Towards a better understanding of physical activity among children and adolescents

by

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CHAPTER 1.

INTRODUCTION

INTRODUCTION

Physical activity has been defined as any bodily movement produced by skeletal muscle that increases energy expenditure above resting values (Casperson et al. 1985) and includes obligatory, spontaneous, and purposeful body movements. Physical activity also represents the most variable component of total daily energy expenditure. From a research perspective, physical activity can either be an independent or dependent variable, and thus the need for the accurate measurement of physical activity is paramount (Welk 2002). More specifically, accurate measures of physical activity play a critical role in surveillance (Pate et al. 2002), the development of guidelines and recommendations aimed at reducing the risk for health-related problems (Strong et al. 2005), and the improvement of observational and intervention research (Epstein et al. 2005).

The goal of any assessment is to minimize the difference between the true and the measured level. This difference can be viewed as error, which in turn can be classified as systematic and/or random (Equation 1.1).

Equation 1.1 $$X_i = T_i + b + E_i,$$

where X_i is the true measure, T_i is the measured value, b is the systematic error and E_i is the random error.

Systematic error occurs when the measured value consistently under- or over-estimates the true value. In physical activity research involving children and adolescents, variation in body size is a source of systematic error that has largely been unaccounted for in research designs. Typically, the sample is separated by gender and compared across chronological age groups, regardless of differences in body size. Accounting for differences in body size is important in the interpretation of physical activity data among youth given the

heterogeneous physical characteristics of similarly aged youth (Eisenmann and Wickel 2005). In contrast to systematic error, random error is bi-directional and exists as analytical and biological error. In terms of physical activity assessment research, the analytical error can be reduced by using an assessment tool with low inter- and intra-device variability and by adhering to consistent protocol instructions. Biological error occurs when the actual level of physical activity changes between measurements (e.g. day-to-day variation). Thus, understanding the day-to-day variability in physical activity is valuable to ensure the proper design, analysis, and interpretation of studies of physical activity and health.

Determining the contribution of daily activities, such as youth sport, recess, and physical education will also aid in interpreting day-to-day differences in physical activity levels and add to a better understanding of the physical activity phenotype among youth. Beyond this measurement aspect, understanding the day-to-day variability in physical activity may also shed light onto the biological basis of activity (Thorburn and Proietto 2000). From a biological perspective, Rowland (1998) has summarized the importance of physical activity during childhood and has offered theoretical and empirical evidence that suggests daily levels of physical activity are controlled within the central nervous system in an effort to regulate energy homeostasis. Thus, an examination of the day-to-day variability may provide additional insight into the biological basis of physical activity.

Overall, understanding and accounting for sources of error in study designs and statistical analyses will minimize the difference between the measured and true value. In this dissertation I examine and explain sources of error and variation associated with physical activity assessment among youth. Sources of systematic (body size) and random (day-to-day variability) error will be examined and interpreted to improve the assessment of physical

activity and to provide a better understanding of the physical activity phenotype during childhood and adolescence. This information is valuable in the interpretation and development of physical activity guidelines and recommendations aimed at improving the quality of health among youth.

Altogether, the series of papers presented in this dissertation will allow for a better understanding of the assessment, interpretation, and sources of error associated with the physical activity phenotype during growth and maturation. To provide appropriate background for this research an extended literature review on physical activity (current levels of physical activity; methods of physical activity assessment; age-, gender- and maturity-related differences) is provided in Chapter 2. Each chapter thereafter is a study in manuscript form (i.e., abstract, introduction, methods, results, discussion, acknowledgements, and references). Some aspects of each paper, particularly the methods section, are repetitive, but lend to the readability of the paper. Chapter 3 examines the influence of body size on the assessment of physical activity and seeks to validate a widely used energy expenditure prediction equation. Chapter 4 describes the day-to-day variability in the energy expended through sedentary, light, moderate, and vigorous activity. Chapter 5 describes the maturity-associated variation in physical activity. Chapter 6 examines the contribution of youth sport to total daily physical activity. The final chapter provides a summary of findings in this dissertation and recommendations for future research (Chapter 7).

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CHAPTER 2.

LITERATURE REVIEW

INTRODUCTION

The terms physical activity and energy expenditure are widely used throughout the exercise science literature; however, they are not interchangeable. Physical activity includes any movement, voluntary or involuntary, produced by skeletal muscle and encompasses leisure time physical activity, exercise, sport, occupational work, household chores, and spontaneous movement (Casperson et al. 1985). Physical activity can be assessed with instruments that record the body's response to mechanical movement (e.g., pedometers and accelerometers), physiological stress (e.g., heart rate monitors and indirect calorimetry), or a combination of both (e.g., Sensewear Armband). Energy expenditure reflects total-body metabolism and encompasses the metabolic cost associated with maintaining basal levels of metabolism, the energy cost of physical activity, the thermic effect of food, and the energy cost of growth in children and adolescents. Resting metabolic rate accounts for the greatest percentage of total energy expenditure (~60-70%), while the thermic effect of food (~5-10%) and cost of growth (<3%) contribute relatively smaller amounts to total energy expenditure. The energy cost of physical activity (i.e., activity energy expenditure) is the main modifiable component of total energy expenditure (Goran et al. 1993), and therefore the assessment of physical activity has become the focus of many health-related studies.

Precise measures of physical activity are important for several reasons. From a public health perspective, understanding the dose-response relationship between levels of physical activity and health is critical in creating physical activity recommendations (Strong et al. 2005) and monitoring physical activity participation rates (e.g., surveillance research) (Pate et al. 2002). An accurate assessment of physical activity is also needed to improve our understanding of biological and behavioral factors that influence levels of physical activity

(Sallis et al. 2000), which in turn advances intervention research (Epstein et al. 2005). Among youth, a number of factors make the assessment of physical activity a challenge (Welk et al. 2000). For example, youth activity patterns are brief and intermittent (Bailey et al. 1995) and involve a variety of movement patterns, some of which are difficult to capture with current assessment tools (e.g., upper body movements, cycling, swimming). Thus, inaccurate depictions of physical activity may exist because of the limitations of the assessment tool or because of the participant's inability to accurately recall previous activity. It is generally recommended that self-report tools should not be used among children less than 10 yrs old because of their uncertain cognitive ability to describe previous bouts of activity (Sallis 1991). Beyond the cognitive issues surrounding self-report tools, the act of monitoring physical activity may lead to a misinterpretation of actual levels of physical activity. The term *reactivity* has been used to describe the change in behavior during physical activity monitoring. Additionally, little is known about biological factors that may influence the interpretation of physical activity levels. For example, differences in body size may influence the interpretation of energy expenditure prediction equations. Also, the potential effects of biological maturation on levels of physical activity in boys and girls are not well understood.

The purpose of this review is to summarize the various physical activity assessment tools and physical activity recommendations. This review will also summarize the current levels of physical activity with special reference to the age-, gender- and maturity-related variation in activity levels among boys and girls.

METHODS OF ASSESSING PHYSICAL ACTIVITY

A number of physical activity assessment tools are currently available; however, no single assessment tool perfectly measures physical activity, especially among children (Welk et al. 2000; Sirard and Pate 2001). The goal of any assessment tool is to measure one or more dimensions of physical activity (i.e., type, frequency, duration, or intensity). The *type* of physical activity can be broadly categorized as aerobic or anaerobic, walking or running, daily chores or sport. The *frequency* of activity refers to the number of bouts per day or week, while the *duration* of activity indicates the number of minutes or percent of time in activity per hour or per day. The *intensity* of activity describes the relative degree of effort and is commonly reported as a percentage of maximal effort or absolute value (e.g., 3 METS).

Physical activity assessment tools can be classified as subjective or objective. Subjective assessment tools, such as questionnaires, diaries, logs, and interviews, are commonly used to describe the type, frequency, duration, and intensity of physical activity. Subjective tools provide a time- and cost-efficient method to capture information about activity among a large number of people; however, subjective tools require individuals to report previous bouts of activity, and thus may be limited by recall bias. Individual and/or cultural perceptions of physical activity may also limit the use of subjective tools. For example, some individuals may not account for certain types of activity (i.e., leisure activity) because it is enjoyable and may not be considered in the same context as moderate-to-vigorous physical activity.

To combat the methodological issues associated with subjective assessment tools, objective tools offer an alternative approach to measure physical activity. Objective

assessment tools measure physical activity according to mechanical (pedometers and accelerometers) or physiological (heart rate monitors and indirect calorimetry) responses to bodily movement. Although objective tools reduce the amount of human error (i.e., recall bias), other sources of measurement error can be introduced. For example, pedometers and accelerometers likely underestimate true levels of physical activity because they are unable to accurately assess non-locomotor activities (swimming or biking) or upper body movements. Thus, advantages and disadvantages exist for each assessment tool; however, each tool fills a special niche in physical activity related research. A detailed description of subjective and objective assessment tools has been provided elsewhere (Sirard and Pate 2001; Welk 2002; Livingstone et al. 2003), and therefore a brief overview of several assessment tools with special interest to the child and adolescent population is provided below.

Self-Report

Questionnaires, diaries, and logs offer a practical approach to measure physical activity because they can be administered to a large group of individuals at a relative low cost. For this reason, self-report tools are used in large epidemiological studies and national surveys to monitor levels of physical activity (e.g., Youth Risk Behavior Study (YRBS)). The YRBS is a representative survey that examines health-related risk factors of high school students between grades 9 and 12. Data from the YRBS is used to examine age, gender, and ethnic differences in physical activity and inactivity (e.g., television viewing (hrs/wk)) and annual participation rates for physical education and organized sport. Data from the YRBS is also used to create physical activity objectives for adolescents nationwide (e.g., HealthyPeople 2010).

Additional self-report tools are also available to characterize habitual activity (e.g., Physical Activity Questionnaire for Children (PAC-Q)) or capture activities over multiple days (e.g., 3-day Bouchard activity diary). The Bouchard diary is unique in that total energy expenditure can be estimated by summing the metabolic cost of daily activities; however, the standard metabolic cost associated with each activity, including rest, negates the inter-individual variability in metabolic efficiency for a given activity. Nonetheless, Bratteby et al. (1997) found an acceptable level of agreement between total energy expenditure calculated from a version of the Bouchard diary and the doubly labeled water method among 50 adolescents over a 7-day period. The mean difference in total energy expenditure between the two methods was 1.2%.

An accurate assessment of physical activity using self-report depends on the ability of the participant to recall daily activity. In contrast to adult patterns of activity, children's activity is quite irregular with most bouts of vigorous activity lasting less than 15 seconds and rest intervals approximating 4 minutes (Bailey et al. 1995). This intermittent pattern of activity likely contributes to a child's cognitive inability to provide accurate self-report assessments of daily activity. Self-report tools that divide the day into specific intervals of time may also lead to an inaccurate view of physical activity. For example, a 15-min interval of time may include bouts of light, moderate, and vigorous intensity activity; however, only the predominate activity intensity can be reported. Thus, over- or under-estimations may occur with a coding scheme that separates the day into distinct intervals of time.

Self-report tools provide an attractive compliment to objective assessment tools because information regarding the type and time of daily activity can be recorded. This information becomes especially useful in the interpretation of accelerometer data, which is

time coded upon downloading. Specifically, self-reported times can be used to examine the contribution of daily activities (recess, physical education, youth sport) and also verify protocol compliance. A collection of physical activity questionnaires for health-related research has been published in a compendium in *Medicine and Science in Sports and Exercise* (1997).

Pedometers

Pedometers provide a relatively inexpensive (~$20) way to objectively measure the volume of physical activity (steps/day); however, information regarding the type of activity or the number and duration of activity bouts is unattainable. An indication of intensity can be calculated with a pedometer by dividing the total steps by the minutes worn (e.g., 4200 steps/60 min = 70 steps/min); however, this approach is rarely used because the outcome (steps/min) may not truly represent the intensity level over the entire assessment period.

Despite the pedometer's practical approach to measure physical activity (i.e., steps/day) strong correlations have been found between pedometer steps and activity counts from an accelerometer (median r = 0.86) and time spent in activity assessed with direct observation (median r = 0.82) (Tudor-Locke et al. 2002). Also, Rowlands et al. (1999) determined that pedometer step counts over 3-6 days is significantly correlated with cardiorespiratory fitness in 8 to 10 yr old children (r= 0.59). This convergent agreement between outcome measures from other assessment tools lends support for the utility of pedometers to measure physical activity; however, issues do exist regarding the accuracy of pedometers at slow speeds (Beets et al. 2005). Among 20 children (10 boys and 10 girls), pedometer-derived steps were compared to observed steps during treadmill walking at 40, 54, 67, 80, and 94 m/min. Acceptable levels of agreement were found for speeds above 67

m/min, however, the pedometer's ability to accurate record steps at speeds less than 67 m/min was limited (Beets et al. 2005). The pedometer's lack of accuracy at slow locomotor speeds has also been observed among adults (Melanson et al. 2004). Together, these findings suggest that a locomotor speed threshold may exist for the pedometer to accurately record step counts. This issue may be particularly important for younger children who move slowly throughout the day.

A separate issue with pedometry involves the interpretation of pedometer steps between children of varying body size. For instance, there is an observable differences in leg length exist between 6 and 12 year old children. The difference in segmental length is important to consider because the number of steps to cover a given distance will be greater in the younger child. Thus, should 12,000 steps for a 6 year old be considered equivalent to 12,000 steps for a 12 year old? Using allometric principles, we previously determined that pedometer steps between a 6 and 12 year old can only be considered the same if they are taken at the same speed (Eisenmann and Wickel 2005). Unfortunately, pedometers are limited in that they are unable to distinguish between different speeds. Nonetheless, special attention should be directed to interpreting pedometer steps among children of varying body size and locomotor characteristics.

As mentioned earlier, a certain amount of reactivity exists with each activity-monitoring tool. Since the outcome measure from a pedometer (total steps) can be viewed by the participant, normal behavior may be altered or daily step totals may be physical manipulated (e.g., shaken) in an effort to achieve a daily step goal (i.e., 10,000 steps/day). An approach used by Vincent and Pangrazi (2002) to examine reactivity among children involved the use of sealed pedometers that eliminated the visual feedback (i.e., step total).

While the authors concluded that reactivity was not an issue in children using sealed pedometers, few have examined the issue of reactivity using unsealed pedometers. Ozdoba et al. (2004) reported that pedometer steps accumulated from a sealed pedometer were not significantly different from the number of steps recorded with an unsealed pedometer.

Pedometers provide a simple and practical approach to measure physical activity among children and adults. Daily step recommendations have been established to promote lifestyle improvements and their ease of use allows individuals to track relative changes over time. Thus, pedometers are a valuable tool for the general population and researchers.

Accelerometers

(Note: Since accelerometers are the main tool used in this dissertation, a more detailed review is provided here). Accelerometers are now widely used to measure physical activity among children and adults because they provide a comprehensive description of daily activity (e.g., frequency, intensity, and duration). Accelerometers use internal piezoelectric transducers and microprocessors to convert bodily accelerations into quantifiable digital signals, referred to as activity counts. These activity counts are recorded and stored in intervals ranging from 1 second to 10 min periods, or epochs. Activity counts can be expressed as counts/day or counts/min, or they can be converted into units of energy expenditure (kcal/min or METs) or time spent above a particular intensity level (e.g., moderate-to-vigorous physical activity) using available regression equations or cutpoints.

Choosing the appropriate epoch is a critical first step in designing a research study (Trost et al. 2005). For example, too long of an epoch (e.g., 10 min) would mask the intermittent pattern of activity observed in children, while short epochs (e.g., 1-sec) may provide data that is difficult to interpret and limits the storage capacity of the instrument.

Traditionally, 1-min epochs have been selected and therefore are most commonly used to predict energy expenditure (kcals/min or MET value); however, a certain amount of debate exists regarding the appropriate epoch interval to describe the nature of youth physical activity. Nilsson et al. (2002) demonstrated an inverse relationship between epoch length and estimated time in vigorous activity ($\geq$ 6 METS) in 7 yr old children. By decreasing the epoch duration from 1-min to 5-sec the amount of vigorous activity increased by 30 minutes. Therefore, selecting the appropriate epoch is critical in characterizing activity patterns, and a trade-off clearly exists between an epoch length that captures intermittent activity and one that can be used to predict energy expenditure.

It is generally assumed that activity counts are linearly related to energy expenditure and thus simple linear regression methods have been used to predict energy expenditure and establish thresholds. A limitation of this method is that the equations are sensitive to the type of activity performed during calibration. Prediction equations are primarily based on treadmill locomotor activities (walking/running) and thus will underestimate activities that are non-locomotor (i.e., raking, sweeping, etc.). In contrast, lifestyle equations aimed at capturing non-locomotor activities will likely overestimate daily energy expenditure because of the lower metabolic cost associated with walking. Crouter et al. (2006) recently reported a novel approach to estimate energy expenditure using a two-regression model method. During walking or running activities at a constant speed, limited variability in activity counts exist over a 10-second interval. In contrast, a greater amount of variability in intensity, and thus activity counts, exists during lifestyle activities. Based on the coefficient of variation (CV) from the activity counts, separate regression equations are used to estimate energy expenditure. Although this approach seemingly improves our ability to estimate energy

expenditure an inherent problem with accelerometry involves their inability to assess the metabolic cost of upper body activities and the additional metabolic cost of walking up an incline or carrying a load. It also appears that the Actigraph accelerometer counts level off during high intensity activities (Brage et al. 2003).

The validity of accelerometers to assess energy expenditure among children has previously been examined using the doubly labeled water method over a 14-day monitoring period. Among 26 children (average age: 9 yrs) accelerometer-derived activity counts/min were significantly correlated with total energy expenditure ($r= 0.39$, $p<0.05$) as well as activity energy expenditure ($r= 0.54$, $p<0.01$) (Ekelund et al. 2001). More commonly, indirect calorimetry is used as the criterion standard to assess the validity of accelerometers to measure energy expenditure. In a study by Trost et al. (1998) 30 children wore an accelerometer while walking/jogging on a treadmill at 3, 4, and 6 mph. The results showed that activity counts/min correlated well with energy expenditure (kcal/min) ($r= 0.86$) and VO_2 (ml/kg/min) ($r= 0.86$). Based on this relationship a prediction equation to estimate energy expenditure was developed from 20 of the original 30 participants and was then cross-validated in the remaining 10 children. For the entire protocol (3, 4, and 6 mph) the correlation between the measured and predicted mean energy expenditure was 0.93 ($p< 0.001$) and the SEE was 0.93 kcal/min (Trost et al. 1998). Based on the range of individual differences between the measured and predicted levels of energy expenditure, the authors concluded that this equation would be appropriate for estimating mean energy expenditure for a group but not for an individual. Using a similar approach to quantify energy expenditure, Freedson et al. (2005) developed an age-specific regression equation to calculate a MET value for each activity count interval (Equation 2.1). MET values between 3

and 5.9 reflect moderate physical activity while MET values exceeding 6.0 indicate vigorous physical activity. Commonly, MVPA is reported as activity $\geq$ 3 METS.

Equation 2.1

METs = 2.757 + (0.0015 x counts/min) – (0.08957 x age (yr)) – (0.000038 x counts/min x age (yr)).

Accelerometer activity count thresholds have also been created to quantify the amount of time spent at various physical activity intensity levels (e.g., sedentary, light, moderate, and vigorous); however, there is no consensus in the interpretation of activity count thresholds for MVPA (e.g., >3000 counts/min (Treuth et al. 2004) and >2172 counts/min (Welk 2005)).

As mentioned above, energy expenditure prediction equations are most accurate when the monitoring activities closely match the activities preformed during the calibration study. Eisenmann et al. (2004) demonstrated this point by comparing the predicted energy expenditure of daily activities in children (sweeping, bowling, and basketball) to the measured energy expenditure of activity. The treadmill based energy expenditure prediction equation (Trost et al. 1998) significantly underestimated the energy expenditure during each activity.

Although activity count thresholds and predictive equations provide a method to quantify physical activity and/or energy expenditure, basic assumptions are made with their use. Activity count thresholds are often derived in the laboratory during continuous, steady state treadmill exercise. As mentioned previously, children's activity patterns are intermittent with bouts of physical activity interspersed between bouts of inactivity and consequently steady state is seldom reached. Problems also exist in interpreting accelerometer counts

because they are dimensionless and may be influenced by variables other than physical activity (i.e., body size and speed of movement). In addition, Yngve et al. (2000) found that monitor placement (low back vs hip) and activity setting (track vs treadmill) influenced accelerometer-derived activity counts. In this study it was reported that activity counts were significantly higher when the accelerometer was placed on the hip (compared to the low back) during normal treadmill walking and fast walking. In contrast, activity counts were significantly lower when the accelerometer was placed on the hip (compared to low back) during treadmill jogging. Under free-living conditions it was reported that accelerometer placement did not affect physical activity estimations. Perhaps more important, Yngve et al. (2000) reported significantly higher activity counts during track locomotion compared to treadmill locomotion at a constant speed. This latter finding is important because it implies that treadmill-based prediction equations may overestimate time spent in MVPA under free-living conditions.

Although accelerometers are relatively expensive (~$350) and require additional data processing steps compared to pedometers they are capable of providing a broad description of physical activity. Prediction equations are available to convert accelerometer-derived activity counts into units of energy expenditure (kcals/min or MET value); however, additional research is needed to account for the wide range of activities children participate in throughout the day. Individual prediction equations would likely increase the accuracy of energy expenditure estimates with an accelerometer; however, the additional time involved in this process limits this approach.

Physiological Measuring Systems

Heart Rate Monitoring

In contrast to pedometers and accelerometers that record the mechanical response to bodily movement, heart rate monitoring is based on the physiological response to movement. Heart rate monitoring has been widely used among children to provide an indication of the intensity, duration, and frequency of physical activity (Epstein et al. 2001). The linear relationship between heart rate and oxygen consumption enables energy expenditure to be estimated; however, other factors (i.e., age, gender, training status, environmental conditions, and stress) can also influence this relationship. The slope between heart rate and energy expenditure varies between individuals, and therefore individualized calibration equations have been utilized. Using this approach, separate regression equations are developed to estimate the energy expended during sedentary (i.e., lying, sitting, and standing) and daily activities; however, the lengthy and complex calibration procedures involved in this process may make this method impractical in large samples (Livingstone et al. 2000).

Doubly Labeled Water and Indirect Calorimetry

The doubly labeled water method and indirect calorimetry serve as criterion measures for self-report tools and activity monitors. The doubly labeled water method is a biochemical procedure to measure the energy expended from volitional and non-volitional activities. In brief, two stable isotopes (^{2}H and ^{18}O) are ingested and their excretion rates are monitored over a 5-14 day period. The ^{18}O isotope is eliminated as water and CO_2 while the ^{2}H isotope is eliminated exclusively as water. Total energy expenditure (TEE) can be quantified based on the elimination rate of CO_2. Activity energy expenditure can be estimated when the doubly labeled water method is used in conjunction with indirect calorimetry. Indirect

calorimetry measures O_2 consumption and calculates energy expenditure based on the assumption that 1 L of O_2 consumed is equivalent to 5 kcal of energy expended. Thus, indirect calorimetry can be used to determine the energy expended from activity or during rest. Activity energy expenditure can be determined by subtracting resting energy expenditure (obtained from indirect calorimetry) and the thermic effect of food (10% of TEE) from TEE derived from doubly labeled water.

The doubly labeled water method provides a precise measure of TEE under free-living conditions; however, its use is limited because of the high cost per dose and the limited availability of the isotopes. Indirect calorimetry provides an accurate method for measuring energy expenditure under laboratory conditions. Portable systems are available to determine the energy cost of activities outside the laboratory; however, issues of feasibility and acceptability among participants often limit their use in research.

PHYSICAL ACTIVITY RECOMMENDATIONS

Among adults, the independent effect of regular physical activity on numerous health outcomes (i.e., obesity, type II diabetes, dyslipidemia, and hypertension) led to the development of physical activity guidelines (U.S. Department of Health and Human Services 1996). Many national organizations have adopted the recommendation of 30 minutes of moderate-intensity activity on most days of the week for adults (Pate et al. 1995). Physical activity recommendations for youth have largely been based on expert opinion and the premise that health benefits exist for active lifestyles that persist across the lifespan (Blair et al. 1989). Establishing physical activity recommendations for youth assumes that some health consequence exists for not achieving the recommendation and to date this relationship

is not completely understood. Ideally, physical activity recommendations should be systematically defined (i.e., evidence-based) using randomized controlled studies in which children engaging in different frequencies, durations, and modes of physical activity are compared in response to a particular health outcome (Twisk 2001); however, it is unlikely that such a study is possible. Importantly, the same parabolic relationship observed between physical activity and health in adults may not exist for youth. A summary of physical activity recommendations is presented below and in Table 2.1. A review article by Fulton et al. (2004) also provides a summary of public health and clinical recommendations for physical activity and physical fitness.

Evidence-Based Recommendation

Compared to the adult literature, the relationship between regular physical activity and risk for chronic disease among children and adolescents is less clear. This is perhaps due to several factors, including the cross-sectional nature of most study designs, the hormonal milieu that exists during biological maturation, the use of subjective tools to assess physical activity, or the insufficient time for inactivity to adversely affect traditional risk factors. Regardless, physical activity during childhood is widely recommended to prevent adverse health conditions in adulthood (U.S. Department of Health and Human Services 1996; Eckel and Krauss 1998). Evidence to support this recommendation stems from research that indicates physical activity behaviors (Telama et al. 2005) and obesity (Whitaker et al. 1997) track moderately well from childhood to adulthood.

Recently, an expert panel appointed by the Centers for Disease Control (CDC) systematically reviewed the literature to examine the effects of regular physical activity on health outcomes among youth in an effort to provide an evidence-based recommendation for

daily activity for youth (Strong et al. 2005). Experimental studies demonstrated favorable changes in health status in response to 30 to 45 minutes of continuous MVPA. Thus, to allow for inter- and intra-individual differences in physical activity and to account for the intermittent nature of children's activity patterns it was recommended that children accumulate 60 minutes of MVPA each day.

Recommendations from National Organizations

Many national organizations have promoted regular youth physical activity in an effort to improve general health. HealthyPeople 2010 outlines several health-related goals based on the results from previous national surveys. Included in these objectives are physical activity goals for adults and adolescents (U.S. Department of Health and Human Services 2000). Adolescents should participate in moderate physical activity for at least 30 minutes on 5 or more days each week and limit sedentary activities (e.g., television) to less than 2 hours each day. The physical activity recommendation outlined by the National Association for Sport and Physical Education (NASPE) is higher than the HealthyPeople 2010 recommendation and indicates that youth should accumulate at least 60 minutes of physical activity/day, in addition to limiting sedentary activity to less than 2 hrs/day (National Association for Sport and Physical Education 2004).

Other national organizations have proposed physical activity guidelines for children and adolescents. The proposed physical activity recommendation for Australians (30 min of moderate physical activity/day) (Commonwealth Department of Health and Aged Care 1999) is similar to the HealthyPeople 2010 physical activity recommendations for youth, whereas the physical activity guideline proposed by the United Kingdom expert consensus panel (60 minutes of moderate activity/day) (Cavill et al. 2001) is in agreement with the NASPE

recommendation. The Canadian physical activity guidelines for children and adolescents are different than the above-mentioned guidelines in that youth are recommended to gradually increase their daily amounts of activity in an effort to reach a goal of 90 minutes of activity/day (Health Canada 2002).

Pedometer-Based Recommendations

The President's Council on Physical Fitness and Sports (PCPFS) previously recommended that boys and girls accumulate 13,000 and 11,000 steps/day (PCPFS 2003). This pedometer step recommendation was based on the average number of steps/day observed among elementary-aged boys and girls (Vincent and Pangrazi 2002). Using a different approach, Tudor-Locke et al. (2004) established criterion-referenced standards for daily pedometer steps related to a healthy BMI for 6-12 yr old boys (15,000 steps/day) and girls (12,000 steps/day). However, concern exists as to whether 15,000 steps is the same for a 6 and 12 yr old boy given the observable difference in leg length, and hence number of steps to complete a given distance (Eisenmann and Wickel 2005).

LEVELS AND PATTERNS OF PHYSICAL ACTIVITY

The levels of habitual physical activity in children and adolescents has previously been cross-sectionally examined using subjective (Youth Risk Behavior Surveillance 2004) and objective assessment tools (Trost et al. 2002; Riddoch et al. 2004). Current levels of physical activity according to various assessment tools among large samples of children and adolescents are presented below.

Youth Risk Behavior Survey

The YRBS is conducted by the Centers for Disease Control (CDC) and is a representative sample of youth between grades 9-12. Results from the YRBS indicate that nearly 63% of youth participated in physical activity that made them sweat and breath hard (vigorous activity) for ≥ 20 min on ≥ 3 of the 7 days preceding the survey. Nearly 25% of youth participated in physical activities that did not make them sweat and breath hard (moderate activity) for ≥ 30 min on ≥ 5 of the 7 days preceding the survey. Of those surveyed, nearly 12% did not participate in any vigorous or moderate activity. Almost half (55.7%) of those surveyed were enrolled in physical education for at least one day in a typical week. A high portion of these students (80.3%) participated in exercise or activity ≥ 20 min during their PE class. Almost 30% participated in PE on 5 days. More than half (57.6%) participated in one or more sport teams sponsored by their school or community in the 12 months prior to the survey. About 40% watched TV ≥ 3 hours on a school day.

Pedometers

Vincent et al. (2003) reported the average number of pedometer steps/day in a total of 1954 children between 6 and 12 yrs old from the United States, Australia, and Sweden. On average, children accumulated nearly 13,000 steps/day with boys and girls from the United States averaging fewer steps/day than children from Australia and Sweden. Eisenmann et al. (2006) reported similar results in boys and girls from two midwestern communities in the United States. On average, boys and girls accumulated nearly 12,000 steps/day. Although pedometers provide a global picture of physical activity, no indication of the type, duration, or intensity of activity can be obtained.

Accelerometers

Few population-based studies are available that utilize accelerometry to assess the level of physical activity among youth mainly because of their high price. Two large-scale studies that are available come from population-based reports from the United States (Trost et al. 2002) and from Europe (Riddoch et al. 2004). Key findings from these studies highlight the age and gender differences in physical activity; therefore, a detailed description of these reports will appear in the section below that focuses on age and gender differences.

Pate et al. (2002) reported the compliance of three physical activity guidelines among the U.S. sample. More than 90% of the total sample achieved the Healthy People 2010 activity recommendation for MVPA (≥ 30 min, ≥ 5 day/wk, ≥ 3 METS) (Objective 22.6), while only 3% met the activity recommendation for VPA (≥ 20 min, ≥ 3 day/wk, ≥ 6 METS) (Objective 22.7). Nearly 70% of the sample met the United Kingdom Expert Consensus Group guideline (≥ 60 min, ≥ 5 day/wk, ≥ 3 METS). This guideline is in line with the current evidence-based physical activity guideline and National Association for Sport and Physical Education guideline. Thus, it seems as though children may be more active than previously thought. However, in light of this finding it should be restated that few population-based reports using accelerometry are available to confirm this conclusion; therefore, continued work in this area is warranted. It is also important to consider that, by inference, nearly 30% of the children from this study did not meet current physical activity guidelines. Therefore, more work is needed to clarify the psychosocial and biological obstacles among this portion of children. It is also evident that the level of physical activity among youth is largely dependent on the guideline selected. Perhaps a more detailed view of youth physical activity

levels will soon be available with the advent of accelerometer-derived physical activity measures in the latest National Health and Nutrition Examination Survey (NHANES).

AGE- AND GENDER-ASSOCIATED VARIATION IN PHYSICAL ACTIVITY

Perhaps the most consistent findings in the physical activity literature include the age-related decline in physical activity during adolescence and the gender difference showing boys are more physically active than girls at any age. Although much attention is given to psychosocial factors, the age-related decline in physical activity may also be attributed to biological factors given the consistent findings across human and animal studies (Sallis 2000).

Youth Risk Behavior Surveillance

Results from the YRBS highlight the age- and gender-related differences in self-reported physical activity. Overall, the amount of vigorous physical activity was higher among boys than girls at each grade with declining levels from grades 9 to 12. A similar trend was observed for levels of moderate physical activity. Thus, as expected a greater percentage of girls, compared to boys, reported insufficient amounts of activity and the percent reporting insufficient activity increased with increasing grades. In general, the results for PE indicate that enrollment and attendance in PE was higher in students in grade 9 compared to grade 12. Among boys and girls, a greater percent of younger students (grades 9 and 10), compared to older students (grades 11 and 12) reported watching ≥ 3 hrs of TV on an average school day.

Amherst Health and Activity Study (AHAS)

Using cross-sectional data and an objective assessment tool (accelerometer), Trost et al. (2002) suggested that the progressive decay in physical activity begins during childhood, rather than adolescence. The average amount of MVPA and VPA was compared between four groups of children based on their grade (e.g., grades 1-3; grades 4-6; grades 7-9; and grades 10-12). Overall, the average amount of daily MVPA significantly decreased with increasing grades for boys and girls. With the exception of the youngest group (grades 1-3), it was reported that boys participated in significantly more activity compared to girls (Figure 2.1). Participants from grades 1-3 had the highest amount of MVPA (200 min), while participants from grades 10-12 had the lowest amount of MVPA (50 min). The results for VPA were similar in that the average amount significantly decreased from grades 1-3 to 7-9; however, no significant decline was reported from grades 7-9 to 10-12. In each grade group, boys participated in significantly more VPA compared to girls. Participants from grades 1-3 averaged the most VPA/day (boys: 33 min and girls: 23 min), while participants from grades 10-12 averaged the least VPA/day (boys: 10 min and girls: 5 min).

European Youth Heart Study (EYHS)

Participants from the European Youth Heart Study (EYHS) demonstrated similar age and gender patterns of physical activity; however, this study only examined boys and girls who were 9 and 15 yrs old. Nonetheless, similar age and gender relationships were observed. On average, boys accumulated more MVPA/day than girls at age 9 (192 vs. 160 min/day) and 15 (99 vs 73 min/day) (Riddoch et al. 2004).

MATURITY-ASSOCIATED VARIATION IN PHYSICAL ACTIVITY

Prior to discussing the maturity-associated variation in physical activity, a brief discussion of the assessment of biological maturity is warranted. Biological maturation is broadly defined as the process of becoming biologically mature (Tanner 1962). Considerable between-individual variation exists in the timing (when maturational events occur) and the tempo (rate of maturation) of this process. The observed heterogeneity in maturity status among similarly aged children has reinforced the idea of controlling for maturity status in studies of physical activity among children and adolescents (Baxter-Jones et al. 2005). Biological maturity status can be assessed using a variety of techniques, including sexual, skeletal, and somatic maturation. Each technique will be briefly discussed below.

Sexual maturity

The assessment of secondary sexual characteristics (i.e., breast development and age of menarche in girls, penis and testes development in boys, and appearance of pubic hair in girls and boys) can be determined by health professional (physician/nurse) observation or self-assessment. Written and pictorial criteria (Tanner 1962) are available to identify the stage of maturation for breast, genital, and pubic hair development (Stage 1: absence of secondary sex characteristics; Stage 2: initial development of each characteristic; Stage 3 and 4: continued development; Stage 5: mature state). This assessment method is relatively inexpensive and easy to administer; however, there may be issues regarding the physician observation or inaccuracies with the self-report. In addition, the use of secondary sexual characteristics to assess maturation is limited to the period of pubertal development.

Skeletal maturity

Skeletal maturity provides a good method to assess maturity because definitive start and stop points are constant among individuals (i.e., progression from cartilage to bone), although the tempo varies considerable between individuals. Hand-wrist x-rays provide an acceptable representation of the skeleton and can be compared to standard age-specific plates to examine the entire hand-wrist area or specific bones (Greulich-Pyle Method). Skeletal age can be calculated to determine if the individual is late, average, or early maturing, compared to the age-specific plate. Individual bones can also be assessed based on criteria to estimate skeletal age (Tanner-Whitehouse Method; Fels Method). The determination of skeletal age offers a technique that is based on physiological changes of bone; however, the use of this technique is limited to expensive equipment and exposure to x-rays.

Somatic maturation

Somatic maturation provides a non-invasive approach to estimate maturity. Repeated measurements of height are recorded in 3-6 month increments and are plotted over time. The age at peak height velocity (PHV) represents the age at which the child is growing at a maximal rate (cm/yr) and is a somatic indicator of maturation (Figure 2.2). The use of this approach to estimate maturity is limited because of the number of measurements that must be obtained over a period of time. Although repeated somatic measurements are needed to determine the tempo of maturation, cross-sectional data can be used to estimate the number of years an individual is away from PHV, which is a somatic indicator of maturation. Recently, Mirwald et al. (2002) developed sex-specific maturity-offset equations (Equation 2.2) to estimate the number of years away from PHV.

Equation 2.2

Maturity offset (boys) = -9.236 + 0.0002708 (leg length x sitting height) – 0.001663 (age x leg length) + 0.007216 (age x sitting height) + 0.02292 (weight:height)

Maturity offset (girls) = -9.376 + 0.0001882 (leg length x sitting height) + 0.0022 (age x leg length) + 0.005841 (age x sitting height) – 0.002658 (age x weight) + 0.07693 (weight:height).

The equations were developed using data from the Saskatchewan Pediatric Bone Mineral Accrual Study (BMAS), which included 228 children (113 boys and 115 girls) between 4 yr from PHV and 3 yr after PHV. The equations were verified with samples from the Saskatchewan Growth and Development Study (SGDS) and the Leuven Longitudinal Twin Study (LLTS). Additionally, the correlation coefficient between skeletal age offset and maturity offset approximated 0.83 (Mirwald et al. 2002). This method provides a non-invasive and inexpensive approach to assess the timing of maturity. Although the utility of this approach to distinguish early versus late maturers in the field setting has not been firmly established, this method appears promising to efficiently account for biological differences among similarly aged youth.

Few studies exist that have examined whether or not maturity status influences objectively measured physical activity levels. Thompson et al. (2003) examined 7-yr longitudinal changes in physical activity levels among Canadian boys and girls to determine if the age-related decline was confounded by biological age. Physical activity was assessed with the physical activity questionnaire for children (PAQ-C) and age at peak height velocity (PHV), determined from serial measures, provided an indication of biological maturity. Biological age was calculated and defined as years from PHV (e.g., -1, 0, +1, etc.).

Participants were grouped into 1-yr increment biological age groups, ranging from 4 years before PHV (pre-adolescent) to 5 years after PHV (post-adolescent). Among boys and girls PAQ-C scores decreased with increasing chronological age with girls demonstrating lower levels of physical activity compared to boys. However, when boys and girls were aligned by biological age, no significant differences were observed between PAQ-C summary scores. The decline in physical activity was observed when using chronological and biological age; however, gender-related differences were only observed when subjects were aligned by chronological age, with boys demonstrating higher levels of physical activity compared to girls. Using this approach, differences in physical activity between early, average, and late maturers were not examined because, for example, a boy 1 yr away from PHV could be an average maturing 13 yr old or a late maturing 14 yr old.

Kemper et al. (1997) examined the relationship between physical activity and early, average, and late maturation among 200 boys and girls over a 9 yr period. Physical activity levels were self-reported on five occasions and biological maturation was estimated using hand-wrist radiographs on four occasions. Although not significant, late maturing boys and girls reported slightly higher amounts of activity compared to early maturing boys and girls.

YOUTH SPORT, RECESS, AND PHYSICAL EDUCATION

Physical activity guidelines recommend children and adolescents participate in at least 60 minutes of activity each day (Strong et al. 2005). Although epidemiological evidence is available to determine the percentage of youth who achieve physical activity guidelines (Pate et al. 2002) few studies have examined the contribution of daily activities to total daily physical activity. This information is important to improve our understanding of structured

and unstructured physical activity opportunities and may also be used to advance intervention research aimed at increasing activity levels.

Annually, more than 38 million youth participate in organized sport (National Council of Youth Sports 2001); therefore, youth sport may provide a much-needed outlet for physical activity for a large number of children. However, only one study has examined the contribution of youth sport to total daily physical activity. Katzmarzyk and Malina (1998) used the 3-day Bouchard diary to determine the percentage of total daily energy expenditure (TDEE) and moderate-to-vigorous energy expenditure (MVEE) expended during youth sport participation. Compared to girls, the results indicate that boys expend a greater percentage of TDEE during youth sport (~20 vs. 16%). However, girls expend a greater percentage of MVEE during youth sport, compared to boys (~65 vs 55%). These results should be interpreted with caution given the small sample size (27 boys/27 girls) and wide variety of activities.

The importance of organized youth sport extends beyond increasing daily levels of physical activity during childhood. Participation in youth sport provides opportunities for children to develop physical and social skills, but may also predict physical activity levels in adulthood (Telama et al. 1997).

Aside from youth sport, the typical school day and particularly recess and physical education seemingly provide two avenues for children to accumulate physical activity; however, relatively little is known about the overall contribution of these activities. Recent findings by Ridgers et al. (2005) and Nader (2003) suggest the overall contribution of recess and physical education may be low. Using an accelerometer, Ridgers et al. (2005) found that nearly 75% of the total recess time among 5-10 yr old children was spent at a low intensity

level. Similar results were reported by Nader (2003) during physical education class among 3rd grade boys and girls. Using an observational method to classify physical activity levels, Nader (2003) reported that 37% of physical education was spent above a moderate intensity level, implying that a majority of the time in physical education is spent at a light intensity level.

SUMMARY

Several areas related to physical activity have been reviewed. It is evident that a variety of assessment tools (questionnaires, diaries, pedometers, and accelerometers) are available to measure habitual physical activity during childhood and adolescence. Despite their limitations, accelerometers have become a popular choice to measure physical activity because they are small, lightweight, and relatively non-invasive. In addition, prediction equations are available to estimate energy expenditure (kcals/min or METS) or time spent in light, moderate, vigorous or moderate-to-vigorous physical activity (MVPA).

Among adults, accumulating adequate amounts of moderate-to-vigorous physical activity (MVPA)/day has been shown to reduce the risk of many chronic health conditions. Although the relationship between levels of MVPA and health outcomes is not as clear among children and adolescents, scientific committees and national organizations have developed daily physical activity recommendations for youth. Thus, considerable interest has been placed on the physical activity levels of children and adolescents.

The age-specific MET prediction equation has been widely used to translate the accelerometer-derived activity counts into a measure of energy expenditure (e.g., METS). Estimated levels of MVPA can be determined based on the MET value of daily activities,

where activities ≥ 3 METS are classified as MVPA. Age- and gender-related differences in MVPA have been reported, however the possible confounding effects of biological maturation have not been considered. Additionally, limited information is known about the predictive validity of the age-specific MET prediction equation to measure energy expenditure in children of various body sizes.

Although the focus in physical activity research is typically on the average amount of daily physical activity, it is also important to understand the primary sources of daily physical activity. The relative contributions of youth sport, recess, and physical education have not been thoroughly examined. This information may be useful in intervention studies aimed at increasing levels of physical activity. Additionally, a better understanding of the day-to-day variability in physical activity and energy expenditure may improve our understanding of the physical activity phenotype of children and adolescents.

The purpose of this dissertation focuses on 1) the assessment and interpretation of physical activity and energy expenditure and 2) the variability in habitual physical activity in children and adolescents.

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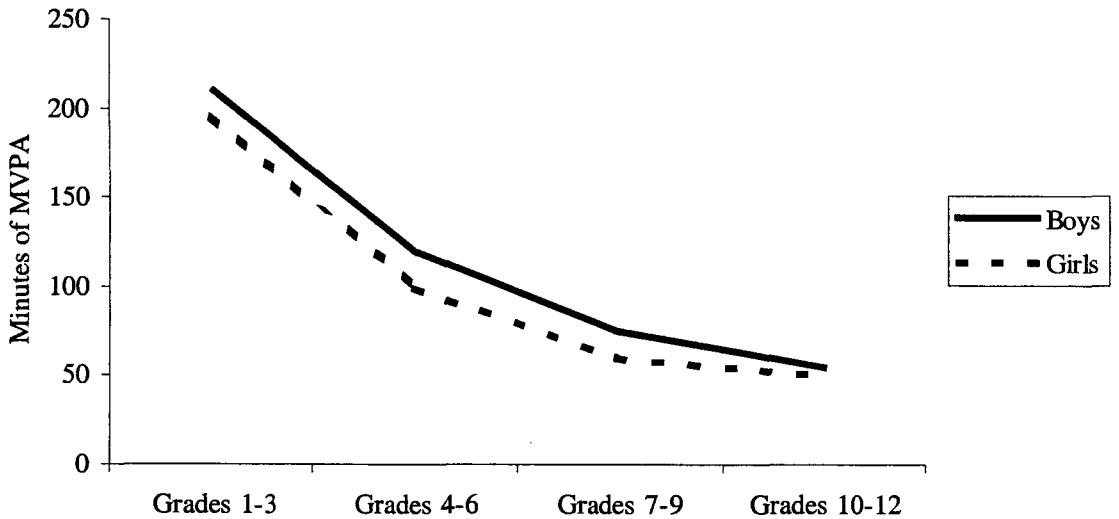

Figure 2.1. Age- and sex-related decline in minutes of moderate-to-vigorous physical activity.

Adapted from Trost et al. (2002).

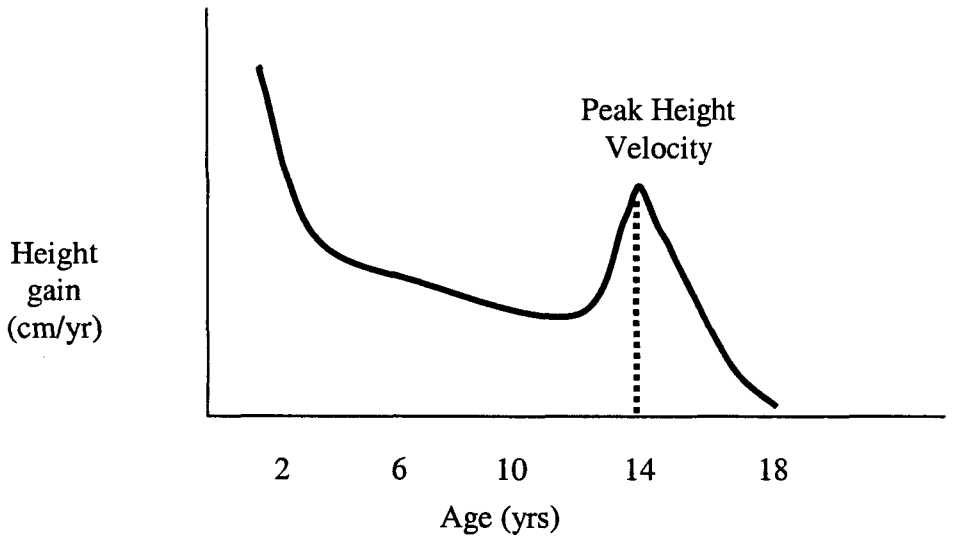

Figure 2.2. Peak height velocity curve (cm/yr) for an average maturing boy.

Table 2.1. Summary of physical activity recommendations for children and adolescents.

Organization	Guideline
National Association for Sport and Physical Education activity/day	60 min of physical activity/day; less than 2 hrs of sedentary
Evidence-based Recommendation (Centers for Disease Control)	60 min of physical activity/day
Healthy People 2010	
Objective 22.6	30 min of moderate activity on ≥ 5 days/wk
Objective 22.7	20 min of vigorous activity on ≥ 3 days/wk
United Kingdom Expert Consensus Group	At least 60 min of moderate physical activity/day
Canada Fitness Guidelines	Children and adolescent should increase physical activity by 30 minutes in an effort to reach the goal of 90 minutes of activity/day
American College of Sports Medicine	20-30 min of vigorous exercise each day
International Consensus Conference on Physical Activity Guidelines for Adolescents	20 min of continuous moderate to vigorous activity at least 3 sessions/wk
Health Education Authority symposium (Young and Active)	All young people should participate in at least 1 hr of moderate to vigorous activity
National Physical Activity Guidelines for Australians	30 min of moderate physical activity/day
National Academy of Sciences, Institute of Medicine	At least 60 min of moderate physical activity/day
National Institute of Health	30 min of moderate physical activity/day

CHAPTER 3.

PREDICTIVE VALIDITY OF AN AGE-SPECIFIC ENERGY EXPENDITURE EQUATION AMONG CHILDREN OF VARYING BODY SIZE

ABSTRACT

The purpose of this study was to cross-validate an age-specific MET regression equation among children and adolescents of various body size. A total of 67 children (41 boys and 26 girls) between 6 and 13 yrs of age completed five 3-min walking trials (1, 2, 2.5, 3, and 4 mph) on a motorized treadmill. During each trial, participants wore an Actigraph accelerometer while oxygen consumption was assessed by indirect calorimetry. Using the Actigraph activity counts, the predicted MET values were determined with an age-specific MET equation (Freedson et al. 2005) and were compared to the measured MET value using dependent t-tests. Participants were divided into body mass tertiles to determine if body mass influenced the difference between measured and predicted MET values. The measured MET value was similar to the predicted MET value at 1 mph (2.1 vs 2.2 METS); however, the predicted MET value was significant greater than the measured MET value at the remaining speeds (2.7 vs 3.4 METS (2 mph); 3.1 vs 4.5 METS (2.5 mph); 3.7 vs 5.5 METS (3 mph); 5.1 vs 6.8 METS (4 mph)) ($p<0.05$). The mean difference between the measured and predicted MET values was significantly greater at 2.5 and 3 mph in the two lighter tertiles compared to the heaviest tertile. The results suggest that the age-specific MET equation, which is widely used in pediatric physical activity research, significantly overestimates energy expenditure at slow walking speeds. This effect was primary observed among smaller children.

INTRODUCTION

Currently, there is considerable interest in the physical activity levels of children (Riddoch and Boreham 1995; Strong et al. 2005). However, reliable and valid measurements of physical activity are necessary to understand the level of habitual physical activity and the relationship between physical activity and health. Self-report tools are commonly used in surveillance (e.g., Youth Risk Behavior Survey) and epidemiological studies to assess physical activity since they are inexpensive and easy to use; however, self-reported physical activity may not be accurate because of recall issues or biased responses, especially in children under 10 yrs (Sallis 1991). Because of the limitations associated with self-report the use of accelerometers to measure physical activity has increased and is now almost standard practice in studies of physical activity (Troiano 2005).

Uniaxial accelerometers, such as the Actigraph (Actigraph, LCC, Fort Walton Beach, FL), process vertical accelerations at the hip in response to ambulatory movement and produce a dimensionless unit ('activity count') over a user-defined interval of time. Based on the linear relationship between activity counts and oxygen consumption (VO_2) (ml of O_2/kg/min), regression equations have been developed for children and adolescents to estimate energy expenditure (kcals/min (Trost et al. 1998), METS (Freedson et al. 2005), and activity energy expenditure (Puyau et al. 2002)). However, complexities exist during normal growth and maturation that make the relationship between activity counts and VO_2 difficult to interpret. For instance, VO_2 at rest and during submaximal work decreases from childhood to adolescence (Krahenbuhl et al. 1989; Forster et al. 1994; Ariens et al. 1997) due to several factors including alterations in gait coordination, substrate utilization, and thermoregulatory control (Rowland 1996). Supporting evidence from comparative mammalian physiology

suggests that the decline in VO_2 is primarily related to differences in body size (specifically body mass) (Taylor et al. 1970). Thus, at a given locomotor speed (or at rest) the relative VO_2 will be higher in a small child compared to large child.

Energy expenditure prediction equations have accounted for the physiological differences between small and large children by including body mass (Trost et al. 1998) or chronological age (Freedson et al. 2005) into the regression equation. However, given the heterogeneity in body size, and thus energy cost, at a given chronological age (Malina et al. 2004) the use of an age-specific equation (Freedson et al. 2005) may be problematic. The age-specific equation is widely used in pediatric research to determine the intensity of activities based on the predicted MET value (e.g., light activity (1.5≤ METS <3); moderate activity (3≤ METS <6); and vigorous activity (≥6 METS)). Activity intensities above 3 METS have been used as the threshold to define moderate-to-vigorous physical activity (MVPA) (Trost et al. 2002) and this intensity of activity has been included in current youth physical activity recommendations (Strong et al. 2005). To date, little is known about the predictive validity of the age-specific equation to predict MET values in children of varying body sizes. Trost et al. (2006) recently reported that the age-specific MET equation significantly overestimated energy expenditure during walking (3 mph), fast walking (4 mph), and running (6 mph). However, it is unclear whether this equation can be used to predict energy expenditure during slow locomotor speeds. This issue is important to consider given that a large percent of waking hours are spent in light intensity activities (Bratteby et al. 1997; Montgomery et al. 2004). Accordingly, the purpose of this study was twofold: 1) to cross-validate the widely used age-specific MET regression equation and 2) to examine the

influence of body mass on activity counts derived from an accelerometer. It was hypothesized that activity counts would be greater in heavier children.

METHODS

Participants

A total of 67 children (41 boys and 26 girls) between 6 and 13 yrs of age participated in the study. Participants were recruited from a summer youth camp at a large midwestern university and were free of any orthopedic or gait abnormalities that influenced their ability to walk on a treadmill. Parental consent and child assent were obtained from each participant prior to the initiation of the study protocol. The Institutional Review Board approved the study.

Anthropometry

The participant's date of birth was subtracted from the observation date to determine chronological age (yrs). Stature was measured to the nearest 0.1 cm using a fixed stadiometer (Harpenden). The measurement was obtained while the participant was standing with feet flat on the floor, hands at sides, and head positioned in the Frankfort plane. Body mass was measured with a strain gauge scale (Seca 770) to the nearest 0.1 kg, in minimal clothing (i.e., bulky sweatshirts and jackets were removed). The body mass index (BMI) was calculated by dividing the participant's body mass (kg) by their standing height (m^2).

Instrumentation

Accelerometer

A single Actigraph uniaxial accelerometer was used in this study to reduce the amount of error attributed to differences between monitors (i.e., inter-monitor error). The accelerometer was programmed to record activity counts in 5-second epochs. The small size

of this accelerometer (5.1 x 4.1 x 1.5 cm, 42.6 g) provides a non-invasive approach to assess locomotor movement.

Indirect Calorimetry

Indirect calorimetry provided a criterion standard for quantifying VO_2 and energy expenditure. Breath by breath respiratory gases and flow were measured with the Cosmed Quark b^2 metabolic system (Rome, Italy). Prior to and following use, the O_2 and CO_2 analyzers were calibrated against room air and a known reference gas (16% O_2 and 5% CO_2), and the turbine flowmeter was calibrated with a 3-L syringe.

Protocol

The participants arrived at the laboratory during a scheduled time and were provided with an opportunity to familiarize themselves with the treadmill and the assessment tools. Each participant was then fitted with a Hans Rudolph mask designed to capture respiratory gases and the Actigraph accelerometer was attached to the participants' waistband on the lateral boarder of the right hip. The metabolic cart and the accelerometer were synchronized at the start of the protocol to facilitate data interpretation. Participants completed five, 3-min treadmill stages (1, 2, 2.5, 3, and 4 mph) in a randomized order. Each stage was separated by a 1-min rest period in which participants were instructed to straddle the treadmill and remain motionless. During the mandatory rest interval the treadmill was adjusted to the next treadmill speed. At the conclusion of the protocol, the metabolic data was saved on a computer and the stored activity counts were downloaded for subsequent data processing and analysis.

Data Reduction

Steady-state VO_2 was determined by averaging the data over the last minute of each stage. Resting metabolic rate (RMR) (ml/kg/min) was estimated using the Food and Agriculture/World Health Organization/United Nations University (FAO/WHO/UNU) prediction equation (World Health Organization 1985) and MET values at each stage were calculated by dividing the average VO_2 by estimated RMR. The average 5-second accelerometer count over the last minute of each stage was converted into a 1-minute average activity count so that a predicted MET value could be calculated with the age-specific MET equation (Freedson et al. 2005) (Equation 3.1).

Equation 3.1.

METS = 2.757 + (0.0015 x counts per minute) – (0.08957 x age (yr)) – (0.000038 x counts per minute x age (yr)).

Statistical Analysis

Descriptive statistics for age, stature, body mass, and RMR were determined for boys and girls and the entire sample. Repeated measures analysis of variance (RMANOVA) followed by pair-wise comparisons examined the mean difference in accelerometer counts and VO_2 between treadmill stages. Dependent t-tests were used to compare the measured and predicted MET values during each treadmill speed. Bland-Altman plots were used to visually examine the relationship between the measured and predicted MET values at each treadmill speed. To examine the influence of body size on the measured and predicted MET value the participants were divided into body mass tertiles (small:

and the difference between measured and predicted MET values at each treadmill speed. Finally, a MET prediction equation was created from the data using stepwise multiple regression. Independent variables included activity counts/min, body mass, chronological age, stature, and the interaction terms. Visual comparisons were made between the published age-specific MET equation (Freedson et al. 2005) and the derived MET regression equation developed from the current study. Statistical significance was set at $p < 0.05$. Statistical analyses were completed with SPSS version 12.0.

RESULTS

On average, the physical characteristics (Table 3.1) and submaximal VO_2 values (data not shown) were not significantly different between boys and girls ($p>0.05$), thus they were analyzed as a single group. RMANOVA indicated significant mean differences in accelerometer counts [$F(4,244) = 426.1$, $p<0.001$] and VO_2 [$F(4,132)= 324.0$, $p<0.001$] between each treadmill speed (Figure 3.1). Pair-wise comparisons found significant mean differences in accelerometer counts and VO_2 between each treadmill speed ($p<0.05$). At each treadmill speed the variability in accelerometer counts/min and VO_2 should be noted. For example, at 2.5 mph the accelerometer counts ranged from 1144 to 7303 counts/min and the VO_2 ranged from 9.1 to 22.6 ml of O_2/kg/min. After controlling for age, no significant mean difference in accelerometer counts was found between body mass tertiles (Figure 3.2).

The measured MET value was similar to the predicted MET value at the slowest treadmill speed (1 mph) (2.1 vs 2.2 METs); however, the measured MET value was significantly lower than the predicted MET value at the remaining speeds (2.7 vs 3.4 METs (2 mph); 3.1 vs 4.5 METs (2.5 mph); 3.7 vs 5.5 METs (3 mph); 5.1 vs 6.8 METs (4 mph)) ($p<0.05$) (Figure 3.3). Figure 3.4 shows the mean difference between the age-adjusted

measured and predicted MET values according to body mass tertile. The mean difference between the measured and predicted MET values was significantly greater at 1, 2.5 and 3 mph in the two lighter tertiles compared to the heaviest tertile. A similar trend was observed at 2 mph although the group differences were not significant (data not shown for 4 mph because only a few small participants were identified). The Bland-Altman plots confirm that on average the MET prediction equation overestimated the MET value at each treadmill speed (Figure 3.5). At each treadmill speed the overestimation appeared to be greater among the smaller children. The overall difference between the measured and predicted MET values was negatively correlated with the mean MET value at 2 mph ($r= -0.26$; $p= 0.04$), 2.5 mph ($r= -0.59$; $p< 0.001$), and 3 mph ($r= -0.57$; $p< 0.001$). The unadjusted and age-adjusted correlations for each body mass tertile are presented in Table 3.2.

Stepwise linear multiple regression analysis indicated that MET values could be estimated from the *activity counts/min x body mass* interaction term. The multiple R-squared for the prediction equation was 0.74 and the standard error of the estimate (SEE) was 0.53 METS. Although the *age x stature* interaction term could be entered into the model ($p< 0.05$), the inclusion of this term only increased the multiple R-squared by 0.003. Thus, the final prediction equation based on this analysis was:

METS = 2.149 + (0.000013 x activity counts/min x body mass).

For comparative purposes, an additional equation was developed from the data in the current study that included the same factors as the original published MET equation (Freedson et al. 2005). The MET prediction equation based on data from this study was:

METS = 1.313 + (0.000269 x counts/min) + (0.088 x age) + (0.0000227 x counts/min x age).

DISCUSSION

Multiple regression equations are available to convert accelerometer-derived activity counts into units of energy expenditure (kcals/min or MET value). The age-specific MET equation developed by Freedson et al (2005) is frequently used in the pediatric physical activity literature. This equation is commonplace since it allows for the partitioning of daily activity into moderate (3 METS) and vigorous (6 METS) physical activity. However, the accuracy of this equation to predict MET values among children of various body sizes has not been thoroughly investigated. Understanding the influence of body size is critical in the interpretation of accelerometer data given the heterogeneity in body size at a given chronological age among children and adolescents.

With the exception of the slowest treadmill speed (1 mph), the predicted MET level significantly overestimated the measured MET level during each treadmill speed. Few studies have cross-validated the age-specific MET equation using a range of walking speeds (1 to 4 mph). In a recent study, Trost et al. (2006) concurrently examined the predictive validity of three youth-specific energy expenditure equations (mean age= 13.7 yrs) (Trost et al. 1998; Puyau et al. 2002; Freedson et al. 2005) during four self-paced overground tasks (walking at a normal pace (~ 3 mph), walking at a brisk pace (~ 4 mph), running (~ 6 mph), and running at a fast pace (~ 8 mph)) in which VO_2 was measured with a portable indirect calorimetry system. Similar to our results, the age-specific MET equation significantly overestimated energy expenditure during the normal and brisk walking stages. The results of the current study extend the findings from Trost et al. (2006) by showing that the age-specific MET equation also overestimates energy expenditure during slower walking stages (e.g., 2 and 2.5 mph). Thus it appears that the age-specific MET equation significantly overestimates

energy expenditure during walking/running intensities ≤ 6 mph, but accurately predicts energy expenditure during fast running. This has important implications because most activities of daily living in children occur at ≤ 6 mph (Bratteby et al. 1997; Montgomery et al. 2004).

Over- or underestimated levels of energy expenditure are likely to occur in cross-validation studies because different activities may be measured. Thus, the measured MET values reported in this study are likely lower than the predicted MET values because different locomotor speeds were used in the calibration study. Although Freedson et al. (2005) indicate that two treadmill walking speeds and one running speed was used in the development of the age-specific MET equation, the precise speeds were not reported so direct comparison can not be made.

It was hypothesized that differences in body mass may also account for some of the discrepancy between the measured and predicted MET values. This hypothesis was based on the premise that the accelerometer signal may be greater when the accelerometer is further away from the body's center of gravity (i.e., heavier children will produce greater accelerometer signals compared to smaller children) (Westerterp 1999). In the current study the mean difference in accelerometer-derived activity counts and the mean difference between the measured and predicted MET values was compared across body mass tertiles (small: ≤ 26.5 kg; medium: 26.5 < mass ≤ 35.9; large: > 35.9 kg). Our results indicate that activity counts are independent of body mass during slow walking (≤ 4 mph). It could be that the mean difference between the small and large tertile created in this study (9.4 kg) was not large enough to influence the accelerometer signal. It appears from our results that the influence of body mass becomes important to consider when the age-specific MET equation

is used to predict energy expenditure. At walking speeds of 2.5 and 3 mph a mean difference of nearly 1 MET was observed between the large tertile (> 35.9 kg) and the two lighter tertiles (≤ 35.9 kg). Although the age-specific MET equation overestimated the measured MET value at each locomotor speed, our results imply that the age-specific MET equation may be more accurate for large children and that energy expenditure is overestimated in relatively smaller children. This finding could be attributed to physical differences (e.g., body mass) in participants from the original calibration study and the current study. Although a wider age range was used in the original calibration study (6 to 18 yrs), the results from the current study are independent of age since it was controlled for in the analysis.

The MET prediction equations based on data from the current study were not specifically developed to replace the published age-specific MET equation (Freedson et al. 2005). Instead, these equations were developed for comparative purposes. Since slower treadmill speeds (≤ 4 mph) were used in this study differences in the Y-intercept terms were found. Compared to the published age-specific MET equation (Freedson et al. 2005), this equation has a lower Y-intercept likely due to differences in treadmill speeds. The treadmill speeds used in the current study (1, 2, 2.5, 3, and 4 mph) were presumably lower than those used in the development of the published MET equation (two walking speeds and one running speed). Although the multiple R-squared term were similar between the two prediction equations, the SEE from the equation developed in the current study was lower than the SEE reported for the published MET equation (0.53 vs 1.1 METS). This indicates that a greater amount of variability in the predicted MET value exists with the published MET equation. The lower Y-intercept term (1.313) and SEE (0.60) in this equation compared to the published MET equation are likely the result of the slower treadmill speeds used in the

current study. The observed difference between the prediction equations has implications on the proper interpretation of physical activity or energy expenditure levels in children and adolescents. With the published age-specific equation (Freedson et al. 2005) MET overestimations will likely occur during slower ambulatory movements, even more so among smaller children. This is critical given that a high percentage of a child's day is spent at in light intensity activities (Bratteby et al. 1997; Montgomery et al. 2004). This systematic overestimation may also lead to erroneous conclusions regarding the age-related trends and current levels of physical activity. Although longitudinal data collected with an accelerometer is not available to precisely detail the age-related trends in activity, the results from cross-sectional studies that rely on the published age-specific MET equation commonly report that younger (and thus smaller) children accumulate more physical activity (Trost et al. 2002).

In order to rectify the problem with current youth-specific prediction equations recent advances should be considered that allow for a range of activities to be accurately assessed. Recently, Crouter et al. (2006) developed a two-line regression model that can be used to predict energy expenditure during lifestyle and ambulatory (walking/running) activities. Since this approach is relatively new to the field, the usefulness of this model under free-living conditions has not yet been established. It is unknown whether this approach will work among children and adolescents since this model was originally developed in adults (average age = 35 yrs).

The results from the present study should be interpreted with the following limitations in mind. First, our sample was divided into tertiles to examine the influence of body mass on the interpretation of accelerometer counts and MET levels. Although each body mass

category had more than 20 participants, the generalizability of our results may be limited. Second, RMR was predicted rather than measured and thus individual MET values may be over or underestimated. Third, the range of locomotor speeds used in the current study (1 to 4 mph) did not allow us to examine the influence of body mass during running or other lifestyle activities. However, the main purpose of the study was to examine the ability of the age-specific MET equation to predict energy expenditure at slow ambulatory speeds.

In conclusion, the results from this study and others (Trost et al. 2006) highlight the limitations associated with the age-specific MET equation to predict energy expenditure during normal and slow-paced walking. This equation appears to overestimate the energy expenditure of relatively small children compared to their larger counterparts. However, given the widespread use of the age-specific MET equation it will be difficult to change current practices. It is recommended that a large study of varying ages (4-18 yrs) and locomotor speeds be conducted to establish more suitable equations.

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Table 3.1. Physical characteristics of the participants.

Variable	Boys (n=41)	Girls (n=26)	Total (n=67)
Age (yr)	9.4 ± 2.2 (5.5 - 13.2)	9.4 ± 1.9 (5.9 - 12.5)	9.4 ± 2.1 (5.5 - 13.2)
Stature (cm)	135.7 ± 14.7 (110.3 - 158.4)	136.5 ± 14.9 (115.5 - 170.5)	136.0 ± 14.7 (110.3 - 170.5)
Mass (kg)	33.0 ± 10.0 (20.0 - 60.5)	35.1 ± 13.7 (20.3 - 71.6)	33.8 ± 11.5 (20 - 71.6)
Estimated RMR (kcal/kg/min)	0.026 ± 0.005 (0.017 - 0.033)	0.026 ± 0.004 (0.018 - 0.033)	0.026 ± 0.004 (0.017 - 0.033)

Values are mean ± sd (range). No significant differences between genders.

Table 3.2. Unadjusted and age-adjusted correlations from the Bland-Altman plots.

Body size tertile	Treadmill speed (mph) 1	2	2.5	3
Small (≤ 26.5 kg)				
Unadjusted	0.02	-0.74*	-0.74*	-0.84*
Age-adjusted	0.16	-0.71*	-0.67*	-0.78*
Medium (> 26.5 kg and ≤ 35.9 kg)				
Unadjusted	0.22	-0.11	-0.71*	-0.76*
Age-adjusted	0.55*	-0.09	-0.71*	-0.76*
Large (> 35.9 kg)				
Unadjusted	0.13	-0.06	-0.14	-0.21
Age-adjusted	0.32	-0.04	-0.10	-0.19
Overall				
Unadjusted	0.11	-0.26*	-0.59	-0.57*
Age-adjusted	0.42*	-0.28*	-0.59	-0.57*

* Significant correlation ($p<0.05$).

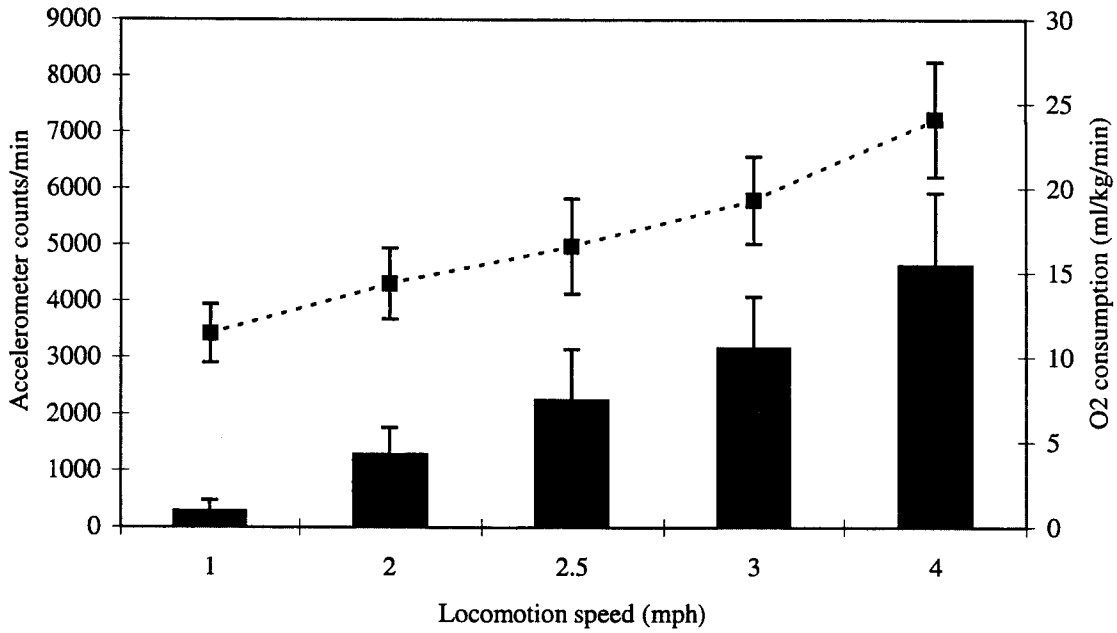

Figure 3.1. Average accelerometer counts (shaded boxes) and oxygen consumption (dashed line) during each treadmill speed.

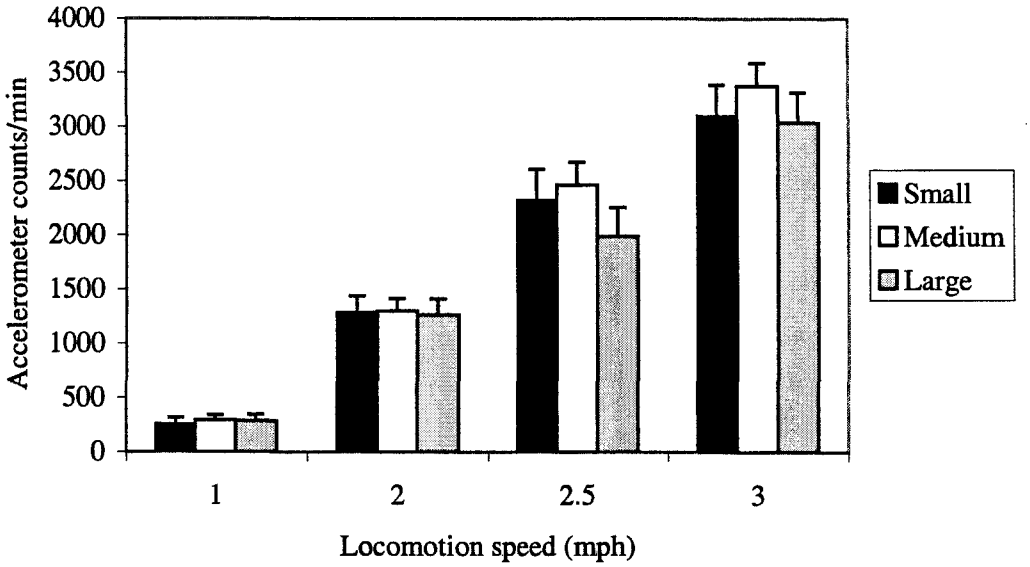

Figure 3.2. Age-adjusted accelerometer counts for small, medium, and large children at each treadmill speed.

No significant difference in accelerometer counts between body mass tertiles at each treadmill speed.

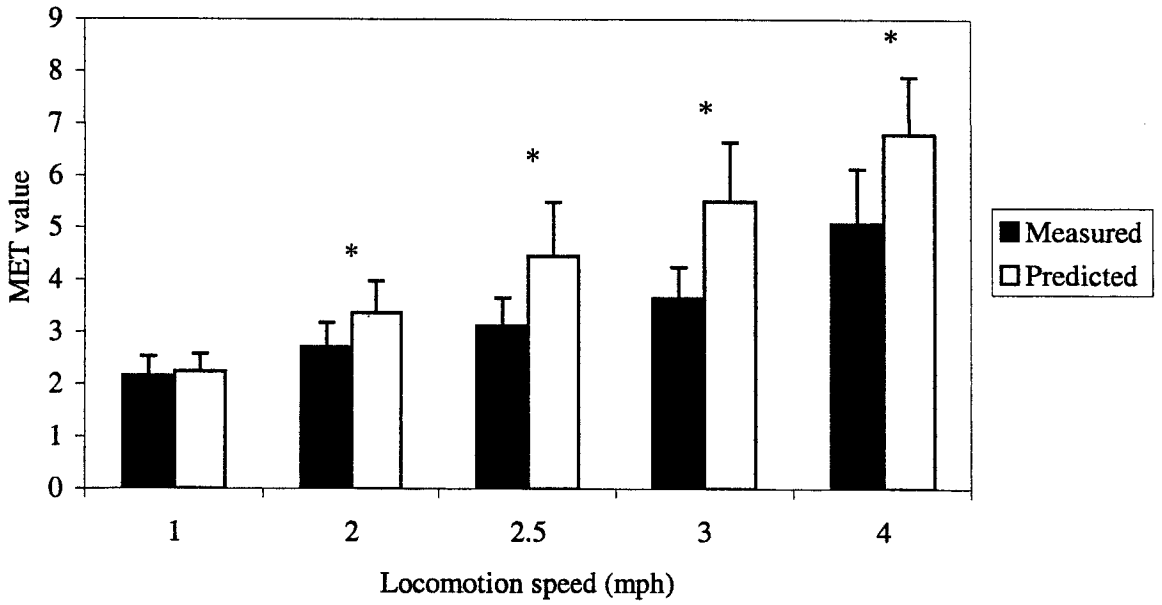

Figure 3.3. Measured and predicted MET value at each treadmill speed.

* Significant difference between MET values ($p<0.05$).

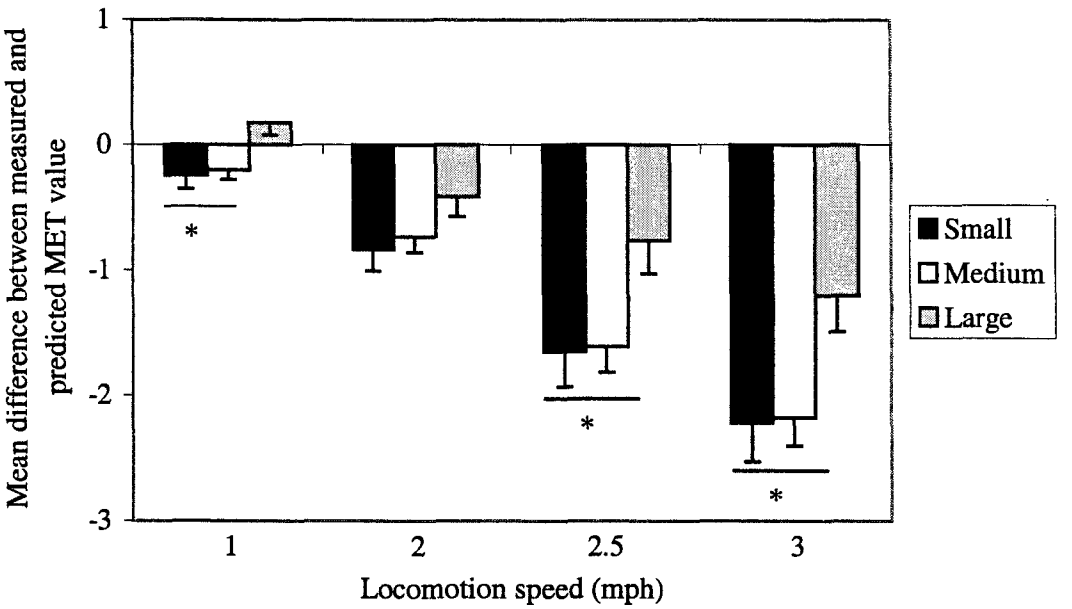

Figure 3.4. Age-adjusted mean difference between measured and predicted MET values for small, medium, and large children at each treadmill speed.

* Significantly different than the largest body mass tertile ($p<0.05$).

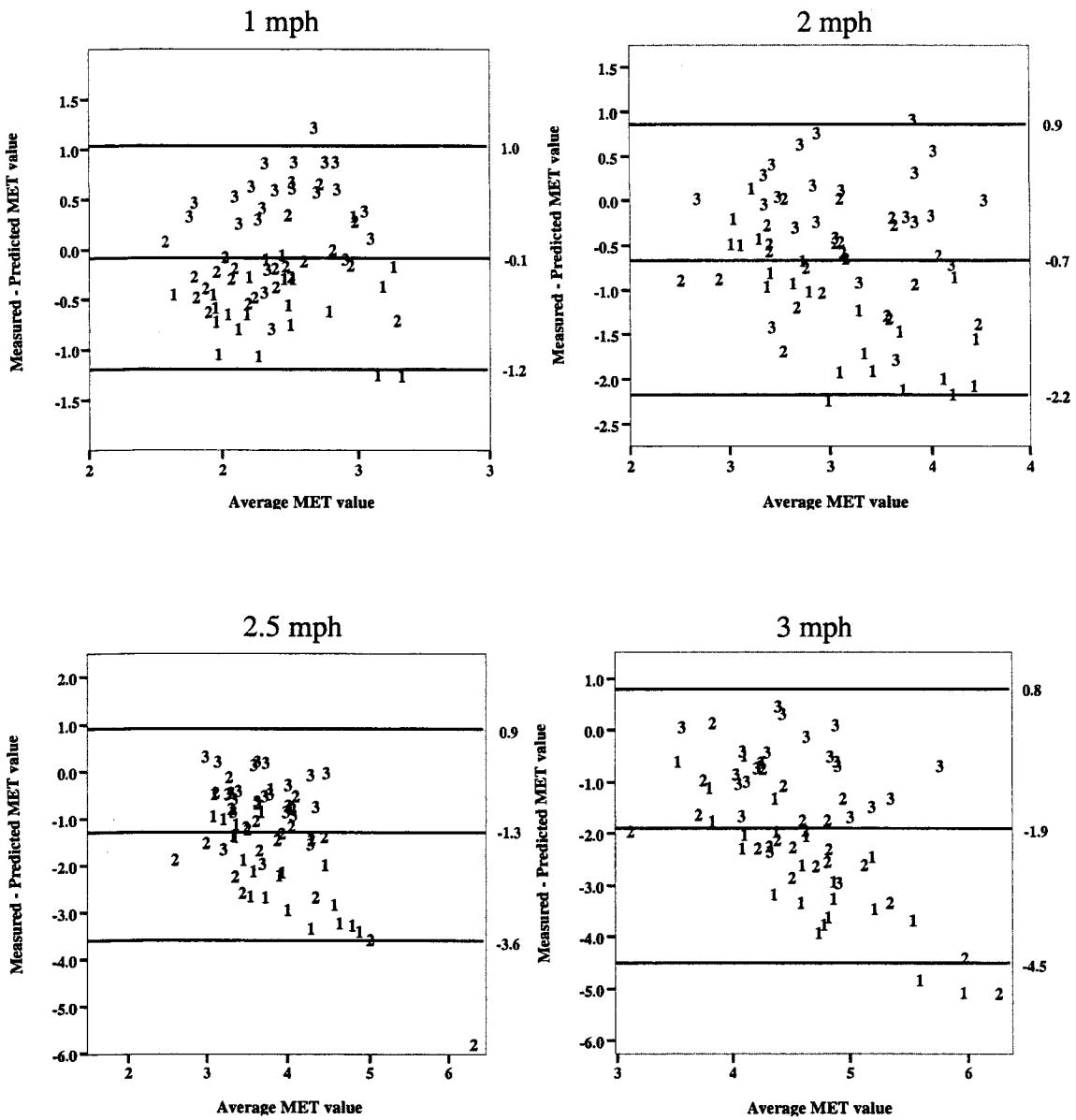

Figure 3.5. Bland-Altman plots displaying the mean difference between measured and predicted MET values at each speed.

CHAPTER 4.

DAY-TO-DAY VARIABILITY IN DAILY ENERGY EXPENDITURE AMONG 9-15 YR OLD YOUTH

ABSTRACT

The purpose of this study was to examine the day-to-day variability in daily energy expenditure among 9 to 15 year old boys (n=31) and girls (n=35). During a 7-day assessment period physical activity was assessed with an accelerometer and the components of energy expenditure (sedentary, light, moderate, and vigorous) were derived based on the calculated MET values. Repeated measures analysis of variance (RMANOVA) was used to examine the day-to-day differences in components of energy expenditure and the proportion of variance due to activity intensity, participants, or days was determined using Generalizability theory. The coefficient of variation (CV) was calculated for each individual and reported as within-individual CV and group CV. Most of the variance in total energy expenditure (TEE) was accounted for by the activity intensity term (70.6%) and the *activity intensity x participant* interaction (23.2%). No meaningful differences in TEE were found (effect size= 0.04) and less than 1% of the variance in TEE was attributed to the *activity intensity x day* interaction. Our results suggest that TEE remains relatively stable over a 7-day monitoring period in 9-15 yr old youth. However, additional work is needed to determine if biological factors regulate daily levels of physical activity in an effort to maintain TEE.

INTRODUCTION

Total energy expenditure (TEE) represents the combined metabolic cost of basal metabolism, the thermic effect of food, and physical activity (Mcardle et al. 1996). Basal metabolism represents the greatest proportion of TEE (60-70%) while the metabolic cost of physical activity contributes the largest source of within-individual variability (i.e., day-to-day variation). The day-to-day variability in physical activity has previously been examined to determine the number of monitoring days needed to estimate habitual physical activity

(Trost et al. 2000). However, from a biological perspective, the day-to-day variability may also be used to explore the biological basis of physical activity. In a review by Rowland (1998) several lines of evidence are provided that indicate that the physical activity portion of TEE is internally regulated in an effort to maintain energy homeostasis.

In this study, it was hypothesized that limited variability would exist for total energy expenditure (TEE) despite day-to-day differences in activity intensities (i.e., sedentary, light, moderate and vigorous energy expenditure). Support for this hypothesis is available from doubly labeled water studies that indicate a relatively low amount of variation exists in TEE under free-living conditions (coefficient of variation (CV) ~12%) (Black and Cole 2000). The doubly labeled water method is limited in that it is unable to partition activity energy expenditure (AEE) into separate activity intensities. This type of information can however be obtained from accelerometers by translating stored activity counts into estimated MET levels (Freedson et al. 2005).

The day-to-day variation in physical activity has previously been reported among children and adolescents (Mota et al. 2003; Jago et al. 2005); however, these studies relied on ≤ 4 monitoring days and TEE was not reported. Some evidence is available to suggest TEE is lower on Sundays compared to the remaining days of the week (Ribeyre et al. 2000); however, limited data are available to support this finding. Therefore, the purpose of this study was to examine the day-to-day variability in TEE among adolescents over a 7-day period. Generalizability theory was used to partition and quantify the sources of variability in the repeated measurements of TEE.

METHODS

Participants

Participants for this study were selected from a pool of participants who participated in a study examining the reliability and validity of the Youth Media Campaign Longitudinal Survey (YMCLS), a tool designed by the Centers for Disease Control to monitor youth activity patterns. Although the recruitment strategy and participant characteristics have been described (Welk et al. in review), a brief description will be provided here. Eight urban schools (4 elementary schools and 4 middle schools) were selected based on the socioeconomic status of the surrounding neighborhood (percent eligible for free and reduced lunch) and level of ethnicity (percent of minority students). Two elementary and two middle schools were from lower SES neighborhoods (55% - 90% of students eligible for free and reduced lunch) with higher minority rates (40% - 57%), while the other two elementary and two middle schools were from higher SES neighborhoods (17% - 49% eligible for free and reduced lunch) with lower minority rates (12% - 31%).

A total of 198 children completed the 7-day activity monitoring protocol; however, only those participants with 7 days of acceptable accelerometer data were included in this analysis since we were interested in examining day-to-day changes in TEE. Monitoring days were considered acceptable if fewer than four, 20-min periods of consecutive zeros were found in the accelerometer data for a given day. Thus, the sample for this study included 66 children (31 boys and 35 girls) representing 33% of the original activity-monitoring sample. Each monitoring day was 900 minutes. No significant differences in the physical characteristics (age, height, weight, BMI) were found between this sub-sample and the remaining sample ($p>0.05$). Before the initiation of the study protocol parental consent and

child assent was obtained. The study was approved by the University Human Subjects Review Board.

Anthropometry

Descriptive characteristics (age, height, weight, and BMI) were collected. Chronological age (yrs) was calculated by subtracting the participant's date of birth from the observation date. Standing height was measured with a portable stadiometer (Seca Road Rod, Seca Corporation, Hanover, MD) to the nearest 0.1 cm while the participant was standing upright with their feet flat on the stadiometer platform. A strain gauge scale (Lifesource, A&D Maker, Milpitas, CA) was used to measure body mass to the nearest 0.1 kg. The body mass index (BMI) was calculated by dividing the participant's body mass (kg) by their height (m^2).

Estimated Energy Expenditure

The Actigraph accelerometer (ActiGraph, LLC, Fort Walton Beach, FL) was used to estimate energy expenditure over the 7-day monitoring period. This accelerometer is small and lightweight (5.1 x 4.1 x 1.5 cm, 42.6 g) and is worn at the mid-axillary line on the hip. The Actigraph has been shown to be reliable and valid among children and adolescents to measure physical activity and energy expenditure (Trost et al. 1998; Ekelund et al. 2001; Eisenmann et al. 2004).

Before the accelerometers were distributed to the participants, each accelerometer was calibrated in-house following standard procedures outlined by the user manual. At this time the accelerometer was also programmed to collect activity counts in 1-minute intervals. After the monitoring period, the accelerometers were downloaded and minute-by-minute

activity counts were analyzed using an age-specific MET regression equation (Freedson et al. 2005). The number of MET-minutes was then determined for each activity intensity (i.e., sedentary (<2 METS), light (2≤ METS <4), moderate (4≤ METS <6), and vigorous activity (≥6 METS)) and energy expenditure was estimated based on the assumption that 1 MET = 1 kcal/kg/hr. Total energy expenditure (TEE) represented the summed value of energy expenditure at each activity intensity.

Statistical Analysis

Descriptive statistics were determined for the participants and the components of energy expenditure. An independent t-test was used to examine gender differences in height, weight, age, and BMI. The variability in TEE and the energy expended during sedentary, light, moderate, and vigorous activity between monitoring days was characterized by the coefficient of variation (CV = SD/mean). The CV was calculated for each individual to describe the within variability in energy expenditure components. Although the CV was not the main statistical approach used to assess the variability in energy expenditure the authors thought it was important to report the CV for comparative purposes. A two-way *(day x activity intensity)* repeated measures analysis of variance (RMANOVA) model was used to examine the mean daily differences in energy expenditure. The mean square and error terms for 'day', 'activity intensity', and 'participant' were used to partition and quantify the total variability using the Generalizability theory approach described by Morrow (1989). Bivariate correlations examined the relationship between age, BMI and the components of energy expenditure. Statistical significance was set at $p < 0.05$. Statistical analyses were completed with SPSS version 12.0.

RESULTS

The mean values for age, height, weight, and BMI were similar between boys and girls ($p>0.05$), and therefore genders were combined to increase the sample size and the ability to detect day-to-day differences in energy expenditure components (Table 4.1).

On average, the energy expended through sedentary activities (< 2 METS) contributed the largest proportion of TEE (~50%). This percentage was the highest on Sunday (52%) and lowest on Friday and Saturday (48%). The contribution of light, moderate, and vigorous energy expenditure to TEE was 35%, 10%, and 5%, respectively. The average within-individual CV for TEE approximated 7% suggesting that limited variability exists in TEE despite relatively large amounts of daily variation in moderate (CV= 69%) and vigorous (CV= 83%) energy expenditure (Figure 4.1). Individual CVs for TEE ranged from 2.5% to 16.7% highlighting the between-individual differences in energy expenditure regulation.

A significant main effect for day was found [$F(6,390) = 2.18$, $p=0.05$] suggesting mean day-to-day differences in energy expenditure components existed in the sample; however, the small effect size (0.03) and relatively low absolute difference between days implies that the differences may not be meaningful. The significant main effect for intensity [$F(3,195) = 195.5$, $p< 0.000$] combined with the large effect size (0.75) indicates that true differences existed between the energy expended during sedentary, light, moderate, and vigorous activity with a monitoring day. Although the *day x activity intensity* interaction term was significant [$F(18,1170) = 2.52$, $p< 0.000$], the small effect size (0.04) implies that the daily differences in energy expended during sedentary, light, moderate, and vigorous activity may not be meaningful (Figure 4.2). The intraclass correlations (ICC) for sedentary (0.99), light (0.95), moderate (0.85), and vigorous (0.82) energy expenditure also demonstrate the

high level of agreement between days. Vigorous energy expenditure demonstrated the largest amount of daily variation, ranging from 69 kcals on Sunday to 112 kcals on Tuesday. The ICC value for TEE was 0.99 indicating that limited day-to-day variation existed.

Generalizability theory provided a method to partition and quantify the sources of variance in TEE. The results indicate that most of the variance in TEE was accounted for by the activity intensity term (70.6%) and the *activity intensity x participant* interaction (23.2%). Only a small proportion of the variance was explained by the *activity intensity x day x participant* interaction term (5.6%) or the participant term (1.3%). Less than 1% of the variance was attributed to the *activity intensity x day* interaction, while the day term and the *day x participant* interaction term did not account for any of the variance in TEE.

In general, the correlations between age and the energy expenditure components were low and non-significant; however, BMI was significantly correlated with sedentary energy expenditure ($r=0.83$, $p<0.001$), light energy expenditure ($r=0.49$, $p<0.001$), and TEE ($r=0.91$, $p<0.001$).

DISCUSSION

Previous studies have examined the day-to-day variability in physical activity to determine the appropriate number of monitoring days or to examine the effect of a particular day (i.e., weekday vs weekend day) on levels of physical activity. In the current study, we were interested in the day-to-day variability from a human biological, rather than a measurement, perspective. In this study, we hypothesized that day-to-day changes in activity intensities (i.e., sedentary, light, moderate, and vigorous) would exist in an effort to maintain energy homeostasis over a 7-day period. The statistical approach used in this analysis

(Generalizability theory) to partition and quantify the sources of variance adds to the novelty of this study.

The results suggest that limited day-to-day variability exists in TEE or the components of TEE (i.e., sedentary, light, moderate, and vigorous energy expenditure). In this study, none of the variance in TEE could be accounted for by a particular day. This is an interesting finding because weekend days, particularly Sundays, have been considered days in which physical activity levels are lower than the remaining week days among children (Jago et al. 2005). The discrepancy between studies may be related to the differences between outcome measures (i.e., physical activity vs energy expenditure) or because of differences in statistical methods. In the current study, the proportion of variance accounted for by a particular day was quantified using the Generalizability theory, whereas the conclusions from Jago et al. (2005) were drawn from a repeated measures design where the variance accounted for a particular day was not determined. Our results are more comparable to those from Matthews et al. (2002) who used a random effects model to estimate the variance in physical activity accounted for by a particular day of the week. Matthews et al. (2002) determined that the day-of-the-week effect accounted for 1-8% of the total variance in accelerometer counts/min and time spent in moderate-to-vigorous activity in adults. The small effect size for the *day x activity intensity* interaction term reported in the current study suggests that no meaningful differences in energy expenditure components existed between monitoring days.

Greater detail regarding the day-to-day variability in energy expenditure was provided by examining the *intensity x day* interaction term. In partial support of our hypothesis, limited variability in TEE was found; however, less than 1% of the variance was

attributed to the *intensity x day* interaction indicating that the energy expended during sedentary, light, moderate, and vigorous activity did not statistically differ between monitoring days. From a biological perspective, significant day-to-day differences in activity intensities may not be needed if only slight absolute adjustments are needed to maintain TEE.

The relative stability in TEE observed in the current study is in contrast to the results reported by Ribeyre et al. (2000) in which TEE was measured over a 7-day period using individual heart rate (HR)-VO_2 curves. Although the main purpose of Ribeyre et al. (2000) study was to compare the energy expended during school, exercise, sleep, eating, and miscellaneous activities between athletic and non-athletic boys and girls, large absolute differences in TEE were reported between high and low days in athletic boys (1130 kcals) and girls (690 kcals). Smaller absolute differences in TEE were reported between high and low days for non-athletic boys (714 kcals) and girls (542 kcals) (statistical difference between days not reported). Thus, their results suggest that TEE is not maintained over a 7-day period in athletic and non-athletic boys and girls. It is difficult to directly compare our results with those from Ribeyre et al. (2000) because of the differences in assessment tools and statistical methods. The current study used an accelerometer to estimate TEE while Ribeyre et al. (2000) used individual HR-VO_2 curves to account for the inter-individual variation in the metabolic cost of activity. The use of heart rate to estimate TEE may be limited because factors other than physical activity (i.e., stress, environmental conditions, diet composition) can increase heart rate and thus lead to overestimations of TEE. Indeed, it is unclear whether TEE remains relatively stable over an extended monitoring period (i.e., 7-days). The results in the current study suggest that limited day-to-day variability exists in TEE and the components of TEE; however, results from previous studies (Ribeyre et al.

2000) suggest that day-to-day differences in TEE exist. The conflicting results between studies may be attributed to the way energy expenditure was determined (accelerometry vs heart rate monitoring). In comparison, results using doubly labeled water suggest that a relatively low amount of variation in TEE exists (CV~ 10%) over extended periods of time (e.g., 77 days) (Goran et al. 1993). Although the doubly labeled water method provides a precise measure of TEE, day-to-day fluctuations cannot be determined because of the methodological limitations associated with this technique.

Nearly 70% of the variance in TEE could be attributed to the mean differences in activity intensities within a monitoring day. On average, nearly 85% of TEE (nearly 1432 kcals) was accounted for by activities below 4 METs (sedentary (50%) and light (35%) activity). In comparison, the average amount of energy expended through moderate and vigorous activity was approximately 250 kcals/day, which represented the remaining 15% of DEE. Our results are comparable to the results from Bratteby et al. (1997) who found that on an average day 46% of the time was spent in sedentary activities (sleeping (19%) and sitting (27%)) while nearly 19% of the time was spent in moderate or vigorous activities assessed in 374 adolescents using a self-report activity diary.

A majority of the remaining variance was attributed to the *activity intensity x participant* interaction (23.2%). This finding highlights the inter-individual variation in the average amount of energy expended during sedentary, light, moderate, and vigorous activity. The reported difference in energy expenditure components between participants is likely the combined influence of behavioral and biological factors. From a biological perspective, the heritability of physical activity has been reported to range from 29 to 63% (Kaprio et al. 1981; Pérusse et al. 1989; Maia et al. 2002), thus it is plausible to conclude that heredity

contributes to the inter-individual variation in physical activity, and thus energy expenditure. Additional evidence to partially explain the inter-individual variation was provided by Simonen et al. (2003) who reported linkage evidence for physical activity (chromosome 13q22-q31) and physical inactivity (chromosome 7p11.2, 20q13.1). Identifying biological factors that may increase the propensity to be physically active or inactive is an important step in understanding the physical activity phenotype. This information also lends itself to the development of more specific intervention strategies aimed at increasing physical activity levels.

The *activity intensity x day x participant* interaction contributed the remaining portion of the variance (5.6%). This suggests that for a given participant activity intensities did not change much between monitoring days. A relatively low amount of variance (1.3%) was attributed to the participant term. None of the variance was accounted for by the *day x participant* interaction, which suggests that relatively similar values were observed on any given day for any given participant.

The present study is not without limitations. In the absence of repeated measures it is difficult to determine if the amount of daily variation is reproducible, and thus inherent to the individual. It is clear that physical activity patterns and thus energy expenditure levels are influenced by the season, therefore future studies examining the variability in physical activity or energy expenditure should include multiple assessment periods throughout the year. The Actigraph accelerometer can only assess movements in the vertical plane and it cannot assess upper body energy expenditure or the increased metabolic cost of carrying a load or walking up an incline. However, no other field-based tool is available that doesn't have similar limitations. Measuring physical activity with accelerometers may be limited in

that upper body movement and other common activities performed by children (i.e., swimming and cycling) are largely unaccounted for, and therefore our understanding of the stability of physical activity may be misunderstood.

In conclusion, the results of this study suggest that TEE assessed with an accelerometer remains relatively stable over a 7-day monitoring period in 9-15 yr old boys and girls. Although no meaningful day-to-day differences in sedentary, light, moderate, or vigorous energy expenditure were found, the small absolute changes may be interpreted as a mechanism to regulate TEE and thus provide support for the biological basis of physical activity. Additional work is needed to understand biological factors, including genetics, which may contribute to the inter-individual differences in energy expenditure. This information is critical in this area to improve our understanding the variability in TEE mechanisms that may regulate daily physical activity and energy expenditure in children and adolescents.

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Table 4.1. Physical characteristics of the participants.

Variable	Boys (n=31)	Girls (n=35)	Total (n=66)
Age (yrs)	11.9 ± 1.4 (9.9 to 15.0)	11.6 ± 1.1 (9.8 to 14.1)	11.7 ± 1.3 (9.8 to 15.0)
Stature (cm)	150.3 ± 8.0 (138.0 to 169.0)	150.2 ± 12.3 (130.8 to 172.7)	150.3 ± 10.4 (130.8 to 172.7)
Mass (kg)	50.8 ± 12.7 (32.2 to 75.5)	49.5 ± 19.1 (25.6 to 118.0)	50.1 ± 16.3 (25.6 to 118.0)
BMI (kg/m^2)	22.3 ± 4.6 (15.9 to 34.0)	21.3 ± 5.6 (14.9 to 42.0)	21.8 ± 5.1 (14.9 to 42.0)

Values represent mean ± SD (range). No significant differences between boys and girls.

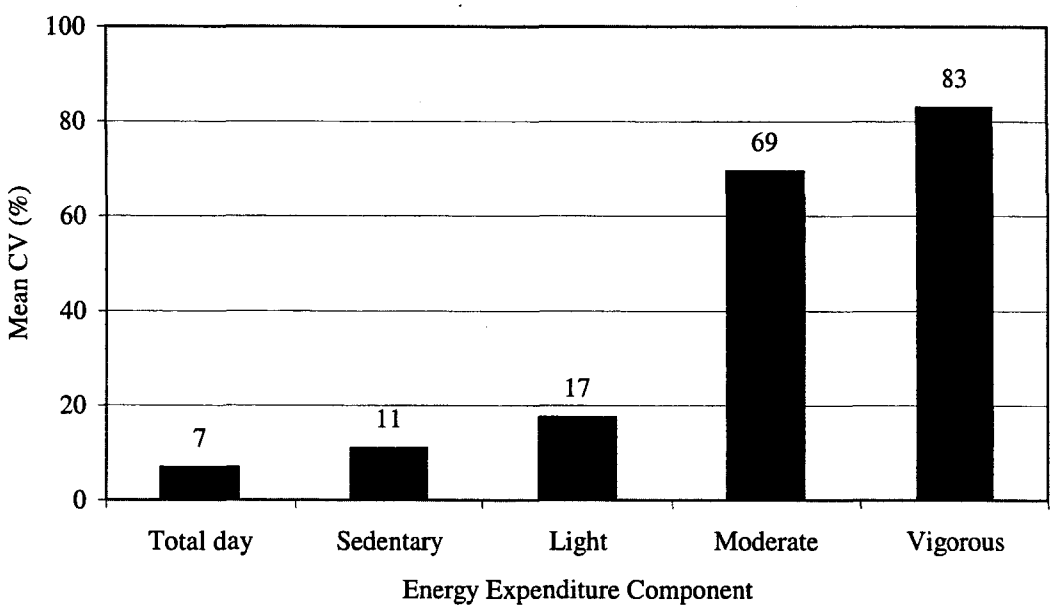

Figure 4.1. Average within-individual coefficient of variation (CV) for the total day and for sedentary, light, moderate, and vigorous activity.

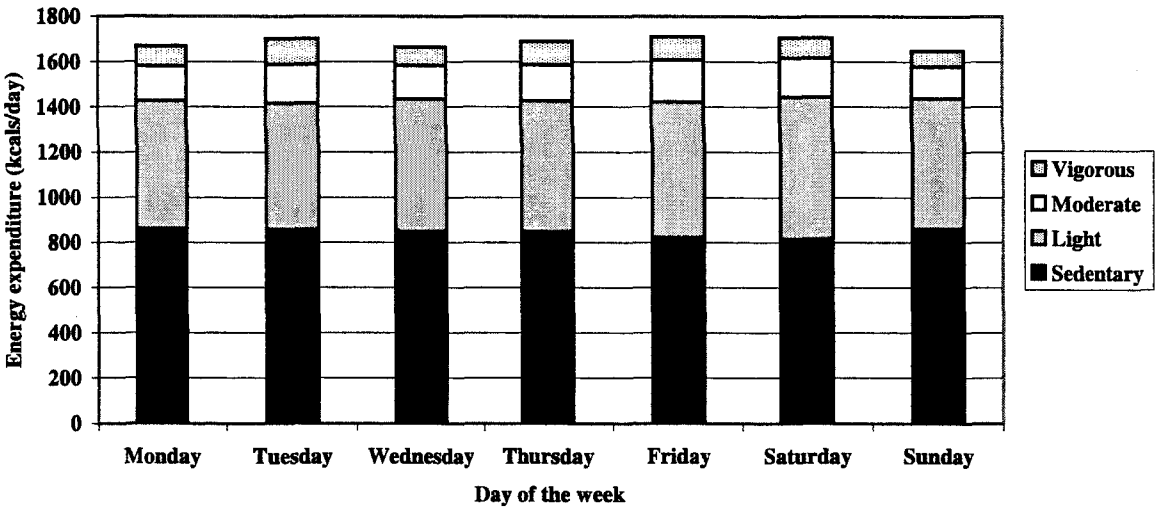

Figure 4.2. Estimated energy expenditure during sedentary, light, moderate, and vigorous activities during the 7-day monitoring period.

CHAPTER 5.

MATURITY-ASSOCIATED VARIATION IN ACCELEROMETER-DETERMINED PHYSICAL ACTIVITY AMONG 9-14 YR OLDS

ABSTRACT

The purpose of this study was to examine the difference in objectively measured moderate-to-vigorous physical activity (MVPA) among early, average, and late maturing youth. A total of 161 (76 boys, 85 girls) 9-14 yr old children were recruited to participate in the study. Anthropometric variables (chronological age, standing height, sitting height, body mass, and leg length) were collected and the maturity offset, or number of years away from peak height velocity (PHV), was derived. Biological maturity groups (early, average, and late maturers) were created based on the estimated age at PHV (estAPHV). Habitual physical activity was determined with the Actigraph accelerometer over a 7-day period. Early maturing boys participated in more MVPA than late maturing boys (17 min), while late maturing girls participated in ~10 and 16 more minutes of MVPA compared to early and average maturing girls, respectively. Although the results of this study did not demonstrate significant differences in MVPA between early, average, and late maturing youth, the absolute differences between maturity groups should be considered.

INTRODUCTION

The age- and gender-related differences in habitual physical activity among children and adolescents are well-documented (Sallis 2000). In general, boys are more active than girls and levels of physical activity progressively decline during adolescence. Given the role of physical activity in the prevention of chronic disease (U.S. Department of Health and Human Services 1996), there has been interest in understanding the age-related decline in physical activity (Sallis 2000). Although most of the attention has been placed on the psychosocial factors that influence physical activity in youth (Sallis et al. 2000), there has been limited attention given to biological factors that may also contribute to this decline.

Biologically, the decline in physical activity among older adults and animals is related to the dopaminergic neurotransmitter system, specifically the deterioration of the D2 dopamine receptor (Ingram 2000). Since it is unlikely that the observed decline in physical activity during the adolescent period is the result of this biological mechanism, other biological factors should be considered during this period of the lifespan.

In the current study, it was hypothesized that early maturing boys and late maturing girls would accumulate more moderate-to-vigorous physical activity (MVPA) compared to their biological counterparts. This hypothesis stems from the observation that the somatic effects of key pubertal hormones (i.e., growth hormone and insulin-like growth factor-1) are exhibited first among early maturers (Tanner 1962; Roemmich and Rogol 1999; Malina et al. 2004) and may directly or indirectly influence the ability (or perceived ability) to engage in physical activity or organized sport (Malina et al. 2004). That is, compared to their average or late maturing counterparts, early maturing boys would likely be taller, heavier, and have a greater relative amount of muscle tissue. Thus, in activities that are largely dependent on body size (e.g., basketball or football) early maturers may have a biological advantage. In contrast, the somatic changes that occur at the onset of biological maturation among girls (e.g., increased fat mass) may adversely influence participation in physical activity. Indeed, at a given chronological age, the somatic characteristics of early maturing boys and late maturing girls may have biologically advantageous roles when it comes to participation in physical activity or organized sport. Involvement in organized sport becomes critical during the adolescent period as a way to increase levels of daily energy expenditure (Katzmarzyk and Malina 1998) and MVPA (Wickel and Eisenmann in review).

Limited information is available regarding the role of biological maturation on levels of physical activity during adolescence; therefore the purpose of this study was to examine the difference in objectively measured physical activity among early, average, and late maturers. It was expected that the somatic characteristics associated with early maturation in boys (i.e., increased lean body mass) and late maturation in girls (i.e., delayed increase in fat mass) would promote a greater accumulation of MVPA/day.

METHODS

Participants

This study represents a secondary analysis of data that was originally collected to examine the reliability and validity of the Youth Media Campaign Longitudinal Survey (YMCLS). Although the sample has previously been described (Welk et al. in review) a brief description of the participants is provided here. A total of 98 boys and 115 girls between 9 and 14 yrs were recruited from 4 elementary and 4 middle schools from a large urban area. Two elementary and two middle schools were located in relatively high minority neighborhoods (40% - 57% minorities) where a majority of students were eligible for free and reduced lunch. The remaining two elementary and middle schools were located in relatively low minority neighborhoods (12% - 31% minorities) where a lower percent of students were eligible for free and reduced lunch. Although majority of the sample was white (77%) with the remaining proportion either black (8%), Hispanic (8%), or from other race/ethnic groups (7%). Parental consent and child assent was obtained from each participant prior to the initiation of the study protocol, which was approved by the University Human Subjects Review Board.

Anthropometry

Standard procedures were followed to measure standing height, sitting height, and body mass (Malina 1995). A portable stadiometer (Seca Road Rod, Seca Corporation, Hanover, MD) was used to measure standing height and sitting height to the nearest 0.1 cm. Leg length was calculated by subtracting the participant's sitting height from their standing height and recorded to the nearest 0.1 cm. Body mass was measured using a strain gauge scale (Lifesource, A&D Maker, Milpitas, CA) and was reported to the nearest 0.1 kg. The body mass index (BMI) was calculated by dividing the participant's body mass (kg) by their height (m^2). Chronological age was calculated by subtracting the participant's date of birth from the observation date.

Biological Maturity Status

Given the methodological and practical limitations of assessing maturation by skeletal, somatic, and sexual indicators, Mirwald et al (2002) recently proposed a non-invasive technique to estimate the number of years away from peak height velocity (PHV), or maturity offset, using cross-sectional data (Equation 5.1).

Equation 5.1.

Boys: Maturity offset = -9.236 + 0.0002708 (leg length x sitting height) – 0.001663 (age x leg length) + 0.007216 (age x sitting height) + 0.02292 (weight:height)

Girls: Maturity offset = -9.376 + 0.0001882 (leg length x sitting height) + 0.0022 (age x leg length) + 0.005841 (age x sitting height) – 0.002658 (age x weight) + 0.07693 (weight:height).

Although the maturity offset does not provide an indication of tempo of maturation, it does provide an indication of timing between individuals to allow for comparisons between

biological groups. The maturity offset can be used as a continuous variable to predict a dependent variable (e.g., physical activity) or it can be used to create biological categories (-2, -1, 0, 1, or 2 yrs from PHV) to examine group differences. For the current study, a participant's maturity offset was subtracted from their chronological age to provide an estimation of age at PHV (estAPHV). Comparisons can then be made between biological groups (e.g., early, average, and late maturers) given the average ages for PHV among boys (~14 yrs) and girls (~12 yrs) (Malina et al. 2004). In this study, average maturing boys and girls included those with an estAPHV between 13.5-14.5 and 11.5-12.5 yrs, respectively. For boys and girls, late maturers had an estAPHV greater than 14.5 and 12.5 yrs, respectively. Likewise, early maturing boys and girls had an estimated APHV less than 13.5 and 11.5 yrs, respectively.

The validity coefficient between skeletal age and maturity offset was 0.83 (Mirwald et al. 2002), suggesting acceptable agreement between the two approaches to estimate maturity status. The maturity-offset equation has also been cross-validated with 121 boys and 88 girls. Mean differences between actual and predicted maturity offset was 0.24 yrs and 0.001 yrs in boys and girls, respectively.

Physical Activity Assessment

The Actigraph accelerometer (ActiGraph, LLC, Fort Walton Beach, FL) was used to measure habitual physical activity. Prior to use, each accelerometer was calibrated and programmed to collect activity counts in 1-minute epochs. Before distributing the accelerometers oral and written instructions about the study protocol and the use of the accelerometer was provided. Participants were instructed to wear the accelerometer during

all-waking hours over a 7-day period, except while swimming or bathing. The Actigraph was attached worn around the waist at the mid-axillary line of the hip.

A total of 198 children completed the activity monitoring protocol. However, some of the participants were excluded because they did not have at least four days of acceptable accelerometer data (n=21) or because they were identified by an outlier analysis (n=3). In the original study, individual monitoring days were excluded if more than 3 strings of consecutive zeros were found. Additional participants were excluded from the analysis if their accelerometers were lost (n=2), failed to download (n=8), or produced excessively high activity counts (n=3). Thus, a total of 161 participants were included in the current analysis. For these participants, an age-specific MET regression equation (Freedson et al. 2005) was used to determine the average amount of time spent in MVPA (METS ≥ 3). Accelerometers have been shown to be reliable and valid tools among children and adolescents (Trost et al., 1998; Ekelund et al., 2001; Eisenmann et al. 2004).

Statistical Analysis

Two-way analysis of covariance (ANCOVA) (*sex x maturity group*), controlling for chronological age, examined the differences in physical activity. One-way ANOVA was used to examine the age and age-adjusted differences in MVPA. Partial correlations, controlling for chronological age, examined the relationship between estAPHV and physical activity. Chronological age was accounted for in the analyses because a boy with a maturity offset of –1 could be an average maturing 13 yr old or a late maturing 14 yr old. Statistical significance was set at $p < 0.05$. Statistical analyses were completed with SPSS Version 12.0.

RESULTS

The final sample included 76 boys (34 early, 38 average, and 4 late maturers) and 85 girls (27 early, 47 average, and 11 late maturers). Descriptive characteristics of the participants are presented in Table 5.1. The mean chronological age (~12 yrs) was similar among boys and girls. As expected, the mean estAPHV occurred earlier in girls (11.9 yrs) than boys (13.6 yrs) and a considerable amount of variation existed in the estAPHV for girls (10.7 to 13.1 yrs) and boys (12.2 to 14.7 yrs). Among boys, no significant differences in stature, leg length, mass, or BMI were found between biological maturity groups, although early maturing boys were taller and heavier. Early maturing girls were significantly taller and heavier than late maturing girls.

Figure 5.1 displays the average amount of MVPA among boys and girls according to a chronological scale (yrs) and a chronological age-adjusted biological scale (estimated years from PHV). On a chronological scale, an age-related decline in average MVPA/day was observed among boys [$F(4,75) = 11.2$, $p< 0.000$] and girls [$F(5,84) = 15.7$, $p< 0.000$]. Boys had significantly ($p<0.05$) higher average amounts of MVPA/day at 10, 13, 14, and 15 yrs. When aligned to PHV the average chronological age-adjusted amount of MVPA/day was similar within gender (i.e., boys [$F(5,75) = 0.67$, $p= 0.65$] and girls [$F(5,84) = 0.81$, $p= 0.55$]) with the exception of – 4 yrs from PHV among boys (n= 2). On average, boys had higher adjusted amounts of MVPA/day compared to girls at each biological age interval (-2, -1, 0, and 1 yr from PHV).

Compared to average and late maturing boys, early maturing boys participated in nearly 6 and 17 more minutes of MVPA/day, respectively. Late maturing girls participated in ~10 and 16 more minutes of MVPA compared to early and average maturing girls,

respectively (Figure 5.2). After controlling for differences in chronological age, the relationships between estAPHV and physical activity were low and non-significant for boys (r= -0.05; p= 0.70) and girls (r=0.12; p=0.29).

DISCUSSION

To our knowledge, this study is the first to report accelerometry-monitored physical activity data among early, average, and late maturing youth. The results indicate that the average amount of MVPA is not significantly different (at least statistically) between early, average, and late maturers; however, the absolute differences in MVPA between maturity groups should not be ignored.

Using the maturity offset equation to derive estAPHV, the average estAPHV among our sample of girls (11.9 yrs) and boys (13.5 yrs) was similar to findings from several samples of contemporary adolescents (Tanner 1962; Mirwald et al. 2002; Thompson et al. 2003; Malina et al. 2004). The wide range in estAPHV among girls (10.7 to 13.1 yrs) and boys (12.2 to 14.7 yrs) is also consistent with previous reports and highlights the between-individual variability in the timing of biological maturation. The high percentage of boys (94%) and girls (86%) from the original sample considered as average or early maturers is consistent with the maturity status distribution among other samples (Malina et al., 2005).

Despite the heterogeneity in biological maturity status among boys and girls in the current study, the average amount of MVPA was not statistically different between late, average, and early maturers. However, the results indicate that early maturing boys accumulated nearly 17 more minutes of MVPA/day compared to late maturing boys, and late maturing girls accumulated nearly 13 more minutes of MVPA/day compared to early and average maturing girls. Thus, our results provide some support of the hypothesis that early

maturation in boys and late maturation in girls may influence the absolute amount of MVPA/day.

Few studies have specifically examined maturity-related differences in physical activity; therefore, direct comparisons with our results are limited. Thompson et al. (2003) collected serial measures of anthropometric and physical activity variables among 138 boys and girls over a 7-yr period to determine if the gender-related differences in physical activity would persist after participants were aligned by biological age. Significant gender differences in physical activity were eliminated (except 3 yr before PHV) when boys and girls were aligned according to their biological age, rather than their chronological age. These findings highlight the importance of controlling for maturity-related differences in physical activity among boys and girls; however, distinct differences are apparent between the present study and the Thompson et al. (2003) study. Thompson et al. (2003) created biological 1-yr age groups so boys and girls could be aligned according to a common biological marker. Using this approach, differences in physical activity between early, average, and late maturers cannot be examined because, for example, a boy 1 yr away from PHV could be an average maturing 13 yr old or a late maturing 14 yr old. In the current study, the maturity offset was subtracted from the participant's chronological age, thus providing a method to estimate late, average, or early maturation given that the average age of PHV for boys and girls approximates 14 and 12 yrs, respectively (Tanner 1962; Malina et al. 2004).

Kemper et al. (1997) examined the relationship between physical activity and early, average, and late maturation among 200 boys and girls over a 9 yr period. Physical activity levels were self-reported on five occasions and biological maturation was estimated using hand-wrist radiographs on four occasions. Although not significant, late maturing boys and

girls reported slightly higher amounts of activity compared to early maturing boys and girls. Among youth of similar chronological age (13-14 yrs), we found no significant difference in pedometer assessed physical activity (steps/day) between early, average, and late maturers; however, in partial agreement with Kemper et al. (1997), late maturing boys in our study averaged nearly 2000 more steps/day than early maturing boys (Wickel and Eisenmann in review). Beyond the methodological differences between studies, the absolute levels of physical activity (self reported or steps/day) were highest among late maturing boys. In the current study, early maturing boys accumulated the greatest absolute amount of MVPA/day. The discrepancy between studies can likely be attributed to the differences in outcome measures between assessment tools (i.e., pedometer steps vs. accelerometer activity counts). Although pedometers provide a global picture of physical activity (steps/day) they are unable to differentiate between walking steps (i.e., light activity) and running steps (i.e., MVPA), especially among children of varying body size. Using allometric principles, we have shown that pedometer-assessed step counts can only be considered the same between youth of varying body size if the steps are taken at the same speed (Eisenmann and Wickel 2005).

A key biological feature of the adolescent period involves the maturation of the hypothalamic-pituitary-gonadal (HPG) axis (Tanner 1962). During puberty the HPG axis mediates the release of gonadotropins, which result in neural reorganization (Sisk and Zehr 2005) and rapid changes in body size, physique, and body composition (Roemmich and Rogol 1999). It is plausible that the neural, somatic, and hormonal changes that occur during puberty may directly or indirectly influence locomotor behavior (i.e., daily physical activity). In addition to hormones responsible for changes in body size and composition (i.e., growth hormone and insulin-like growth factor-1), other hormones, such as leptin, may play a critical

role during the pubertal period. Recent reviews (Rowland 1998; Thorburn and Proietto 2000) summarize the evidence that biological processes regulate levels of physical activity and energy expenditure. Specifically, leptin appears to be an important regulator of energy balance (Ahima and Flier 2000).

The precise role of leptin during the pubertal period is uncertain; however, it has been suggested that leptin acts as a molecular signal connecting nutritional status to the pubertal activation of the HPG axis (Rogol et al. 2002). Thus, it seems reasonable to believe that children with optimal energy stores are likely to be early maturers. Among boys this logic is consistent with the hypothesis that late maturers may be less physically active (compared to early maturers) in an effort to regulate energy balance and achieve optimal energy stores to initiate puberty. Among girls, a different biological mechanism may exist that promotes energy storage (thereby reducing physical activity) in an effort to optimize reproductive potential among early maturing girls. To date, few studies are available to clarify the role leptin plays in regulating physical activity, and thus energy expenditure, during biological maturation. Using cross-sectional data, Romon et al. (2004) examined plasma leptin levels and habitual physical activity assessed by a pedometer (steps/day) among boys and girls at different pubertal stages. Among boys, plasma leptin and levels physical activity (steps/day) were significantly different among Tanner stages 1-5. In general, levels of physical activity decreased from Tanner stage 1 (10,509 steps/day) to Tanner stage 5 (8,103 steps/day); however, an observable trend (either increasing or decreasing) in leptin levels was not apparent among boys across Tanner stages. In contrast to boys, an observable trend in plasma leptin, but not physical activity (steps/day), was noticed among pubertal girls. Plasma leptin levels increased from Tanner stage 1 (4.4 ng/ml) to Tanner stage 5 (12.9 ng/ml); however,

physical activity (steps/day) remained relatively constant. These findings do not clarify the relationship between leptin and physical activity among pubertal boys; however, the findings do suggest that physical activity (steps/day) is negatively related to leptin levels among pubertal girls. This relationship among girls may support the hypothesis that leptin regulates energy expenditure (i.e., physical activity) in an effort to maximize reproductive ability (Moschos et al., 2002).

This study was not without limitations. First, the cross-sectional design does not allow us to examine individuals as they progress through puberty; therefore, our results are based on differences in the timing of biological maturation and not the tempo of biological maturation. Second, the relatively low number of late maturing boys in our sample makes it difficult to draw definitive conclusions about our results. Third, a general assessment of maturity (i.e., skeletal age assessment) was not available for current study; however, Mirwald et al. (2002) previously demonstrated the validity of the maturity offset predictive equations to estimate years away from PHV. Fourth, key pubertal hormones, such as leptin (which may influence energy homeostasis), were not examined in the current study, and therefore comparisons to previous reports (Romon et al. 2004) could not be made. Future studies seeking to elucidate the hormonal milieu during puberty and the effects on physical activity should incorporate biochemical assays and account for chronological age in the classification of early, average, and late maturation.

In conclusion, the average amount of MVPA was similar among early, average, and late maturing youth. Although the differences between maturity groups were not statistically significant ($p > 0.05$), the absolute levels of MVPA should be considered. On average, early maturing boys and late maturing girls accumulated the most MVPA. From a biological

perspective, this finding suggests that the somatic characteristics associated with early and late maturation among boys and girls, respectively, may influence activity patterns in youth. Clearly, additional work is needed in this area to clarify the implications of early, average, or late maturation on levels of physical activity during adolescence.

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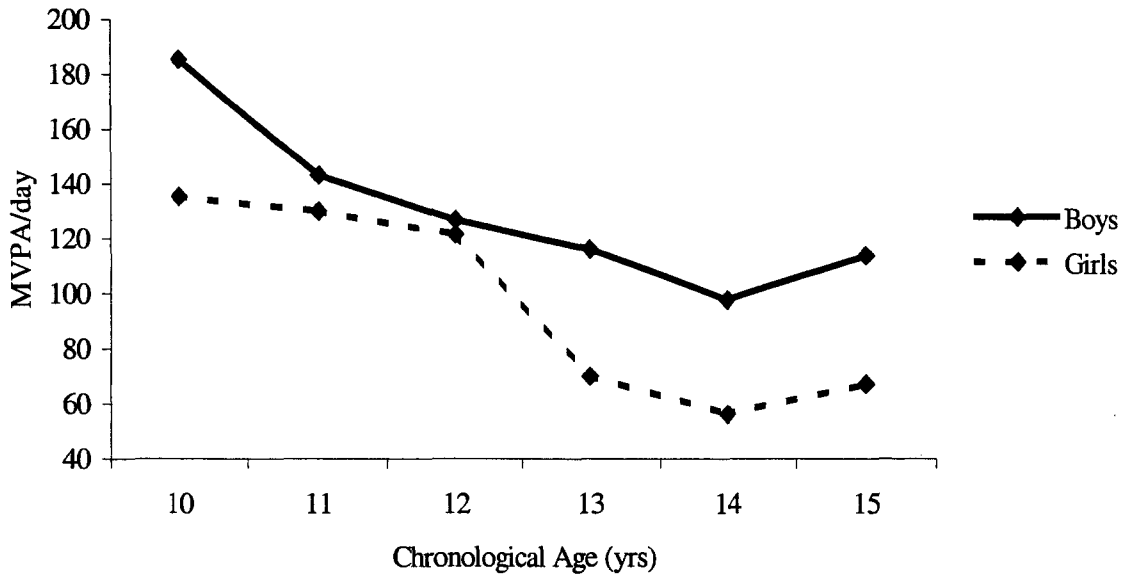
Table 5.1. Physical characteristics by gender and maturity status.

		Maturity Status		
Girls	**Total (n= 85)**	**Early (n= 27)**	**Average (n= 47)**	**Late (n= 11)**
Stature (cm)	151.8 ± 10.6	155.9 ± 7.5	151.3 ± 11.2	145.7 ± 10.4
Est. leg length (cm)	72.6 ± 5.4	74.3 ± 2.9	72.6 ± 6.0	69.0 ± 5.2
Mass (kg)	52.6 ± 17.0	65.6 ± 15.0	49.2 ± 15.0	40.2 ± 12.3
BMI (kg/m^2)	22.4 ± 5.3	26.6 ± 1.0	20.7 ± 0.6	17.3 ± 1.1
Chronological age (yrs)	12.0 ± 1.4	11.6 ± 1.0	12.1 ± 1.5	12.7 ± 1.5
Maturity offset (yrs)	0.2 ± 1.4	0.4 ± 1.0	0.1 ± 1.5	-0.0 ± 1.5
Est. age at PHV (yrs)	11.9 ± 0.5	11.2 ± 0.2	12.0 ± 0.3	12.7 ± 0.2
Boys	**Total (n= 76)**	**Early (n= 34)**	**Average (n= 38)**	**Late (n=4)**
Stature (cm)	151.9 ± 10.5	153.9 ± 11.4	149.9 ± 9.8	155.1 ± 2.6
Est. leg length (cm)	73.8 ± 6.1	74.2 ± 6.4	73.1 ± 6.1	77.0 ± 2.1
Mass (kg)	49.3 ± 14.2	53.2 ± 16.0	45.7 ± 12.5	50.1 ± 2.8
BMI (kg/m^2)	21.0 ± 4.5	22.6 ± 0.7	20.2 ± 0.7	20.8 ± 1.6
Chronological age (yrs)	11.9 ± 1.4	11.4 ± 1.4	12.2 ± 1.2	13.7 ± 0.5
Maturity offset (yrs)	-1.6 ± 1.2	-1.7 ± 1.3	-1.7 ± 1.1	-0.9 ± 0.5
Est. age at PHV (yrs)	13.6 ± 0.5	13.1 ± 0.3	13.9 ± 0.3	14.6 ± 0.1

Values are mean ± SD (range).



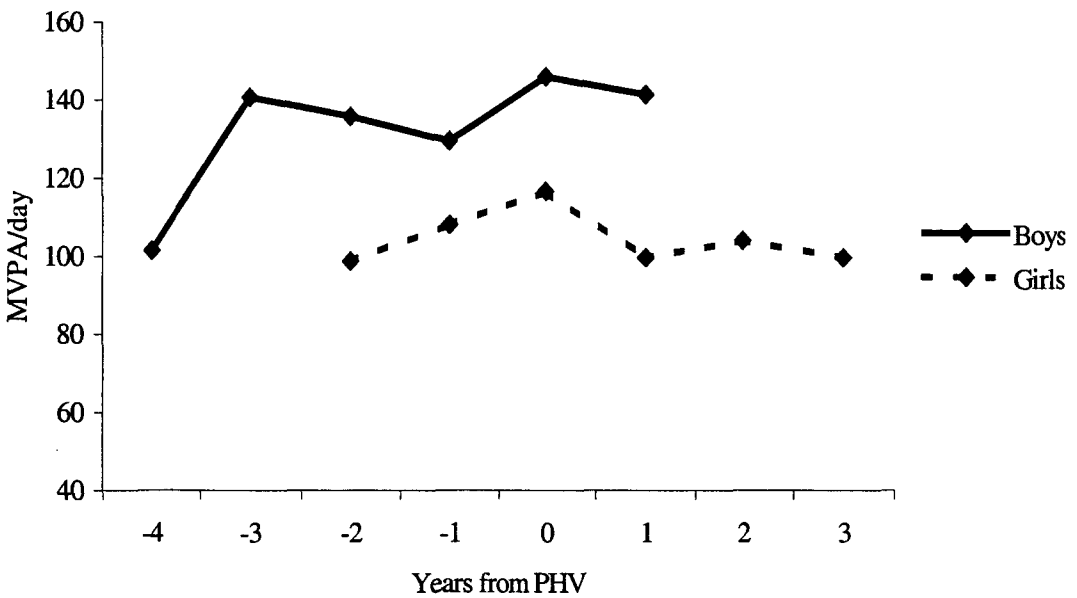


Figure 5.1. Average amount of MVPA among boys and girls according to a chronological scale (yrs) and a chronological age-adjusted biological scale (estimated years from PHV).

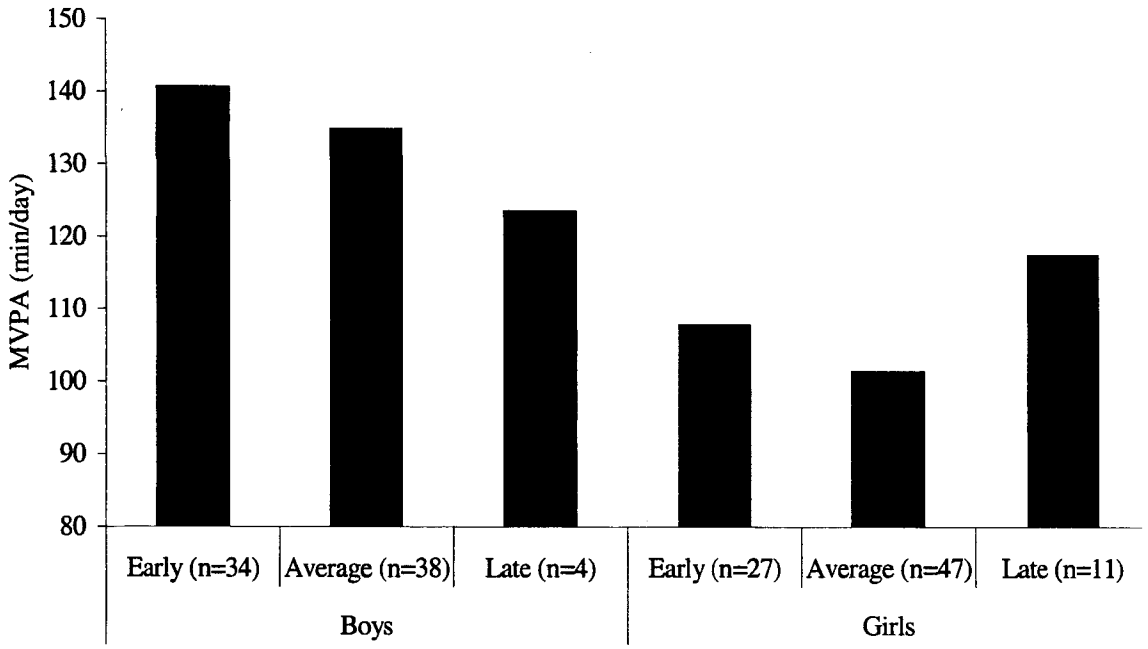


Figure 5.2. Age-adjusted levels of MVPA among early, average, and late maturing boys and girls.

No significant maturity-related differences between groups.

CHAPTER 6.

CONTRIBUTION OF YOUTH SPORT TO TOTAL DAILY PHYSICAL ACTIVITY AMONG 6-12 YR OLDS

ABSTRACT

The purpose of this study was twofold: 1) to determine the contribution of organized youth sport to total daily physical activity (PA) and 2) to examine the contribution of daily recess and physical education. Using a cross-sectional design, 140 children wore an accelerometer during a school day in which they participated in organized youth sport. A sub-sample (n=43) wore the accelerometer on a non-sport day to examine differences in PA. Total daily PA and PA during youth sport, recess, and physical education were estimated. The contribution of youth sport, recess, and physical education was determined by dividing the amount of PA from each activity by the total daily amount of PA. Approximately 120 minutes of moderate-to-vigorous physical activity (MVPA) were achieved on the monitoring day. Youth sport contributed approximately 25% of the total MVPA, while PE and recess contributed nearly 16% and 8%, respectively. Nearly half of the accumulated minutes of MVPA were attributed to unstructured activities (~60 min). Among boys, flag-football participants accumulated the lowest amount of MVPA (~32 min), while basketball participants accumulated the greatest amount of MVPA (~40 min). Among girls, the amount of MVPA was greater during basketball (~40 min) compared to soccer (~30 min). For the entire sample, most of the time during youth sport was spent in either light (42%) or moderate (53%) intensity activity while the percent of time spent in vigorous activity was low (5%). On a youth sport day participants accumulated ~30 additional minutes of MVPA and reduced the amount of light intensity activity by ~30 minutes. The amount of additional MVPA during a youth sport day (~30 min) was not maintained on a non-sport day. Therefore, youth sport provides an additional opportunity to increase daily levels of MVPA.

INTRODUCTION

The topic of physical activity (PA) among contemporary youth has gained considerable attention (American Academy of Pediatrics 2001). Evidenced-based PA recommendations indicate youth should accumulate at least 60 minutes of moderate-to-vigorous physical activity (MVPA) each day (Strong et al. 2005). Population-based PA data from the United States (Trost et al. 2002) and Europe (Riddoch et al. 2004) indicate that youth, on average, accumulate more than 100 minutes of MVPA each day. However, little information is known regarding the source of this PA. During the typical school day, recess and physical education (PE) seemingly provide two opportunities for children to accumulate PA; however, little is known about the overall contribution of these activities to daily PA levels. Ridgers et al. (2005) recently examined the intensity levels of recess using an accelerometer and found that nearly 75% of total recess time was spent at a low intensity level. Using an observational method, Nader (2003) determined that 37% of PE was spent above a moderate intensity level. Besides recess and PE, actively commuting to and from school also provides an additional opportunity to increase daily levels of PA among youth (Cooper et al. 2003; Sirard et al. 2005).

Another opportunity for daily PA is organized youth sport. Annually, more than 38 million youth participate in organized sport (National Council of Youth Sports 2001); therefore, youth sport may provide an additional opportunity for PA in addition to recess and PE for a large number of children. However, only one study has examined the contribution of youth sport to total daily PA. Using a 3-day activity diary, Katzmarzyk and Malina (1998) determined that boys and girls expended approximately 20% of their daily energy expenditure during youth sport. Although this study provides insight into the role of youth

sports and daily PA, it is limited by the use of a self-report assessment tool. In particular, the use of an activity diary in younger children is limited given the uncertain ability to recall the duration and intensity of PA (Sallis 1991). The intermittent nature of children's activity also makes it difficult to appropriately code the intensity or predominant activity in a 15-min block of time. Given the methodological issues dealing with self-report tools with children and the paucity of data on this subject the primary purpose of this study was to determine the contribution of organized youth sport to total daily PA using an accelerometer, which is now a widely used objective assessment tool (Troiano 2005). A secondary purpose of this study was to examine the contribution of daily recess and physical education to daily PA. It was expected that youth sport would contribute a large portion of MVPA to children's daily PA.

METHODS

Participants

A total of 156 (119 boys, 37 girls) 6 to 12 yr old children participated in the study (mean age= 9.6±1.4). Children participating in basketball, soccer, and flag-football were recruited from the local Parks and Recreation Department. Initially, coaches were contacted about the study protocol. Of the coaches who were interested, information was presented to their team and to the parents. Participants were then selected based on their willingness to participate in the study. Soccer was the only sport in which boys and girls played on a single team and therefore both sexes were recruited equally. Basketball had separate teams for boys and girls, of which more boys' basketball coaches showed interest in participating in the current study. The unbalanced gender design was also attributed to the all-boy flag-football teams. Informed parental consent and assent were obtained prior to participation in the study. The study was approved by the University Human Subjects Review Board.

Anthropometry

Stature and body mass were measured following standard procedures (Malina 1995). Stature was measured with a portable stadiometer (Seca Road Rod, Seca Corporation, Hanover, MD) to the nearest 0.1 cm. Body mass was measured with a strain gauge scale (Lifesource, A&D Maker, Milpitas, CA) to the nearest 0.1 kg. The body mass index (BMI) was calculated by dividing the participant's body mass (kg) by stature (m^2).

Physical Activity Assessment

The ActiGraph accelerometer (ActiGraph, LLC, Fort Walton Beach, FL) was used in this study to assess physical activity. The ActiGraph is a small, lightweight uniaxial device that attaches to an elastic belt or clip and is worn at the mid-axillary line on the hip. The device measures vertical acceleration ranging in magnitude from 0.05 to 2.00 G with a frequency response of 0.25 to 2.50 Hz. The ActiGraph accelerometer has been shown to be a reliable and valid instrument among children and adolescents (Trost et al. 1998; Ekelund et al. 2001; Eisenmann et al. 2004).

Accelerometers were calibrated using the Manufacturing Technology Inc. calibrator (Model CAL-71) prior to usage and upon return. During the calibration process, the battery life was checked and the accelerometer was verified to be within the ± 5% curves established by the manufacturer's operation manual. Accelerometers were programmed to collect activity counts in 30-sec epochs to reflect the spontaneous nature of children's activity. A member of the research team distributed the unit and informed participants and parents with oral and written instructions for using the accelerometer. Accelerometers were worn during all waking hours (except while swimming or bathing) during one school day in which the child participated in an after-school organized youth sport. Participants were instructed to

maintain their normal daily routines. An activity log was provided to the participant to record the time the accelerometer was put on in the morning and removed prior to bed. Daily activities (youth sport, recess, and physical education) were also recorded on the activity log to assist data interpretation. A sub-group of participants (n=43) wore the accelerometer on a non-sport school day to allow for comparisons between sport and non-sport days.

Stored epochs were downloaded to a computer using the Actigraph software. A compliance check of the data identified spurious values and periods of consecutive zeros lasting ≥ 20 minutes. Participants were removed from the data set if they had more than 3 periods of consecutive zeros lasting ≥ 20 minutes. A total of 16 participants (10% of original sample) were excluded from the analysis due to abnormal values (n=2), failure to download (n=8), or failure to comply with the protocol (n=6). The final sample included 113 boys and 27 girls.

The data were processed by combining the 30-sec epochs to form 1-min epochs. The age-specific MET regression equation (Freedson et al. 2005) was utilized to determine the amount of time spent in sedentary (<1.5 METS), light (1.5≤ METS <3), moderate (3≤ METS <6), and vigorous (≥6 METS) activity (Equation 6.1). Moderate-to-vigorous PA was calculated by summing the moderate and vigorous activities.

Equation 6.1. MET = 2.757 + (0.0015 x counts/min) – (0.08957 x age (yr)) – (0.000038 x counts/min x age (yr)).

A macro written in EXCEL determined the absolute amount of time and percentage of spent in sedentary, light, moderate, vigorous, and MVPA for the entire day, and during youth sport, recess, PE, and unstructured activity. For this study, unstructured activity was

determined by subtracting the time spent in youth sport, recess, and PE from the total monitoring time.

Statistical Analysis

Multivariate analysis of covariance (MANCOVA) was used to examine if gender differences existed in PA intensities (sedentary, light, moderate, vigorous, and MVPA) for the entire day and for youth sport, PE, recess, and unstructured activity. MANCOVA was also used to examine the differences in PA intensities on a sport and non-sport day. Where applicable, age, unstructured time, total recess time, activity time, and day length were used as covariates. Bivariate correlations were used to examine the relationship between MVPA accumulated during youth sport, recess, and PE and MVPA accumulated during unstructured activity. Statistical significance was set at $p < 0.05$. Statistical analyses were completed with SPSS Version 12.0.

RESULTS

Physical characteristics according to gender and sport are displayed in Table 6.1. In the total sample, boys and girls approximated the 75th percentile for stature and body mass (Centers for Disease Control and Prevention 2000). On average, boys and girls playing soccer were younger, shorter, and lighter compared to children playing basketball and football (boys only). The average BMI among participants approximated the 85th percentile (Centers for Disease Control and Prevention 2000). In general, boys were older than girls (9.8 vs. 9.0 yr, respectively).

Figure 6.1 shows the distribution of time spent in light, moderate, and vigorous physical activity over the entire day (average monitoring time ~ 800 min) for the total sample and by gender. Participants accumulated approximately 120 minutes of MVPA (~111

moderate and 8 vigorous), which represented nearly 15% of the total monitoring time. Using age and day length as covariates, no significant differences were found between boys and girls in the amount of time spent in light, moderate, vigorous intensity activity.

Similar amounts of MVPA were accumulated between boys and girls during youth sport, recess, and unstructured activity (Figure 6.2). During PE, boys participated in significantly more MVPA than girls (~13 vs. 8 min, respectively) (p=0.04). Youth sport contributed approximately 25% of the total minutes of MVPA (~30 min) for boys and girls, while PE and recess contributed nearly 16% and 8%, respectively. Nearly half of the accumulated minutes of MVPA were attributed to unstructured activities (~60 min).

Figure 6.3 shows the time spent in light, moderate, and vigorous intensity PA during youth sport, after controlling for differences in activity time and age. No significant gender differences were found between sports but significant sport differences did exist for light (p= 0.04), moderate (p= 0.003), and MVPA (p= 0.04) intensities. Among boys, flag-football participants accumulated the lowest amount of MVPA (~32 min), while basketball participants accumulated the greatest (~40 min) amount of MVPA. Among girls, the amount of MVPA was greater during basketball (~40 min) compared to soccer (~30 min). For the entire sample, 42% of youth sport time was spent in light intensity activities, while moderate and vigorous physical activity accounted for ~53% and 5% of the time, respectively. Boys and girls basketball had the lowest percentage of time spent in light (~34%) and vigorous (~2%) intensity activity. The *gender x sport* interaction was not significant.

The distribution of intensity between a sport day and a non-sport day is presented in Figure 6.4. Significant differences in the time spent in light (p=0.001), moderate (p=0.003), and MVPA (p=0.001) were observed. On a youth sport day participants accumulated ~30

additional minutes of MVPA (~24 min moderate; ~4 min vigorous) and reduced the amount of light intensity activity by ~30 minutes.

The intensity pattern of recess and PE is presented in Figure 6.5. The average amount of time spent in daily recess was 40 min. No significant differences in gender were observed between the amounts of light, moderate, or vigorous activity. Boys and girls accumulated about 25 minutes of MVPA during recess, which represented ~60% of the total recess time. During PE (~30 min), boys and girls achieved about 13 minutes of MVPA, which represents about 40% of time spent in PE. Boys and girls spent a similar amount of time in light, moderate, and vigorous activity during unstructured activity. An absolute difference was observed between the amount of vigorous activity between boys (~7 min) and girls (~3 min); however, the difference was not significant (p=0.10).

Bivariate correlations between MVPA accumulated during youth sport, recess, and PE and MVPA accumulated during unstructured activity are presented in Table 6.2. The amount of MVPA accumulated during unstructured activity was significantly correlated with MVPA during youth sport for boys (r=0.21; p=0.03) and MVPA during recess for girls (r=0.61; p=0.01).

DISCUSSION

To our knowledge this is the first study to partition MVPA according to youth sport, PE, and recess—which are daily opportunities for PA —and unstructured activity using an objective assessment tool. The results indicate that this sample of children accumulated ~120 minutes of MVPA/day, of which 30 minutes (25%) was from youth sport. On non-sport days the 30 minutes of MVPA was replaced by low intensity activities. Hence, youth sport provides an opportunity to increase total daily levels of MVPA.

Objectively measured PA data are available for population-based samples in the United States (Trost et al. 2002) and Europe (Riddoch et al. 2004). Results from these studies suggest that young children (~9 yrs old) accumulate >100 minutes of MVPA/day. Our results are comparable to these findings as boys and girls participated in nearly 120 minutes of MVPA/day, which was about 15% of the monitoring period. The current study was unique in that the contribution and intensity levels of organized (PE and youth sport) and non-organized activities (recess and unstructured activity) were considered. The contribution of these activities is important to consider given the relatively high participation rates for youth sport (National Council of Youth Sports 2001).

Annually, more than 38 million youth participate in organized youth sport (National Council of Youth Sports 2001); therefore, it represents a source of daily PA that should be examined more closely. In the current study, the contributions of three different youth sports (flag-football, soccer, and basketball) were examined. Overall, the results indicate that youth sport contributes about 25% to daily MVPA with slight differences between sports (Figure 3). Compared to soccer and basketball, the contribution of flag-football was likely lower because many of the positions in flag-football (e.g., offensive or defensive linemen) do not require a lot of locomotor movement.

The average time participating in youth sport approximated 60 minutes. Interestingly, about 40% of youth sport time was spent in light intensity. Compared to soccer and flag-football, basketball represented the sport with the lowest amount of time spent at a light intensity (~30%). This finding can likely be explained by the physiological demands between sports. Compared to soccer and basketball, the nature of activity during flag-football is more intermittent. Individual plays are separated by bouts of inactivity in preparation for the next

play (i.e., huddle). The pattern of activity during youth sport may also be attributed to the desire of the individual player or the coaching style. Skill position players in flag-football (quarterback, runningback, and wide receiver) are likely to accumulate more activity assessed by the accelerometer, compared to the linemen, because of the requirements of their position. However, the difference between positions was not examined in the current study. It appears that the youth sports examined here do not involve a lot of vigorous activity. Soccer elicited the most vigorous activity for boys (~6 min) and girls (~5 min).

In the only other study to examine the contribution of youth sport to daily PA, Katzmarzyk and Malina (1998) determined that youth sport contributes nearly 60% of the daily moderate-to-vigorous energy expenditure among 12-14 year olds. This percentage is noticeably higher than the contribution of youth sport to daily MVPA observed in our study (~25%). This disparity may likely be attributed to the age differences between the samples, and implies that youth sport participation may be more critical among older adolescents given the natural age-related decline in PA. However, it is important to note that comparisons are difficult to make between studies given the different outcome measure (energy expenditure vs. PA), assessment tool (activity log vs. accelerometer), and selected sports. In their study, Katzmarzyk and Malina (1998) examined a relatively small sample (N=56) distributed across a wide variety of sports that included downhill skiing, cheerleading, tennis, basketball, wrestling, swimming, soccer and dance. Thus, it is questionable whether their results are representative of all the sports included in their analysis. In the present study each sport had at least 20 participants, with the exception of girl's basketball; therefore our results may provide a better description of the selected sports of interest.

The results of the present study indicate that the additional 30 minutes of MVPA achieved during youth sport were not maintained on a day without youth sport. This finding is similar to a recent study (Dale et al. 2000) that showed children did not compensate for missed school-related PA opportunities later in the day. In both studies it appears that children do not maintain levels of PA when opportunities, including recess, PE, and youth sport, are missed. Thus, participation in youth sport may be viewed as a method to increase daily levels of activity, but also as a way to reduce inactive behavior. Our findings, along with those from Dale et al. (2000), suggest PA levels among youth are not inherently regulated by biological mechanisms in an effort to maintain energy homeostasis. Although our findings do not agree with the summarized evidence complied by Rowland (1998) regarding the biological aspects of PA, the differences may likely attributed to the relative short assessment period (2 days).

Participants in the present study were instructed to wear the accelerometer for the entire day; therefore, information was also available to examine the contribution of school-based activities. Compared to youth sport, total recess time and time available for PE provided a smaller absolute amount of time for participation. The results indicate that recess and PE contribute ~16% and 8%, respectively, towards daily levels of MVPA. Recently, Ridgers et al. (2005) reported the intensity distribution of daily recess. Approximately 30% and 25% of total recess time was spent participating in MVPA among boys and girls, respectively. Our results indicate that ~60% of recess for boys and girls was spent participating in MVPA. Recess guidelines suggest that 50% of the time should be spent at moderate-to-vigorous intensity (Stratton and Mullan 2003). Among the participants from Ridgers et al's study, <6% of boys and <1% of girls achieved this recommendation. Among

our sample, nearly 30% of boys and girls achieved this recommendation during recess. The differences between studies may be attributed to individual, seasonal, or methodological differences. Ridgers et al. (2005) utilized activity count thresholds based on 5-sec epochs (Nilsson et al. 2002) to determine intensity levels, while the current study used MET cutpoints based on 1-min epochs (Freedson et al. 2005).

Nader (2003) reported the intensity distribution of PE and observed that 37% of the time was spent above moderate intensity activity. This was similar to the percent of time spent in MVPA for girls in our study (40%); however, the percent of time in MVPA for boys was higher (48%). It is likely that the amount of MVPA accumulated during PE is dependent on the instructor (McKenzie et al. 1997). Some instructors may place a higher value on the attainment of motor skills rather than the accumulation of PA. Time spent in PE may also be viewed as an opportunity to discuss health-related issues.

In the current study, approximately half of the accumulated daily MVPA came from activities other than youth sport, daily recess, or PE. This finding suggests that children are inherently active and do not necessarily require a structured environment to accumulate MVPA. It could be argued that the levels of MVPA observed only reflect youth sport participants and it may be unlikely that non-youth sport participants would accumulate ≥ 60 minutes of MVPA outside of recess and physical education. However, data from Trost et al. (2002), which included youth sport participants and non-youth sport participants, suggests that levels of MVPA exceed 100 minutes/day.

Correlations between MVPA accumulated during youth sport, recess, and PE and MVPA accumulated during unstructured activity were examined to determine if youth who were highly active during unstructured play accumulated the most MVPA during other daily

activities. In general, the correlations between MVPA accumulated during unstructured activity and MVPA accumulated during youth sport, recess, and PE were low, with the exception of the correlation between MVPA from recess and MVPA from unstructured activity in girls (r= 0.61). This latter finding suggests some girls may choose sedentary or light intensity activity in the absence of structured activity. Alternatively, some girls are able to accumulate MVPA regardless of the level of organization.

This study was not without limitations. First, the participants were primarily boys (~80%) and a large percentage of girls participated in soccer (~74%). However, given the similarities in intensity levels among boys and girls, there is little reason to believe that the inclusion of more girls would significantly alter the results. Secondly, our results are based on a single day and therefore the intensity levels cannot be assumed to be inherent to the individual. However, it is important to keep in mind that the main purpose of the study was to examine the contribution of youth sport to total daily levels of PA; therefore, the assessment period only represents a day in which the participant participated in a youth sport activity. In addition, the total minutes of MVPA observed in the current study were similar to data obtained by Trost et al. (2002).

In conclusion, youth sport contributes a substantial amount of MVPA (~30 min) to a child's total daily MVPA (~120 min). The amount of additional MVPA during a youth sport day (~30 min) was not maintained on a non-sport day. Therefore, youth sport provides additional opportunities for daily PA engagement. Further research is needed to examine the contribution of youth sport and to examine the relative contribution of sport towards daily PA guidelines.

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Table 6.1. Physical characteristics of the children by sport and total.

Boys	**Total (n=113)**	**Soccer (n= 29)**	**Basketball (n= 33)**	**Flag-football (n= 51)**
Age (yr)	9.8 ± 1.3	8.8 ± 1.3	10.4 ± 1.3	10.0 ± 0.9
Stature (cm)	141.8 ± 9.3	137.0 ± 8.1	145.4 ± 9.2	142.2 ± 9.0
Mass (kg)	38.3 ± 9.6	34.2 ± 9.0	40.9 ± 9.5	38.9 ± 9.4
BMI (kg/m^2)	18.8 ± 3.2	18.0 ± 3.4	19.1 ± 2.8	19.0 ± 3.2

Girls	**Total (n= 27)**	**Soccer (n= 20)**	**Basketball (n= 7)**
Age (yr)	9.0 ± 1.6	8.5 ± 1.6	10.4 ± 0.5
Stature (cm)	137.2 ± 12.4	133.6 ± 12.3	147.6 ± 4.1
Mass (kg)	36.5 ± 11.2	34.7 ± 12.4	41.6 ± 4.6
BMI (kg/m^2)	18.9 ± 3.7	18.8 ± 4.2	19.1 ± 2.2

Values are mean ± SD.

Table 6.2. Correlations between unstructured MVPA and MVPA accumulated during youth sport, recess, and PE.

	Youth Sport	Recess	PE
Unstructured MVPA			
Boys	0.21*	-0.01	0.20
Girls	0.22	0.61*	0.22

*Significant correlation ($p<0.05$).
Note: Unstructured MVPA = Total day MVPA – Youth sport MVPA – Recess MVPA – PE MVPA

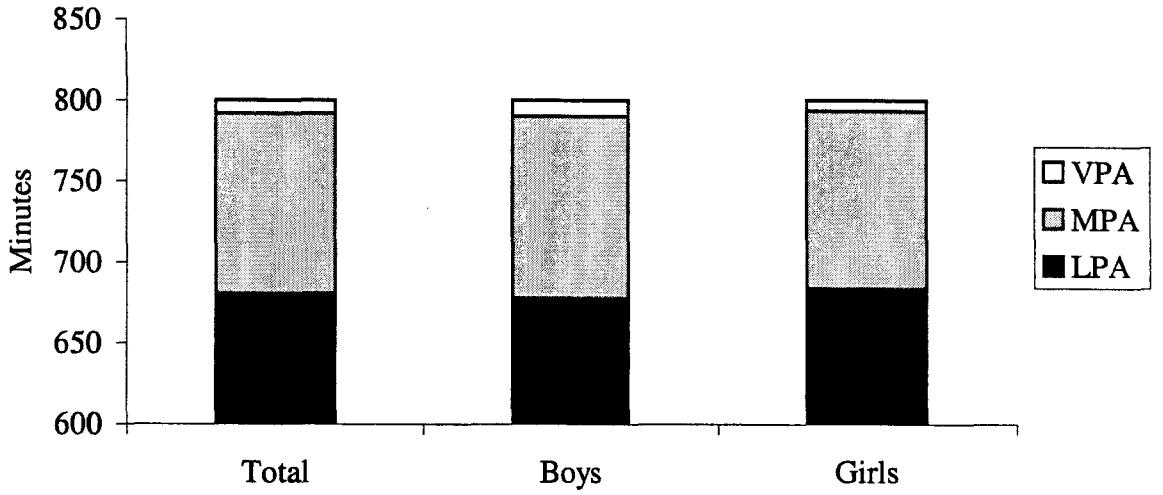

Figure 6.1. Distribution of time spent in light (LPA), moderate (MPA), and vigorous physical activity (VPA) during the monitoring period for the total sample and by gender.

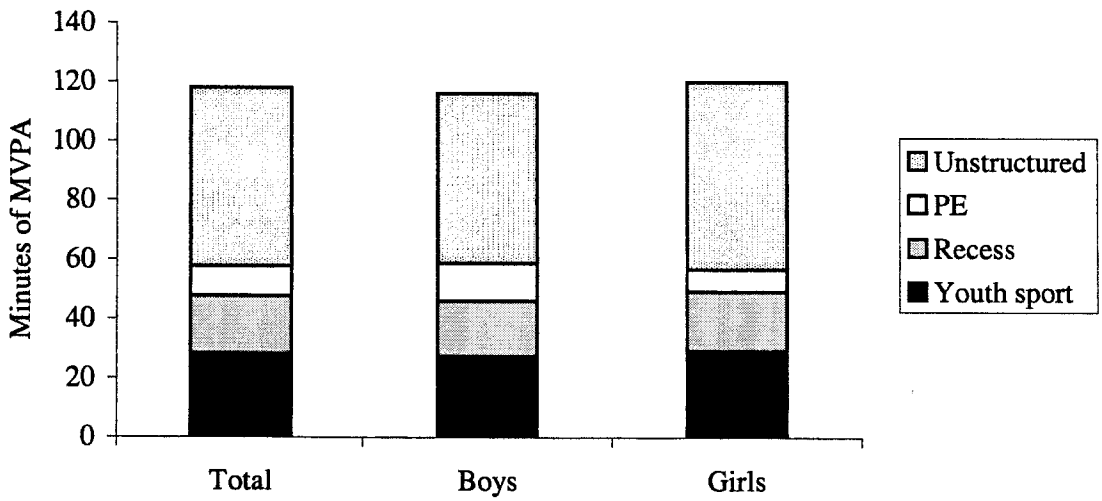

Figure 6.2. Contribution of youth sport, PE, recess, and unstructured activity to total daily MVPA for the total sample and by gender.

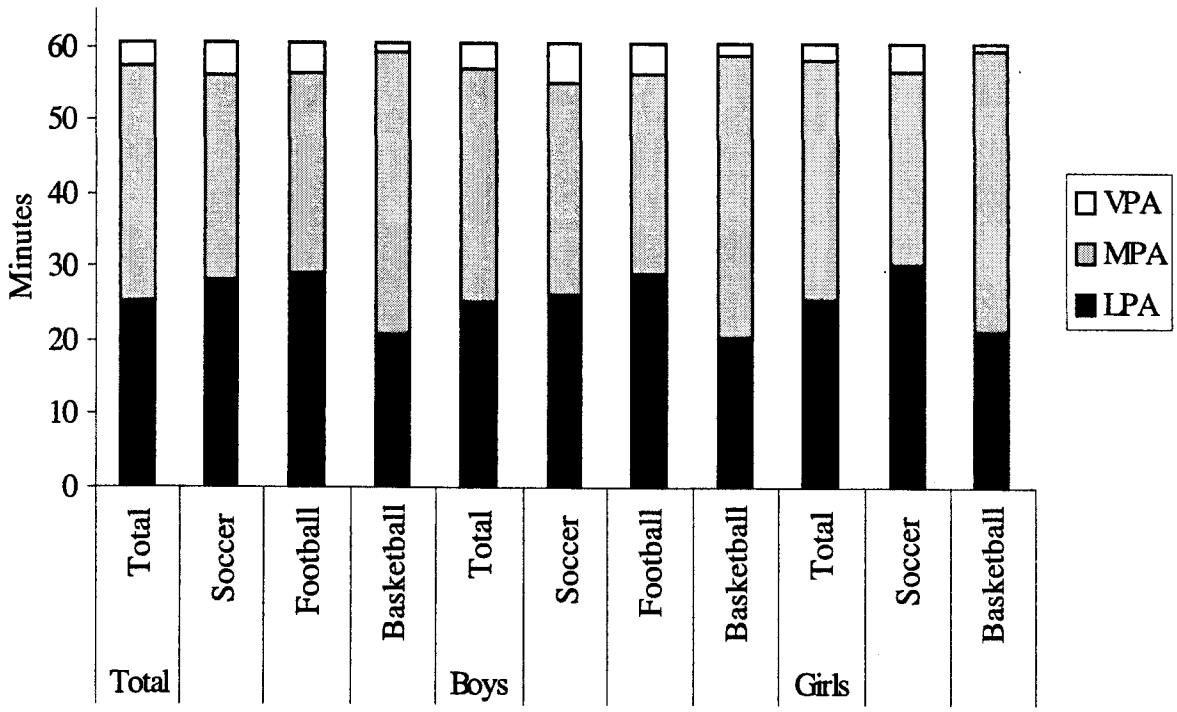

Figure 6.3. Distribution of time spent in light (LPA), moderate (MPA), and vigorous physical activity (VPA) during youth sport separated by gender and sport.

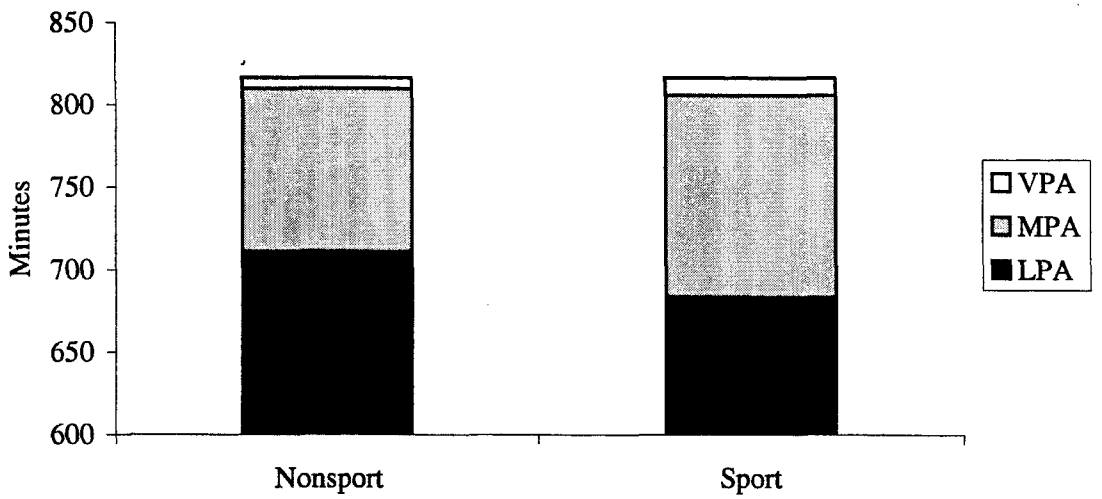

Figure 6.4. Distribution of light (LPA), moderate (MPA), and vigorous physical activity (VPA) on a non-sport and sport day.

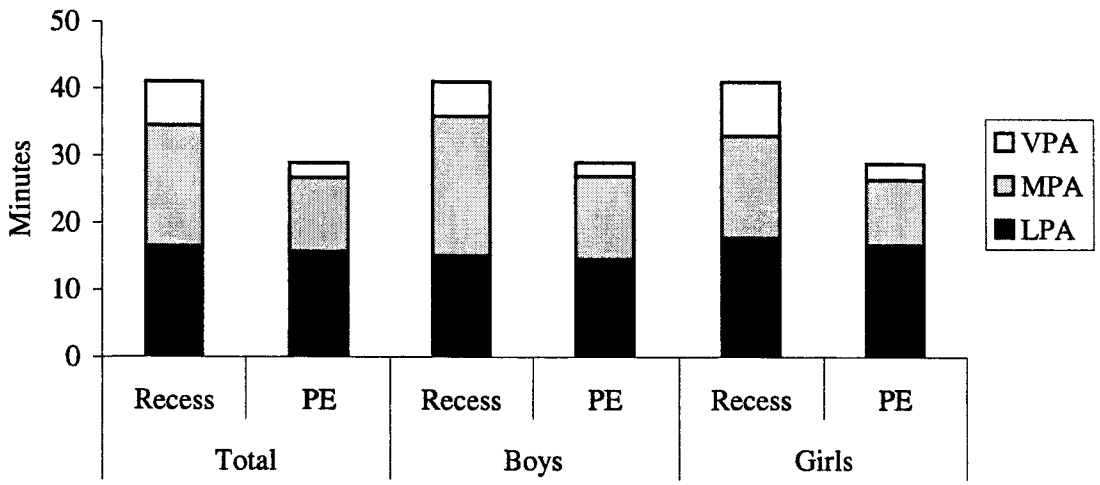

Figure 6.5. Distribution of light (LPA), moderate (MPA), and vigorous physical activity (VPA) during recess and PE for the total sample and by gender.

CHAPTER 7.

SUMMARY AND RECOMMENDATIONS

SUMMARY

This dissertation consists of a series of papers which focused on 1) the assessment and interpretation of physical activity and energy expenditure and 2) the variability in habitual physical activity in children and adolescents. The participants were recruited from elementary and middle schools from the central-Iowa area; local organized youth sport teams; and a university-sponsored summer youth camp. An Actigraph accelerometer was used as the primary assessment tool in each of the studies. This assessment tool was selected based on its ability to quantify the frequency, intensity, and duration of physical activity as initially described in Chapter 2.

The validity of a widely used age-specific MET prediction equation was considered in Chapter 3. This study examined the influence of body mass on accelerometer-derived activity counts and determined the predictive validity of an age-specific MET prediction equation among small (≤ 26.5 kg), medium ($26.5 < \text{mass} \leq 35.9$), and large ($> 35.9$ kg) children. The results suggest that body mass does not influence the accelerometer-derived activity counts. However, the predictive validity of the age-specific MET prediction equation appears to be dependent on body mass. Our results indicate that the average difference between the measured and predicted MET value was significantly greater among relatively smaller children. The average difference between the measured and predicted MET values could be attributed to different treadmill speeds used in the original calibration study. Although a valid point, our findings are noteworthy given the relatively high amount of time spent in low-to-light intensity activity throughout the day. Thus, it appears the age-specific MET equation may overestimate levels of energy expenditure, especially among smaller children.

Despite the limitations associated with this age-specific MET equation, it is widely used in the physical activity literature (and within this dissertation) to translate accelerometer activity counts into time spent in different activity intensities. Although a separate MET prediction equation was presented in Chapter 3 it is worth reiterating that this equation was not used to interpret the accelerometer data presented in Chapters 4-6. The prediction equation presented in Chapter 3 was primarily developed to draw comparisons to the age-specific MET equation and was based on slow walking speeds.

Beyond the measurement issues surrounding the Actigraph accelerometer this dissertation also examined contemporary issues dealing with youth physical activity and energy expenditure levels. Chapter 4 examined the day-to-day variability in estimated energy expenditure. The novelty of this study involved the specific aim and the statistical method employed - generalizability theory. In this study it was hypothesized that total energy expenditure would remain relatively stable despite significant day-to-day changes in the components of total energy expenditure (i.e., sedentary, light, moderate, and vigorous energy expenditure). Previously, the day-to-day variability in physical activity has been examined in an effort to determine the number of assessment days needed to estimate habitual physical activity levels. However, in this study the day-to-day variability was examined to answer a more fundamental related question involving the stability of energy expenditure. The results suggest that total energy expenditure and its components demonstrate limited variability over a 7-day monitoring period. Keeping with the biological perspective, it was concluded that small daily absolute changes in the energy expended from sedentary, light, moderate, and vigorous activity existed to maintain total energy expenditure. In the absence of more precise measures of energy expenditure it was difficult to determine if the 7-day monitoring period

reflected behavioral stability or biological regulation. Results from the generalizability theory indicated that the largest source of variability in total energy expenditure (other than the differences between intensity levels) was from the *participant x activity intensity* interaction term (23%). Traditionally, the inter-individual differences in physical activity or energy expenditure assessments focus on age and gender differences. In Chapter 5, maturity-related differences in moderate-to-vigorous physical activity were examined in an effort to understand other factors that may distinguish participants. In this study, it was hypothesized that significant differences in MVPA would exist between early, average, and late maturing boys and girls after controlling for chronological age. Although significant differences in the average amount of MVPA/day were not found between maturity groups the absolute differences in MVPA were considered. Early maturing boys and late maturing girls averaged the most MVPA/day. Among boys, this observation may be related to the somatic characteristics associated with the maturity process, such as increased stature and lean body mass. Among girls, the observation that late maturing girls averaged more MVPA/day may be due to underlying biological mechanisms that reduce physical activity levels in early maturers to optimize reproductive potential.

Although the focus in physical activity research is typically on the average amount of daily physical activity between groups, it is also important to understand the primary sources of daily physical activity. Chapter 6 determined the relative contribution of youth sport, recess, and physical education to total daily physical activity. The results indicate that, on average, youth sport contributed nearly 25% of the total daily MVPA, which was equivalent to approximately 30 minutes. However, it appears that the additional MVPA accumulated during youth sport was not maintained on a non-youth sport day. The relative contributions

of recess (8%) and physical education (16%) were lower than the relative contribution of youth sport, even after adjusting for the differences in time. Interestingly, our results indicate that nearly 60 minutes of MVPA were accumulated in activities other youth sport, recess, and physical education.

RECOMMENDATIONS FOR FUTURE RESEARCH

Although this dissertation has added insight into our understanding of physical activity levels and patterns among youth, additional research is needed in the following areas:

- Longitudinal studies of objectively measured physical activity are needed to understand physical activity levels across the lifespan and should include consideration of biological mechanisms that may influence levels of physical activity and energy expenditure. The influence of biological maturation on physical activity and energy expenditure remains unclear.
- The genetics of physical activity remains an area that needs further exploration.
- Identification of pubertal biomarkers that may influence physical activity and energy expenditure levels.
- Individual activity count-VO_2 calibration curves would likely improve the accuracy of energy expenditure estimates; however, feasibility issues may limit this approach.
- Energy expenditure prediction equations should incorporate a large number of children and adolescents that range in body size. In addition, the inclusion of a two-line regression model should be explored in a younger population.

- Youth sport, recess, and physical education should be examined throughout childhood using longitudinal designs and appropriate control groups. An appropriate epoch length to capture the intensity levels of these activities is also needed.
- Additional studies are needed to determine if the age-specific MET equation systematically overestimates energy expenditure in relatively smaller children. If so, studies examining the relationship between body mass and physical activity or energy expenditure may draw inappropriate conclusions about activity levels.