant variability in PA accumulation across the whole school-day, school-based interventions should focus on the entire school day, while specifically targeting recess and PE. Before school-day PA recommendations are revised, however, there is a need for standardization across accelerometry measures to ensure that PA in children is being accurately and reliably quantified.

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