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# New Insight For Activity Intensity Relativity: Metabolic Expenditure During Object Projection Skill Performance

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# NEW INSIGHT FOR ACTIVITY INTENSITY RELATIVITY: METABOLIC EXPENDITURE DURING OBJECT PROJECTION SKILL PERFORMANCE

by

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## DEDICATION

To Ali

We were not meant to walk through this life alone.

Thank you for carrying me to heights I had never dreamed possible.

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**ABSTRACT**

This dissertation consist of four studies that examine energy expenditure (EE) during object projection skill performance (OPSP). These four studies have the potential to inform physical education (PE) curricula and physical activity (PA) interventions by providing an understanding the acute EE associated with performing OPSP in developmentally appropriate activities. If OPSP is associated with high EE, then promoting their development during physical activity interventions and physical education (PE) will have both an acute and long-term health-enhancing benefit. Thus, the purposes of these four studies was to examine adult and children's EE associated with the performance of object projection skills at different intensity intervals.

The purpose of Study 1 was to examine the metabolic cost (METS) of performing object projection skills at three practice trial intervals (6, 12 and 30 seconds). 40 adults (female $n$ = 20) aged 18-30 ($M$ = 23.7 ± 2.9 years) completed three, nine-minute sessions of skill trials performed at 6, 12, and 30 second intervals. Participants performed kicking, throwing and striking trials in a blocked schedule with maximal effort. Average METS during each session were measured using a COSMED K4b2. A three (interval condition) X two (sex) ANOVA was conducted to examine differences in METS across interval conditions and by sex. Data indicated a main effect for interval condition ($df$ = 5,114, $F$ = 187.02, $p$ < .001, $\eta^2$ = 0.76) with decreased interval times yielding significantly higher METS [30 sec = 3.45, 12 sec = 5.68, 6 sec = 8.21]. A main effect for sex ($df$ = 5, 114, $F$ = 35.39, $p$ < .001, $\eta^2$ = 0.24) also was found with men demonstrating higher METS across

all intervals. At a rate of only two trials/min, participants elicited moderate physical activity, with 12 and 6 second intervals exhibiting vigorous PA.

The purpose of Study 2 was to compare the EE levels during OPSP as assessed by indirect calorimetry and accelerometry. Thirty-four adults (female $n = 18$) aged 18-30 (23.5 ± 2.5 years) performed three, nine-minute sessions of kicking, over-arm throwing, and striking performed at 6, 12, and 30 second intervals. EE was estimated (METS) using indirect calorimetry (COSMED k4b2) and hip-worn accelerometry (ActiGraph GT3X+). EE using indirect calorimetry demonstrated moderate-intensity physical activity (PA) (3.4 ± 0.7 METS – 30sec interval, 5.8 ± 1.2 METS – 12sec interval) to vigorous intensity PA (8.3 ± 1.7 METS – 6sec interval). However, accelerometry predicted EE suggested only light-intensity PA (1.7 ± 0.2 METS – 30sec interval, 2.2 ± 0.4 METS – 12sec interval, 2.7 ± 0.6 METS – 6sec interval). Accelerometry does not adequately capture the PA intensity level when performing OPSP skills, regardless of differences in performance intervals.

The purpose of Study 3 was to examine boys and girls EE during OPSP at three different intensity intervals. Children (42, *Mage* = 8.1) participated in a within-subjects design with three nine-minute sessions of trial intervals (i.e., 6, 12, and 30 second intervals) where participants performed kicking, throwing, and striking. Skills were performed with maximum effort in blocks of five trials of each skill in serial order until each nine-minute interval session was completed. The average metabolic equivalent of task (METS) during minutes 4-8 of each nine-minute session were calculated using a COSMED K4b2 portable gas analyzer. A 3 (interval condition) X2 (sex) ANOVA was conducted to examine differences in average METS across groups and sex. Data indicated a main effect for interval condition ($df = 2, 123$, $F = 94.36$, $p < .001$, $\eta 2 = 0.605$). Post hoc t-tests demonstrated decreasing performance interval times yielded significantly ($p < .001$) and progressively higher metabolic expenditure across the three conditions (30 sec = 4.5 ± 0.8 METS, 12 sec = 6.3 ± 1.3), 6 sec = 8.3 ± 1.6). There also was a main effect for sex ($df = 1, 120$, $F = 52.28$, $p < .001$ $\eta 2 = 0.305$). Boys demonstrated higher METS at each performance interval ($p < .001$). Average METS for boys and girls respectively were 9.3 (± 1.4) and 7.2 (± 1.2). METS during the six second intervals, 7.0 (± 1.1) and 5.6 (± 1.1) METS during 12 second intervals and 4.8 (± 0.7) and 4.1 (± 0.7) during 30 second intervals. Results indicate skill practice with a maximum of one trial every 30 seconds resulted in the equivalent of at least moderate physical activity (> 4.0 METS) and intervals of 6 seconds demonstrated vigorous physical activity (> 7.0 METS). These data indicate practicing/performing object projection skills, even at intervals that allow for instruction and feedback, (1 trial/30sec) is equivalent to MVPA levels in children.

The purpose of Study 4 was to compare the EE levels during OPSP as assessed by hip- and wrist-worn accelerometry in children (7-9 years). Forty-two children (female $n$ = 20, *Mage* = 8.1 ± 0.8 years) performed three, nine-minute sessions of kicking, over-arm throwing, and striking at performance intervals 0f 6, 12, and 30 seconds. EE was estimated METS using indirect calorimetry (COSMED k4b2) and accelerometers (ActiGraph GT3X+) worn on three different locations (hip, dominant wrist, and non-dominant-wrists). EE using indirect calorimetry demonstrated moderate-intensity physical activity (PA; 4.5 ± 0.8 METS – 30sec interval, 6.3 ± 1.3 METS – 12sec interval) to vigorous intensity PA (8.3 ± 1.7 METS – 6sec interval). However, hip-worn accelerometry predicted EE suggested only light-intensity PA (2.4 ± 0.2 METS – 30sec interval, 2.8 ± 0.5 METS – 12sec interval, 3.4 ± 0.7 METS – 6sec interval) dominant wrist-worn accelerometry predicted EE suggested only light-intensity PA (2.8 ± 0.8 METS – 30sec interval, 3.9 ± 0.6 METS – 12sec interval, 5.2 ± 0.9 METS – 6sec interval). Accelerometry does not accurately categorize the physical activity intensity level when performing OPSP skills, regardless of differences in performance intervals or accelerometer wear location in children.

These data have the potential to significantly impact physical activity intervention strategies and the implementation of PE curricula attempting to promote moderate to vigorous PA by informing specific trial intervals which promote health-enhancing physical activity levels (i.e., MVPA). Information gleaned from this study provides evidence that the practice of OPSP can aid in the achievement (acute) of recommended health-enhancing levels of EE (i.e., MVPA), as well as promote a foundation for skill development that promotes lifelong physical activity.

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# CHAPTER 1

# INTRODUCTION

Physical Activity Guidelines recommend children participate in a minimum of 60 minutes or more of moderate-to-vigorous intensity physical activity (MVPA) every day to achieve substantial health benefits (Health & Services, 2008; People & Services, 2000; Prevention & Promotion, 2011). However, only 20% of children and adults actually meet these guidelines (C. L. Ogden, Carroll, Kit, & Flegal, 2012; Prevention & Promotion, 2011). Performing activities that involve continuous/repetitive locomotor movements such as jogging or participating in activities like soccer or tennis generally have been suggested to achieve these guidelines (Ainsworth et al., 2011; Eisenmann, Wickel, Welk, & Blair, 2005; Farpour-Lambert et al., 2009; Jette, Sidney, & Blümchen, 1990; Martins et al., 2009; Pinnington, Wong, Tay, Green, & Dawson, 2001; Reed, Warburton, Macdonald, Naylor, & McKay, 2008) as they have been noted to demonstrate high energy expenditure levels measured in "METS" (Duffield, Dawson, Pinnington, & Wong, 2004). A MET (metabolic equivalent of task) is the standard unit of energy expenditure (EE) and the physiological equivalent to energy required during resting metabolism, or 3.5 ml of oxygen/kg of body weight/minute in adults (Trost, Loprinzi, Moore, & Pfeiffer, 2011). Activities that require at least 3 METS are classified as moderate intensity activity, with >6 METS being classified as vigorous activities in adults and children (Ainsworth et al., 2011; Cattuzzo et al., 2016; Croix & Korff, 2013; Pandy & Zajac, 1991; Passmore & Durnin, 1955; Ridley, Ainsworth, & Old2008; Trost, Rosenkranz, & Dzewaltowski, 2008; Vedul-Kjelsås, Sigmundsson, Stensdotter, & Haga, 2012). METS are usually measured in a controlled laboratory setting, using a treadmill and fixed expired gas analyzing equipment that requires the user to remain stationary in a lab setting. Advancements of portable gas analyzers now allow for the accurate measurement of METS in a variety of dynamic tasks by allowing for an increase freedom of movement that previously could only be estimated. The Compendium for Physical Activity has been used worldwide to provide researchers with activity intensity values in METS for activities that have established energy expenditure normative values (Ainsworth et al., 2011). A large variation in the methods have been used to quantify MET values in the compendium (e.g., indirect calorimetry, accelerometry, surveys), all of which have been accepted as a valid means to assess activity intensity. A noted limitation of this resource refers to the fact that the Compendium does not estimate the energy cost of physical activity with regard to individual differences. Individual differences (e.g., efficiency of movement, body weight status and training status) in energy expenditure may be significant, resulting in a misrepresentation the true energy cost of an activity for a particular individual as it is stated as a mean MET level in the Compendium (Ainsworth et al., 2011). Movement examples with these types of limitations include activities such as resistance training and cycling.

An additional limitation in the compendium is the lack of established MET values for the performance of discrete movements that may occur intermittently or in a repetitive fashion. Due to the methodological constraints which are imposed by the use of indirect calorimetry to measure energy expenditure in the field, specifically with large sample sizes, the most widely used objective tool for the measurement of physical activity levels are accelerometers (Cattuzzo et al., 2016).

Accelerometers measure variations in movement intensity (i.e., acceleration) and are associated with an individual's center of mass movements as they are typically worn at a point closest to an individual's center of mass (i.e., hip). The acceleration signal is filtered, rectified, and integrated through a user-specified time interval called an epoch (Trost, McIver, & Pate, 2005). Due to the lack of consistent hip translation, as compared to the limbs in many types of movements (e.g., kicking, throwing, striking) and the wide variety of standard intermittent measurement epochs researchers apply to accelerometers, accelerometry driven physical activity (PA) assessment may fail to accurately assess MET values for the performance of discrete skills, specifically object projection skills. As daily physical activity levels (measured via self-report and accelerometry) across childhood and adolescence have been linked to activities which require object projection skills, it is important to specifically understand how the performance of these skills contributes to activity intensity, and thus actual energy expenditure during specified intervals (Ainsworth et al., 2011).

Object projection skills are a subgroup of motor skills classified under the general umbrella term of motor competence (MC), which can be broadly defined as a person's ability to execute the coordination of fine and gross motor skills that are necessary to manage everyday tasks (D. F. Stodden et al., 2008; Vedul-Kjelsås et al., 2012). The development of competence in object projection skills requires repetitive practice that generally involves high rest to work intervals. Like any other human movement, effort levels of object projection skill practice can vary from low to high, but promoting high effort levels is a prerequisite to developing advanced levels of skill as the emergence of more advanced coordination patterns inherently includes the exploitation of neuromuscular mechanisms promoted with high effort eccentric/concentric muscular contractions (Cattuzzo et al., 2016; Croix & Korff, 2013; Girard, Micallef, & Millet, 2005; Pandy & Zajac, 1991; Rodacki, Fowler, & Bennett, 2002; D. F. Stodden, Langendorfer, Fleisig, & Andrews, 2006a). In essence, performance of object projection skills involve complex multi-joint movements that produce high movement speeds and are generally produced with the activation of large muscle groups, whether demonstrating skilled or unskilled movement patterns (D. F. Stodden et al., 2006a). These skills are serially repeated in the context of leisure play, game play and/or practice and specific skill training. Effortful performance of these types of skills involves very high neuromuscular demands with high concentric and eccentric muscular contractions producing high segmental velocities and power production (Campbell, Stodden, & Nixon, 2010; Girard et al., 2005; Holfelder & Schott, 2014; Lubans, Morgan, Cliff, Barnett, & Okely, 2010; MacWilliams, Choi, Perezous, Chao, & McFarland, 1998; Pandy & Zajac, 1991; Rodacki et al., 2002; D. Stodden, Langendorfer, & Roberton, 2009; D. F. Stodden et al., 2006a; D. F. Stodden, Langendorfer, Fleisig, & Andrews, 2006b). These high neuromuscular demands, which are substantially higher than many repetitive cardiorespiratory activities of moderate intensity (e.g., jogging), suggest that energy expenditure would also be high when the skills are repeated in play, practice or training contexts.(Holfelder & Schott, 2014; Machado-Rodrigues et al., 2011; Sparrow, 1983). This type of intermittent high effort activity is a noted limitation in accelerometry-based assessment of physical activity that use various epochs that are extrapolated to activity intensity and thus, energy expenditure (Artero et al., 2011; Chen & Bassett, 2005; Evenson, Catellier, Gill, Ondrak, & McMurray, 2008; Hooker et al., 2011; Pate, Almeida, McIver, Pfeiffer, & Dowda, 2006; Ruiz et al., 2010; Trost et al., 2005; Welk, Schaben, & Morrow Jr, 2004).

Current recommendations for obtaining MVPA for both adults and children include activities that purportedly demand high neuromuscular effort (e.g., basketball, soccer, tennis), but the neuromuscular effort and energy expenditure may be different based on the types of movements produced in these different activities (Health & Services, 2008; People & Services, 2000; Prevention & Promotion, 2011). For example, an extended rally of effortful forehand volleys in tennis may require a different effort than single maximal kick in soccer performed in unison with running, both of which require numerous effortful repetitions during years of practice.

Competency in discrete motor tasks is demanded for successful participation in leisure games and sports and is only obtained through effortful practice. However, at this time there are no established MET values specific to the performance of discrete motor skills that are included in activities such as soccer (kicking), tennis (striking), or baseball (throwing). Also lacking is an understanding of accelerometers ability to accurately predict MET values during the repetitive practice of the discrete skills.

**Measurement Comparison - METS vs. Accelerometry**

Due to the relative lack of high frequency repetitive translations of an individual's center of mass during object projection skill performance as compared to the potentially substantial difference in neuromuscular demand required by object projection skills, accelerometry-based MET estimations may be severely underestimated in these types of movements (Girard et al., 2005; Holfelder & Schott, 2014; Rodacki et al., 2002; D. F.

Stodden et al., 2006a). In fact, the measurement of energy expenditure of repetitive object projection skill performance using indirect calorimetry has not even been attempted. Rather, MET interpolations associated with object projection skill performance has only been estimated (Duffield et al., 2004; D. Stodden & Brooks, 2013; D. F. Stodden, Gao, Goodway, & Langendorfer, 2014). As accelerometers capture movement in specific epochs of only one particular part of the body (i.e., the hip or non-dominant wrist), movements that are short in duration with high global neuromuscular demands (i.e., throwing, kicking and striking) may not be effectively captured by accelerometry. In addition, as movement of the human body during practice and play can vary greatly, it is necessary for the sampling rate of the accelerometer to be set to a sufficient resolution to capture various frequencies and durations of movement. Unfortunately, sampling frequencies are quite variable generally ranging from 1-60 second epochs with little understanding of the nature of object projection movements (Ainsworth et al., 2011). Thus, if accelerometry-based MVPA values are assumed to be correlated with actual MET values, then many ballistic discrete tasks that require high amounts of energy to perform may have previously been greatly undervalued (or unobserved) in their ability to contribute to the accumulation of MVPA throughout a day.

Understanding the contribution of object projection skill performance to total energy expenditure (i.e., actual activity intensity) is significant as higher levels of competency in these skills already is associated not only with increased total PA per day, but also health-related fitness and obesity levels across childhood and adolescence (Cattuzzo et al., 2016; Holfelder & Schott, 2014; Lubans et al., 2010; D. F. Stodden et al., 2006a; Ulrich & Sanford, 1985). Additionally, acquiring high levels of competency in these skills, as compared to locomotor skills, has been suggested to be more effective for promoting a foundation for future PA habits, health-related fitness and a healthy weight status (L. Barnett, Van Beurden, Morgan, Brooks, & Beard, 2008; L. M. Barnett, Van Beurden, Morgan, Brooks, & Beard, 2009; W. S. Barnett, 2011; D. F. Stodden et al., 2014; D. F. Stodden et al., 2008).

Current physical education guidelines advocate for moderate to vigorous activity to be performed for at least 50% of the time in a physical education class (Morrow Jr, Martin, & Jackson, 2010). Many physical activities performed during a physical education setting involve the practice, sport and game play made up of the intermittent performance of MC activities. Understanding the metabolic expenditure (i.e., activity intensity) of intermittent object projection motor skill performance is significant as these types of movements are typically not associated with MVPA as assessed with accelerometry and may lead to an underestimation of the accumulation of MVPA as measured by accelerometry. For example, the intensity level (e.g., MVPA) of object projection skill performance in settings such as physical education, games and sports where repeated practice trials of skills are performed in different contexts may lead to a drastic underestimation of energy expenditure. MET values assigned to sports that are suggested to promote MVPA (e.g., basketball, soccer, tennis) were measured in the context of actual game play, which typically involves perpetual motion (i.e., running) for a given period of time. This continuous motion is captured by accelerometers and is associated with the indirect measurement of energy expenditure. However, a common paradigm to physical education classes, recess and individual practices are intermittent periods of activity featuring repetitive discrete skills that are performed with rest periods in the context of game play and/or with instruction and feedback being provided. This is a type of distributed practice which is favored over constant practice when teaching discrete skills due to their ballistic nature which requires a maximal effort over a short time period to perform. Distributed practice features rest periods in which the practice time may appear to an observer to be relatively restful as the time in activity is often equal to or less than the time spent at rest. This intermittent activity is captured by accelerometers but due to the short duration of the discrete skill and the longer duration of the rest/instructional period that follows, the measurements made by the accelerometers are most closely related that which would be recorded during sedentary activity.

In fact, research demonstrates that the percentage of time in MVPA in physical education classes or recess (as measured by accelerometers or pedometers) rarely meet the recommended guidelines of 50% of time in those activities nor of 60 minutes per day (Health & Services, 2008; Morrow Jr et al., 2010; People & Services, 2000; Prevention & Promotion, 2011). If the practice and performance of object projection skills is not adequately quantified as MVPA, then time spent in MVPA in physical education, recess or sports practice, where repetitive practice or performance of object projection skills may take place, may be significantly underestimated. Thus, in order to accurately assess the status of an individual's activity level, it is necessary to accurately quantify all types and intensities of movement produced by an individual. The proposed studies will allow for the improvement our understanding of the metabolic cost during the performance of various types of movements that have not been systematically addressed in previous research (Ainsworth et al., 2011).

**Statement of Purpose:**

Currently lacking is an understanding of the metabolic expenditure (i.e., intensity level) of object projection skill performance in adults and children (Ainsworth et al., 2011; Machado-Rodrigues et al., 2011; Sparrow, 1983). The proposed studies will address this gap in the literature and inform PA research by examining energy expenditure, as assessed by indirect calorimetry, during object projection motor skill performance in adults (18-30 years of age) and children (7-9 years of age) and will compare the intensity level of object projection motor skill performance as assessed by indirect calorimetry with traditional accelerometer assessment. Conclusions from these results may be critical to advancing knowledge and the understanding of the types of developmentally appropriate activities that are health-enhancing from a metabolic expenditure perspective.

*Study 1*

***Aim 1:*** To examine energy expenditure, as assessed by indirect calorimetry (METS), during object projection motor skill performance *at 6, 12 and 30 second trial intervals* in adults (18-30 years of age).

***Aim 2:*** To examine the level of agreement in assessment of activity intensity levels (METS) as measured via indirect calorimetry (i.e., COSMED) and accelerometry during object projection skill performanc*e* in adults (18-30 years of age) at 6, 12 and 30 second intervals.

*Study 2*

***Aim 1:*** To examine energy expenditure, as assessed by indirect calorimetry (METS) during object projection motor skill performance *at 6, 12 and 30 second trial intervals)* in children (7-9 years of age).

***Aim 2:*** To examine the level of agreement in assessment of activity intensity levels (METS) as measured via indirect calorimetry (i.e., COSMED) and accelerometry during object projection skill performanc*e* in children (7-9 years of age) at 6, 12 and 30 second interval.

# CHAPTER 2

## LITERATURE REVIEW

In an effort to combat the growing obesity trend among children and adolescents (C. Ogden, Carroll, Fryar, & Flegal, 2015; C. L. Ogden et al., 2012) the American College of Sports Medicine, in tandem with the American Heart Association, provided a set of recommendations stating that adults should attempt to attain a minimum of 150 minutes of moderate intensity PA a week or 75 minutes of vigorous intensity per week for health benefits, including moderate-intensity aerobic PA for a minimum of 30 minutes a day, five times a week, or vigorous-intensity aerobic PA for 20 minutes a day, three times a week (Haskell et al., 2007; Nelson et al., 2007). These guidelines also indicate a dose-response relationship which yield additional health benefits when 300 minutes of moderate intensity PA a week or 150 minutes of vigorous intensity per week are obtained (Medicine, 2013). Additionally, adults should perform muscular strengthening activities for a minimum of two days a week (Haskell et al., 2007). Adults seeking to improve their fitness levels or reduce their risk of diseases related to inactivity (e.g., coronary heart disease) should try to exceed the recommendations mentioned above (Bouchard, Blair, Haskell, & Lee, 2001). These guidelines also recommended children participate in a minimum of 60 minutes or more of moderate-to-vigorous intensity physical activity (MVPA) every day to achieve substantial health benefits (Koh, 2010; People & Services, 2000; Prevention & Promotion, 2011). However, only 20% of children and adults actually meet these guidelines

(Prevention & Promotion, 2011). Lifestyle physical activity patterns begin early and impact cardiovascular disease (CVD), body mass index (BMI), blood pressure, fitness and adiposity risk throughout the lifespan and sufficient data exists in support of early implementation for obesity prevention interventions in youth and adults (Eisenmann et al., 2005; Farpour-Lambert et al., 2009; Martins et al., 2009; Nadeau, Maahs, Daniels, & Eckel, 2011). In response to challenges set forth by Healthy People 2020, interventions have been implemented to reduce sedentary time and/or increase MVPA in school-based settings (Brazendale, Chandler, et al., 2015; Reed et al., 2008; R. G. Weaver, Webster, & Beets, 2013) and after-school programs (Brazendale, Beets, et al., 2015). A primary purpose of these interventions has been focused on increasing PA (e.g., Turn up the HEAT, Kids FIT, PACES, SPARK, CATCH) during normal daily activities by providing increased movement opportunities as well as focus on reducing time spent in sedentary activity (Brazendale, Beets, et al., 2015; Brazendale, Chandler, et al., 2015; Cairney et al., 2015; McKenzie, Sallis, Rosengard, & Ballard, 2016; R. G. Weaver et al., 2013; R. G. Weaver, Webster, C.A., Egan, C.A., Campos, M.C., & Michael, R.M. , in press). Unfortunately, these interventions do not necessarily promote physical activity from a developmental perspective (Stodden et al 2008) which point to the promotion of sustained physical activity levels throughout the lifespan (D. F. Stodden et al., 2008). At a young age we are introduced to many types of movement skills including both object control skills (e.g., throwing, kicking, striking) and locomotor skills (e.g., hopping, skipping, leaping; Haywood & Getchell, 2001). Competency in these skills is vital to successful participation in a variety of activities that many children play (e.g., soccer, basketball, tennis) and are recommended by the same governing bodies which produced Healthy People 2020 with the intent of promoting MVPA (Koh, 2010). The performance of activities that involve repetitive locomotor and continuous movements such as running have generally been promoted to achieve physical activity guidelines (Eisenmann et al., 2005; Farpour-Lambert et al., 2009; Martins et al., 2009; Nourry et al., 2005). The vast majority of our understanding of energy expenditure is based on continuous activities. Thus, technology has mainly promoted the indirect measurement of energy expenditure by determining the amount of oxygen consumed and the amount of carbon dioxide eliminated on stationary implements such as treadmills or cycle ergometers (Ainsworth et al., 2011). Until recently, technology has not permitted the evaluation of energy expenditure during the participation in activities like soccer, basketball or tennis, which are activities that require the performance of object projection skills to successfully participate. These discrete movements involve complex multi-joint movements that produce high movement speeds and generally are performed with high effort levels. These movements also involve high levels of activation of large muscle groups and are serially repeated in the context of leisure play, game play, sports or training. The extent to which these FMS movements contribute to total energy expenditure during these activities is currently unknown.

**Metabolic Equivalent of Task (METS)**

A MET is a unit of measure to express the energy expenditure of performing physical activities. The earliest known definitions describe a MET as the ratio of work metabolism to rest metabolism (Dill, 1936). 1.0 MET is equivalent to 3.5 ml of $O2 \cdot kg^{-1} \cdot min^{-1}$ and has been estimated as the metabolism required to sustain life at rest (Ainsworth et al., 2011.)

$$1\,MET = 1\,\frac{kcal}{kg * h} = 4.184\,\frac{kJ}{kg * h} = 1.162\,\frac{W}{kg}$$

Resting Metabolic Rate (RMR) which is obtained during quite sitting was originally believed to be equivalent to 1.0 MET (Ainsworth et al., 2011; Ainsworth et al., 1993). It is now understood that MET values can range from 0.9 (sleeping) to approximately 23 (running at 14 mph) (Ainsworth et al., 2011). An RMR will deviate between individuals; thus, METS express energy expenditure while controlling for weight differences (Byrne, Hills, Hunter, Weinsier, & Schutz, 2005). This allows for the comparison of activity intensity by comparing differences in deviation from 1 MET. For example, an activity with a MET value of 3.0, the baseline equivalent of moderate activity, would require three times the energy that an average person would need to consume while at rest.

Heat is produced and eliminated from the body as a result of the utilization of calories which are consumed and used as fuel for the human body. The measurement of the heat eliminated or stored in any system is known as calorimetry. There are two ways in which this heat transference can be measured in the human body, they are known as direct and indirect calorimetry. Direct calorimetry is the measurement of the amount of heat produced by a subject. Heat produced as a byproduct of work is directly is measured while the subject is enclosed within a small chamber, which can measure changes temperature. Indirect calorimetry measures the amount of heat produced in an oxidation reaction by determining the amount of oxygen consumed by an individual or by measuring the amount of carbon dioxide eliminated and translating these quantities into a heat equivalent. For these quantities to be measured, the volume and contents of every breath taken during a testing session must be recorded. Early research featuring indirect calorimetry to measure the volume of oxygen consumption ($VO_2$) used stoichiometry bags (Douglas bag technique) to collect expired air while a participant expired ventilated air into a mask. These tests were performed in either a stationary position or while performing a continuous activity (i.e., running on a treadmill, cycle ergometer). The measurement of $VO_2$ led to an understanding of maximal oxygen uptake ($VO_2$ max) and its acceptance as a gold standard for the measurement of cardiovascular fitness. Since oxygen consumption at the rate of 3.5 ml of $O2 \cdot kg^{-1} \cdot min^{-1}$ is equivalent to approximately 1.0 MET it is possible to estimate energy expenditure during physical activity using the same technology developed for the study of $VO_2$. As technology improved these bags were replaced by machines which could analyze the rate expired air in real time allowing for advances in our understanding of energy consumption during a vast array of continuous activities, provided they could be performed within the limits of a measuring device. As research in the field of metabolism and physical activity continued it became apparent that the use of portable analysis devices was warranted to determine what differences may exist when the body was taxed in an outdoor and/or unrestricted environment (e.g., walking/running on tracks or trails, rowing on water, cross country skiing). The advent of portable gas analyzers have allowed for an increased understanding of human metabolism in many environments.

The Compendium for Physical Activity was first established in 1993 to provide researchers with activity intensity values in METS for activities with established energy expenditure normative values (Ainsworth et al., 2011). The Compendium was updated in 2000 and again in 2011 and is the largest source for data of its kind in the world. A large variation in the methods have been used to quantify MET values in the compendium (e.g., indirect calorimetry, accelerometry, surveys), all of which have been accepted as a valid means to assess activity intensity, yet not all forms of physical activity can be found in the

Compendium. For example, an estimate of METS during competitive soccer, as measured by indirect calorimetry is listed as 10.0 METS but the repetitive practice of kicking a soccer ball outside of match play does not exist (Ainsworth et al., 2011). A noted limitation of this resource is that "the Compendium does not estimate the energy cost of physical activity in individuals in ways that account for individual differences notably the efficiency of movement, of which the activities are performed. Thus, individual differences in energy expenditure for the same activity can be large and the true energy cost for an individual may or may not be close to the stated mean MET levels as presented in the Compendium." An additional limitation in the compendium is the lack of established MET values for the performance of discrete movements that may occur intermittently or in a repetitive fashion. Some activities of a discrete nature listed in the Compendium (e.g., shot put, discus and hammer throw) have only been estimated and do not relate to repetitive practice (Ainsworth et al., 2011). The Compendium also notes energy expenditure associated with performing a squat with an explosive effort (60-80% of 1RM) is within a range of 4.34-5.05 METS measured via indirect calorimetry (Ainsworth et al., 2011; Mazzetti, Douglass, Yocum, & Harber, 2007). General resistance training (e.g., 8-15 repetitions of varied resistance) requires an effort of approximately 3.50 METS but was only established in women via indirect calorimetry (Ainsworth et al., 2011; Haddock & Wilkin, 2006). Other examples of MET levels relating to both adults and children are noted in Table 1 at the end of chapter 2.

Activities performed by adults that require at least 3 METS are classified as moderate intensity activity, with >6 METS being classified as vigorous activities. The following reported ranges represent levels of PA in adults: a) sedentary behavior, 1.0–1.5

METS b) light-intensity, 1.6–2.9 METS c) moderate-intensity, 3–5.9 METS, d) vigorous-intensity ≥6.0 METS (Ainsworth et al., 2011).

**METS in Children**

Since the advent of The Compendium for Physical Activity many researchers have drawn conclusions to health related physical attributes associated with energy expenditure and energy intake based on adult data (Ainsworth et al., 2011). The Compendium for Energy Expenditures for Youth was developed in an attempt to provide researchers with a compendium of energy costs for youth (ages 6.0-17.9) (Ridley et al., 2008). The majority of the MET data (65%) for activities in which children participate is based on the adult data provided in the adult compendium (Ridley et al., 2008). There has been a recent increase in the number of publications which have added to the understanding of MET levels associated with PA in children; however, the current Compendium for Energy Expenditures for Youth does not contain MET measures that align with the practice of object projection motor skills (Ridley et al., 2008; Clevenger et al., 2016; Howe, Freedson, Feldman, & Osganian, 2010; Lyden, Keadle, Staudenmayer, Freedson, & Alhassan, 2013; Sasaki et al., 2016).The Compendium recommends that the validity of energy expenditure in physical activities in children should be based on measures derived from children (Howe et al., 2010). Assigning appropriate MET values for children to corresponding levels of MVPA does present problems when using adult mass-specific measurements and may lead to significant errors (Ridley et al., 2008; Torun, 1983). A recent review of published research regarding the energy expenditure of everyday children's activities compared recommended methods of adjusting adult METS for valid use in children and were found to be beneficial when predicting the MET values of walking and running in children but that adult METS should be used in all other contexts (Harrell et al., 2005; Ridley et al., 2008; Ridley & Olds, 2008; Torun, 1983).

Due to physical and maturational differences (e.g., energy expenditure decreases at rest and during activity with age, children expend more energy relative to body weight) it has been theorized that children may yield higher levels of EE while performing a similar task to an adult based on their relatively smaller size, underdeveloped locomotive capabilities, and lesser strength (Clevenger et al., 2016; Harrell et al., 2005; Ridley & Olds, 2008). Early research on energy expenditure illustrated that a steady drop in basal metabolic rate occurs from ages 6 to 18 years (Boothby, Berkson, & Dunn, 1936; Goran et al., 1995). Similarly, Harrell et al. concluded that resting energy expenditure is higher in children than in adults (8-18 years), but this effect varies by pubertal stage (Harrell et al., 2005; Bitar, Fellmann, Vernet, Coudert, & Vermorel, 1999; Roemmich et al., 2000). Bitar et al. also supported this drop is metabolic rates over time by indicating that EE at rest is much higher in children than in adults, as well as noting that resting EE is lower in girls than in boys (Bitar et al., 1999). Conversely, Goran et al. measured resting energy expenditure in children who were matched to their parents and reported resting EE was higher in girls than in boys. Overall, recommendations state that once puberty is nearly completed, MET values provided by the Compendium of Physical Activity may be used without a need for adjustment (Harrell et al., 2005). However, there has been no explanation of how to qualify how this approximate stage was to be determined. Thus, the variability in the literature indicated that the categorization of METS with intensity levels of activities follow the recommendations of work by Trost et al. who objectively measured PA in youth and determined that the threshold of 4 METS for moderate activity and 7

METS for vigorous activity should be used for youth ages 6-17 years of age (Trost et al., 2002).

**Accelerometry**

Currently, the most widely used tool for field-based measurement of physical activity levels are accelerometers. Accelerometers were developed in response to the need for an objective and effective alternative to subjective measures of PA (e.g., self-report questionnaires, direct observation), which have been reported to have poor reliability and are inherently time consuming (Baranowski et al., 1984; Migueles et al., 2017; Sallis, 1991). Accelerometers are small wearable devices (e.g., hip, wrist, ankle) which capture accelerations of body segments which can then be filtered and converted to activity counts are then grouped via cut-points to represent various intensity thresholds (i.e., sedentary, light, moderate, vigorous) (Adams, Johnson, & Tudor-Locke, 2013; Chandler, Brazendale, Beets, & Mealing, 2016; Evenson et al., 2008; P. S. Freedson, Melanson, & Sirard, 1998). A point of emphasis in a recent systematic review (Migueles et al) notes that validated algorithms of accelerometer cut points are specifically representative of their age group, location and in some cases movement patterns and should not be used interchangeably (Migueles et al., 2017; Wijndaele et al., 2015).

Cut-points for hip worn accelerometers currently exist for both adults and children (Evenson et al., 2008; P. Freedson, Bowles, Troiano, & Haskell, 2012). The most widely accepted of those cut-points are Freedson et al., in adults and Evenson et al., in children (Evenson et al., 2008; P. S. Freedson et al., 1998). There are many possible variations in cut-points that are available in the literature, however many inconsistencies exist in the methodologies of collecting PA data when using accelerometry. For example, the National

Health and Nutrition Examination Survey (NHANES) implemented an objective assessment of PA using hip worn accelerometers. From this data, age specific cut points for each chronological age band from 6-18 representing moderate and vigorous activity level (i.e., excluding sedentary and light PA) can only be inferred because the cut-points utilized in the analysis are not directly stated by Troiano et al. As a result, recommendations gleaned from this study prohibit their use as a valid measure for youth (ActiGraph, 2017; Troiano et al., 2008). Another methodological inconsistency in reporting is the use of different MET values that align with corresponding PA levels across many validated examples of cut-points in youth. For example, Trost et al assumed the following MET cut points: Sedentary: 0 - 1.78 METS; Light - 1.79 METS - 3.99 METS; Moderate: 4.00 METS - 5.99 METS; Vigorous: >= 6.00 METS, which resulted in the determination of the following cut-points per minute (CPM); Sedentary: 0-99 CPM; Light: 100 - 2219 CPM; Moderate: 2220 - 4135 CPM; Vigorous: >4136 CPM (Trost et al., 2011). In contrast a similar validation study by Freedson et al., in children utilized MET thresholds of: moderate; 3.00 and vigorous; 6.00 which produced cut points of 500 and 4000 CPM respectively.(P. Freedson, Pober, & Janz, 2005; Mahar, Rowe, & Mahar, 2013; Mendoza, Hickey, Gruber, Staudenmayer, & Freedson, 2014). ActiGraph utilizes software known as ActiLife to disseminate data from its accelerometers. This software provides wrist-worn cut points which are based, according to the manufacturer, on internal research and development (ActiGraph, 2017). Accelerometer counts per 1 minute as presented by ActiLife are as follows; sedentary <644.0, light 645.0-1272.0, moderate 1273.0-3806.0, and vigorous intensity >3807.0 PA (ActiGraph, 2017).

Puyau et al. (2002) determined cut-points for accelerometers worn on the right ankle, however no determination was made to distinguish the dominance of the leg associated with the measured ankle (Puyau, Adolph, Vohra, & Butte, 2002). Puyau determined METS for each activity measurement by calculating EE then dividing by the child's measured resting metabolic rate as determined by an accelerometer during a 20-min resting state measurement (Puyau et al., 2002). Accelerometer counts per 1 minute as presented by Puyau et al., are as follows; sedentary <799.0, light 800.0-3199.0, moderate 3200.0-8199.0, and vigorous intensity >8200.0 PA, respectively (Puyau et al., 2002; Puyau, Adolph, Vohra, Zakeri, & Butte, 2004). The aforementioned cut points vary drastically in both their wear locations and validation methodology which demonstrates the high level of variability in how accelerometry cut points align with the measurement of energy expenditure. Thus, the literature indicates the use of the most widely accepted of those cut-points (e.g., Freedson et al., in adults and Evenson et al., in children) for the evaluation of agreement of METS and accelerometry.

To date, cut points for hip worn accelerometers remain the only validated wear location for use in both adults and children (Evenson et al., 2008; P. S. Freedson et al., 1998; Migueles et al., 2017). Current recommendations and practices suggest the evaluation of total raw counts at a collection rate of 100hz to account for variability and to allow for further analysis when future cut-points are established for all other wear locations (ActiGraph, 2017; Migueles et al., 2017; Swartz et al., 2000; Trost et al., 2011; Trost, Way, & Okely, 2006). Validated cut points exist for the use of accelerometers on the non-dominant wrist in adults and on the right ankle in children. These two sets of cut points each have a key flaw; the lack of validity in testing methods and the lack of agreement to recognized MET values in the wrist and ankle cut-points respectively. Furthermore, the Actigraph database maintains that validated wrist cut points for both children and adults and ankle cut-points in adults do not yet exist (ActiGraph, 2017).

Cut-point values are based the variability of captured movements along an axis during given period of time known as an epoch. Early validation studies presented cut-points in 60 epochs but more recently 15-second epochs have been used (Evenson et al., 2008; P. S. Freedson et al., 1998; Pate et al., 2006; Trost, Fees, Haar, Murray, & Crowe, 2012). This inconsistency in validation methodology results in the need to standardize all accelerometer counts in 60 second epochs. This is done by converting CPM to the desired fraction per minute. The evaluation of a given activity should be reflected in the chosen epoch length. For example, in activities with little variation (e.g., sleeping) a longer epoch length is recommended however, in activities that involve movements that are short in duration (i.e., completion in < 2 seconds) with high global neuromuscular demand (i.e., throwing, kicking and striking) may be effectively captured by shorter epoch length (e.g., 1 second, 5 second) (Keele, 1968; Migueles et al., 2017). In addition, as movement of the human body during practice and play can vary greatly, it is necessary for the sampling rate of the accelerometer to be set to a sufficient resolution to capture various frequencies and durations of movement. Unfortunately, sampling frequencies are quite variable generally ranging from 1-60 second epochs with little understanding of the nature of object projection movements.

A progression of physical activity measurement tools for children have progressed from the use of self-report questionnaires, direct observation, doubly labeled water, heart rate monitoring, pedometers (Pate, 1993) to the use of accelerometers due to cost and time constraints posed by the aforementioned methods (Trost, 2001). The same popularity of the ActiGraph that exists for adult PA research exists for children. However, accelerometry-based energy expenditure prediction equations developed for adults (Freedson et al., 1998; Hendelman, Miller, Baggett, Debold, & Freedson, 2000) are not valid for children and adolescents because they do not take into account differences in RMR, the coordination and control of locomotive movement patterns, or developmental age and physiological related differences (Puyau et al., 2004; Trost, 2001; Welk, Corbin, & Dale, 2000).

**Object Control**

Object projection skills are a subgroup of motor skills that can be defined as a person's ability to execute the coordination of fine and gross motor skills that are necessary to manage everyday tasks (Vedul-Kjelsås et al., 2012). The development of competence in object projection skills requires repetitive practice generally involving low work to rest intervals as these types of skills are discrete skills that have a defined beginning and ending. Promoting high effort levels is a prerequisite to developing advanced levels of object projection skills as the emergence of more advanced coordination patterns inherently includes the exploitation of neuromuscular mechanisms that necessitate high effort eccentric/concentric muscular contractions (Cattuzzo et al., 2016; Croix & Korff, 2013; Girard et al., 2005; Pandy & Zajac, 1991; Rodacki et al., 2002). For example, the ground reaction forces (GRF) produced when the supporting foot during a proficient kicking motion comes in contact with the ground can reach between 1.5-2.0 times the weight of the individual performing the kick (Lees, Asai, Andersen, Nunome, & Sterzing, 2010). In baseball the GRF associated with the landing phase of a pitching motion were reported to equal 1.75 times the weight of the throwers body weight (MacWilliams et al., 1998). During the acceleration phase of this same throwing motion, the lower extremity has been shown, with the use of electromyography, to exhibit voluntary contractions of 170% as comparted to that of maximal voluntary isometric contraction (MVIC) (Campbell et al., 2010). These high forces distributed throughout the body during the landing phase are the result of a coordinated forceful effort to accelerate and consequently, decelerate the body (Escamilla & Andrews, 2009). The most notable developmental difference between novice and skilled performers occurs at the hip. The hip in a kicking motion was noted as a critical enabling constraint in the facilitation of the transfer of energy throughout the kinetic chain (Lees et al., 2010). In a study by Roberton and Mosher (1985) and later Nunome et al which yielded a power generation of 2000W at the hip, which was much greater than that 100W promoted at the knee (Nunome, Asai, Ikegami, & Sakurai, 2002; Robertson & Mosher, 1985). Similarly, Stodden et al., noted pelvic angular velocities which exceeded 650/s in performers at the highest developmental level of throwing which were significantly higher than the 197°/s exhibited by those of at the lowest developmental level (D. F. Stodden et al., 2006a). In essence, performance of object projection skills involve complex multi-joint movements that involves high neuromuscular demand (e.g., > 100% MVIC) and produce high movement speeds and power because they are generally produced with high effort that activates large muscle groups (Cattuzzo et al., 2016; Girard et al., 2005; Holfelder & Schott, 2014; Lubans et al., 2010; Pandy & Zajac, 1991; Rodacki et al., 2002; D. Stodden et al., 2009; D. F. Stodden et al., 2006a, 2006b). These skills are serially repeated in the context of leisure play, game play and/or practice and specific skill training. These high neuromuscular demands, which can be substantially higher than repetitive cardiorespiratory activities of moderate intensity (e.g., walking or jogging) suggest that energy expenditure would also be high when the skills are repeated in a practice or training context (Girard et al., 2005; Reid & Schneiker, 2008). This type of intermittent high effort activity is a noted limitation in accelerometry-based activity epochs that are extrapolated to activity intensity and thus, energy expenditure (Artero et al., 2011; Chen & Bassett, 2005; Hooker et al., 2011; Pate et al., 2006; Ruiz et al., 2010; Trost et al., 2005; Welk et al., 2004).

Overall, if performance of object projection skills actually promotes high enough energy expenditure levels (i.e., MVPA), then an important focus of physical activity interventions may be to promote the learning of movement skills that are critical to the successful performance of many games and sports that millions of children choose to participate in while still promoting the attainment of adequate MVPA levels. Currently, research demonstrates that the percentage of time in MVPA in physical education classes or recess (as measured by accelerometers or pedometers) rarely meet the recommended guidelines of 50% of time in those activities nor of 60 minutes of MVPA per day. Due to the intense ballistic nature of the practice of MC skills it may be possible that results from this study reveal that the energy expenditure associated with the practice of MC is high, yet not reflected by the use of accelerometers. Furthermore, no MET values for the repetitive practice of object projection motor skills have been established, nor has the validity of accelerometry been assessed in its capability to accurately reflect the corresponding MET values of these types of skills as they are performed in isolation (i.e., specific skill practice) or in the context of game play (i.e., baseball, soccer, tennis). An important implication of these data may be that MVPA levels in physical education, leisure games and sports may be higher than previously thought, specifically if the curriculum and/or activities inherently include repetitive practice or performance of object projection skills. These data also have important implications for physical education curricula as well as physical activity intervention strategies as it may inform curricular content of interventions attempting to promote the increase of MVPA through the development of MC in regards to a developmental perspective and the promotion of sustained physical activity levels throughout the lifespan.

Thus, research is warranted to not only address questions surrounding the convergent validity of accelerometry with indirect calorimetry assessments, but also to determine the contribution of practice and performance of MC skills on the achievement of recommended daily values of MVPA in activities performed by millions of adults and children in physical education, games and sports that inherently involve object projection skill

Table 2.1. Assorted activities presented in METS

| Description | METS | Measured by | Measured in | Reference |
|---|---|---|---|---|
| Baseball | | | | |
| general | 5.0 | questionnaire | adults | (Taylor, Jacobs et al. 1978) |
| Basketball | | | | |
| general | 6.5 | indirect calorimetry, accelerometry | adults | (Crouter, Clowers et al. 2006; Moy, Scragg et al. 2006) |
| game | 8.2 | accelerometry | youth | (Eisenmann, JC et al. 2004) |
| drill, practice | 9.3 | indirect calorimetry, accelerometry | adults | (Kozey, Lyden et al. 2010) |
| Cycling | | | | |
| general | 7.5 | adapted YMCA protocol | adults | (Moy, Scragg et al. 2006) |
| leisure | 3.62 | Douglas method | adults | (Jing and Wenyu 1991) |
| > 20 mph, not drafting | 15.8 | indirect calorimetry, blood lactate | adults | (Lucia, Joynos et al. 2000) |
| stationary (Spin class) | 8.5 | heart rate | adults | (Rixon, Rehor et al. 2006) |
| moderate effort | 6.2 | indirect calorimetry | youth | (Pfeiffer, Karen et al. 2006) |
| hard effort | 7.8 | indirect calorimetry | youth | (Pfeiffer, Karen et al. 2006) |
| Kickball | | | | |
| general | 7.0 | Estimated | adults | Estimated |
| Racquetball | | | | |
| casual | 7.8 | indirect calorimetry, accelerometry | adults | (Berg, Narazaki et al. 2007) |
| | 6.63 | questionnaire | adults | (Taylor, Jacobs et al. 1978) |
| Running | | | | |
| 2.5 m/s (5.6 mph) | 8.5 | regression equation | youth | (Ridley and Olds, 2008) |
| 2.92 m/s (6.5 mph) | 9.3 | regression equation | youth | (Ridley and Olds, 2008) |
| 6 mph | 9.8 | indirect calorimetry, accelerometry | adults | (Welk, Blair et al 2000) |
| 8 mph | 11.8 | indirect calorimetry | adults | (Mercer, Dolgan et al. 2008) |
| 10 mph | 14.5 | spirometry | adults | (Mayhew and Andres 1975) |
| Soccer | | | | |
| competitive | 10.0 | indirect calorimetry, accelerometry | adults | (Ferrauti, Giesen et al. 2006) |
| general | 7.0 | questionnaire | adults | (Taylor, Jacobs et al. 1978) |
| moderate effort | 8.8 | Douglas method | youth | (Bedale, EM 1923) |
| hard effort | 11.0 | Douglas method | youth | (Bedale, EM 1923) |
| Softball | | | | |
| pitching | 4.0 | Estimated | adults | Estimated |

| | | | | |
|---|---|---|---|---|
| practice | 6.0 | indirect calorimetry, accelerometry | adults | (Bassett, Ainsworth et al. 2000) |
| Tennis | | | | |
| general | 7.3 | adapted YMCA protocol, indirect calorimetry, accelerometry | adults | (Moy, Sragg et al. 2006; Kozey, Lyden et al 2010) |
| doubles | 6.0 | questionnaire | adults | (Taylor, Jacobs et al. 1978) |
| singles | 8.0 | indirect calorimetry, accelerometry | adults | ( Bassett, Ainsworth et al. 2000) |
| table | 4.0 | questionnaire | adults | (Taylor, Jacobs et al. 1978) |
| Track and Field | | | | |
| discus, hammer throw, shot put | 4.0 | Estimated | adults | Estimated |
| javelin | 6.0 | Estimated | adults | Estimated |
| high jump, long jump | 6.0 | Estimated | adults | Estimated |
| Volleyball | | | | |
| Beach | 8.0 | Estimated | adults | Estimated |
| general | 4.0 | questionnaire | adults | (Taylor, Jacobs et al. 1978) |
| competitive, in gymnasium | 6.0 | Douglas method | adults | (Jing and Wenyu 1991) |
| Walking | | | | |
| 2.5 mph | 3.5 | indirect calorimetry | adults$^{F}$ | (Anjos, Wohrlich et al. 2008) |
| 2.0 mph | 2.9 | accelerometery | adults$^{M}$ | (Abel, Hannon et al. 2008) |
| 2.0 mph | 3.1 | accelerometery | adults$^{F}$ | (Abel, Hannon et al. 2008) |
| light effort | 2.9 | regression equation | youth | (Ridley and Olds, 2008) |
| moderate effort | 3.6 | regression equation | youth | (Ridley and Olds, 2008) |
| Weight Training | | | | |
| resistance training, 8-15 repetitions | 3.5 | indirect calorimetry | adults | (Phillips and Ziuraitis 2003) |
| squats, explosive effort | 5 | blood lactate | adults$^{M}$ | (Mazetti, Dourglass et al. 2007) |
| bench, leg press | 2.8 | indirect calorimetry, accelerometry | youth | (Harrell, JS et al. 2005) |
| health club exercise class | 7.8 | heart rate | adults | (Rixon, Rehor et al. 2006) |

*Notes: mph = miles per hour; m/s = meters per second; F = value represents female only sample; M = value represents male only sample*

Activities from Ainsworth et al., 2011

## CHAPTER 3: STUDY 1

### NEW INSIGHT FOR ACTIVITY INTENSITY RELATIVITY: METABOLIC EXPENDITURE DURING OBJECT PROJECTION SKILL PERFORMANCE[1]

[1]**Sacko, R.S.,** McIver, K., Brian A., Stodden D.F. (2018). New Insight for Activity Intensity Relativity, Metabolic Expenditure During Object Projection Skill Performance. *Journal of Sports Sciences.*

## Introduction

Physical Activity Guidelines state that adults should participate in 30 minutes of moderate-to-vigorous physical activity (MVPA) per day or 150 minutes per week and adolescence to participate in a minimum of 60 minutes or more of MVPA every day to achieve substantial health benefits (Haskell et al., 2007). However, only 20% of adults in the United States actually meet these guidelines (Prevention & Promotion, 2011). Performing activities that involve continuous/repetitive locomotor movements such as jogging or participating in activities like soccer or tennis are generally promoted to achieve these guidelines (Eisenmann, Wickel, Welk, & Blair, 2005; Farpour-Lambert et al., 2009; Nourry et al., 2005) as they have been noted to require high energy expenditure levels measured in "METS" (Ainsworth et al., 2011). A MET (metabolic equivalent of task) is the standard unit of energy expenditure and the physiological equivalent to the energy required during resting metabolism, or 3.5 mL of oxygen/kg of body weight/minute in adults (Jette, Sidney, & Blümchen, 1990). Activities that require at least 3 METS are classified as moderate intensity activity in adults, with >6 METS being classified as vigorous activities (Ainsworth et al., 2011; Passmore & Durnin, 1955). METS have traditionally been measured in a controlled laboratory setting, using a treadmill and fixed expired gas analyzing equipment that requires the user to remain in a structured environment. Advancements in portable gas analyzers allow for validated estimated measurement of METS in a variety of dynamic tasks by allowing for increased freedom of movement outside a controlled laboratory environment (Pinnington, Wong, Tay, Green, & Dawson, 2001).

The Compendium for Physical Activity has been used worldwide to provide researchers with activity intensity values in METS for activities that have established energy expenditure normative values (Ainsworth et al., 2011). A large variation in methods have been used to quantify MET values in the Compendium (e.g., indirect calorimetry, accelerometry, surveys), all of which have been accepted as a valid means to assess activity intensity. A noted limitation of this resource is that the Compendium does not estimate the energy cost of physical activity in individuals in ways that account for individual differences, notably the efficiency of movement, of which the activities are performed (Ainsworth et al., 2011). Thus, individual differences in energy expenditure for the same activity can be large and the true energy cost for an individual may or may not be close to the stated mean MET levels as presented in the Compendium (Ainsworth et al., 2011). An additional limitation in the Compendium is the lack of established MET values for the performance of discrete movements with a high neuromuscular demand that may occur intermittently or in a repetitive fashion. Some activities of a discrete nature listed in the Compendium (e.g., shot put, discus and hammer throw) are only estimated and do not relate to repetitive practice with short intervals between trials (Ainsworth et al., 2011). Examples of discrete movements with high neuromuscular demands provided by the Compendium includes performing a squat with an explosive effort (60-80% of 1RM), which yielded a range of 4.34-5.05 METS (Ainsworth et al., 2011; Mazzetti, Douglass, Yocum, & Harber, 2007). General resistance training (e.g., 8-15 repetitions of varied resistance) requires an effort of approximately 3.50 METS, but this MET value was only established in women (Ainsworth et al., 2011; Haddock & Wilkin, 2006). Both examples demonstrate that moderate intensity physical activity levels during the performance of discrete movements are possible.

Daily physical activity levels (measured via self-report and accelerometry) have been linked to activities (e.g., soccer, basketball, tennis) that require both repetitive locomotor skills (e.g., running, jumping, walking) as well as object projection skills (e.g., throwing, kicking, striking) (Ainsworth et al., 2011; Prevention & Promotion, 2011; Kozey, Lyden, Howe, Staudenmayer, & Freedson, 2010; Taylor, H. L et al., 1978). It is important to specifically understand how repeated performance of these various types of object projection skills contribute to activity intensity, and thus actual energy expenditure. Object projection skills are a subgroup of motor skills that are important for interacting with the environment in various capacities (Clark & Metcalfe, 2002). These skills require the ability to effectively execute the gross coordination of gross and fine movements necessary to project or strike an object (Clark & Metcalfe, 2002). The development of competence in object projection skills requires repetitive practice, which generally involves low work to rest intervals, as they are discrete skills that have a defined beginning and ending. Promoting high effort levels also is a prerequisite to developing advanced levels of object projection skills as the emergence of more advanced coordination patterns inherently includes the exploitation of neuromuscular mechanisms that necessitate high effort eccentric/concentric muscular contractions (Cattuzzo et al., 2016; Croix & Korff, 2013; Girard, Micallef, & Millet, 2005; Campbell, Stodden, & Nixon et al., 2010; MacWilliams, Choi, Perezous, & McFarland, 1998). In essence, the performance of object projection skills involve complex multi-joint movements that involve high neuromuscular demand (e.g., the coordination and control of large muscle groups in rapid succession)

(Girard et al., 2005; Holfelder & Schott, 2014; Pandy & Zajac, 1991; Rodacki, Fowler, & Bennett, 2002; Stodden, Langendorfer, Fleisig, & Andrews, 2006b) that produce high movement speeds and power (Stodden, Langendorfer, Fleisig, & Andrews, 2006a; Stodden et al., 2006b) because they are generally produced with high effort and activate large muscle groups. Object projection skills are serially repeated in the context of leisure play, game play and/or practice and specific skill training. Neuromuscular demands associated with the object projection skill performance are substantially higher than repetitive cardiorespiratory activities of moderate intensity (e.g., jogging) suggesting that energy expenditure would also be high when these type of skills are repeated in a play, practice or training context (Girard et al., 2005; Reid & Schneiker, 2008). This type of intermittent high effort activity is a noted limitation in accelerometry-based assessment of physical activity that uses various epochs (e.g., 10, 15, or 60 seconds) that are extrapolated to activity intensity and thus, energy expenditure (Hooker et al., 2011; Trost, McIver, & Pate, 2005). However, movement examples with these types of limitations have generally been restricted to activities such as resistance training. Current recommendations for obtaining MVPA for adults include activities that purportedly demand high neuromuscular effort (e.g., basketball, soccer, tennis), but the neuromuscular effort and energy expenditure may be different based on the types of movements produced in these different activities (MacWilliams et al., 1998; Escamilla & Andrews, 2009; Campbell et al., 2010; Lees, Asai, Andersen, Nunome, & Sterzing, 2010). For example, an extended rally of effortful forehand volleys in tennis may require a different effort than a single maximal kick in soccer performed in unison with running, both of which require numerous effortful repetitions during years of practice. Thus, if MVPA is assumed to be correlated with actual

MET values, then many ballistic discrete tasks that would seem to demand high amounts of energy to perform may have been greatly undervalued (or unobserved) in their ability to contribute to the accumulation of MVPA throughout a day. In fact, to the authors' knowledge, the measurement of energy expenditure of discrete skill performances using indirect calorimetry has not even been attempted. Rather, MET interpolations for activities which are associated with object projection skill performance have only been estimated (Ainsworth et al., 2011).

Currently, there are no established MET values associated with object projection skill performance in adults. An understanding of the intensity levels associated with the practice of object skill performance may provide evidence of a method for the achievement of daily recommendations of MVPA and may be critical to advancing knowledge and the understanding of the types of developmentally appropriate activities that are health-enhancing from a metabolic expenditure perspective. Thus, the purpose of this study is to examine the metabolic expenditure associated with the performance of object projection skills.

## Methods

### *Participants and Setting*

A convenience sample of 40 18-30 year-old adults (20 men; *m*=23.9 yrs., 20 women; *m*=24.0 yrs.) participated in this study. The University Institutional Review Board granted permission for the researchers to conduct the study and participants completed informed consent and a Health History Questionnaire to qualify for participation. Participants who were under the care of a physician that excluded them from physical activity (e.g., heart condition, chest pain, injury, pregnancy, chronic illness) were not allowed to participate. Other exclusion criteria included those: (a) who were taking prescription or non-prescription medications or used an inhaler (b) who had high blood pressure or cholesterol (c) who had suffered a seizure, asthma, lung disease, vertigo, diabetes (d) who were a smoker or (e) who for any reason could not participate in physical activity were not allowed to participate. Participants self-identified their race/ethnicity as 85% Caucasian, 13% African-American, and 2% Asian/Pacific Islander. Testing occurred in an indoor research laboratory that was 40 feet long, 20 feet wide and had ceilings which were 20 feet high to accommodate unrestricted skill performance.

***Study Design***

A within-subjects crossover design was used to examine energy expenditure during three nine-minute bouts of varying intervals of object control skill performance (kicking, throwing and striking). Anthropomorphic measures (i.e., mass, body fat percentage, height) were collected prior to testing by trained staff with participants wearing light weight workout clothing without shoes. Participants performed a general warm-up prior to testing which included dynamic flexibility exercises related to the specific assessments and a self-determined number of repetitions performing each specific skill. Each participant completed three experimental sessions (i.e., 3 motor skill interval sessions) in a randomized order over two sessions separated by no less than 48 hours. Height was measured using a portable stadiometer to the nearest 0.1 cm. Mass was measured using an electronic scale (TANITA, SC-331S) (Kelly & Metcalfe, 2012).

***Metabolic Testing***

In each motor skill interval session, participants repeatedly performed five trials of three skills (kicking, throwing and striking) in blocked fashion for nine minutes. The blocked design was utilized to limit the number of consecutive repetitions of one skill in order to reduce the likelihood of injury from acute fatigue. Three different performance interval sessions were conducted (i.e., 6, 12, or 30-second rest interval schedules) to examine the differential metabolic response to each interval schedule. The interval schedules were determined to cover a spectrum of potential trial schedules that range from more intense (i.e. 6-second intervals) to less intense intervals (i.e. 30-second intervals) that would be expected in different practice, training, or physical education environments. Participants were instructed to consume normal meals on testing days and to avoid the consumption of food or caffeinated beverages at least two hours prior to testing to reduce diet-induced thermogenesis. Participants were asked to report their most recent meal time upon arrival on each testing day. On the first day of testing, participants were familiarized with all testing procedures. In addition, anthropometric and resting state energy expenditure were collected on day one along with one of the three interval trials (in random order). On the second day of testing, participants completed the remaining two interval conditions in random order. Participants performed five trials of each skill (blocked fashion for all three skills) at the selected time interval which were repeated until the completion of a nine-minute interval. A rest period of no less than 10 minutes in a seated position was allocated between each trial to allow for appropriate recovery to the standard resting metabolic rate of 3.5 ml/kg/min (Bielinski, Schutz, & Jequier et al., 1985; Sedlock, Fissinger, & Melby et al., 1989; Melby et al., 1993). During each minute of the session, participants reported a rating of perceived exertion (Romero-Ugalde et al.) using a 15-point scale to ensure participant safety (Borg, 1998). A foam ball (diameter = 21.6cm, weight = 185g; Rainbow® DuraCoat Squeeze™, Gopher, MN), a regulation size tennis ball (diameter = 6.7cm, weight = 56g; QuickStart® 78, Gopher MN) and a softball size plastic ball (diameter = 10.2cm, weight = 42g; ResisDent Ball, Gopher, MN) with an 'oversized' plastic bat (diameter = 11.4cm, length = 71.1cm, weight = 90.7g; Phenom™ bat, Gopher, MN) were used for kicking, throwing and striking respectively. These implements were chosen with a consideration to their similarity to a wide range of implements which may be used in physical education settings, for the safety of participants, and with consideration to limiting laboratory damage.

A COSMED K4b2 portable system for pulmonary gas exchange was used to collect expired respiratory gases on a breath-by-breath basis to measure oxygen consumption ($VO_2$ $kg^{-1} \cdot min^{-1}$) and METS (Duffield, Dawson, Pinnington, & Wong, 2004; Melby, Scholl, Edwards, & Bullough, 1993; Pinnington et al., 2001). The device was worn according to product specifications. The unit was calibrated with standard gases prior to each measurement session. Prior to each nine-minute interval session subjects, participants rested for a minimum of 10 minutes to allow a return to resting state metabolism (Melby et al., 1993). METS were averaged using data collected during minutes 4-8 of each nine-minute skill performance session. A nine-minute interval is long enough to allow for participant to reach a steady state metabolism and is consistent with calibration of standards for the COSMED K4b2 in MVPA testing (Pinnington et al., 2001).

Participants were prompted to begin their performance for each trial using a prerecorded set of instructions created by the authors. Participants were instructed to perform trials with maximum effort and were periodically reminded to perform maximally throughout each trial. Participants were allowed to approach each performance trial movement in a manner of their choosing (e.g., stepping approach). Immediately following the instructions the recording gave a 3-second count down prior to the sound of a beep that was set at intervals of 6, 12, or 30-seconds, depending on the specific interval session.

Descriptive statistics were calculated for the total sample and by sex and reported as means (± SD). Average METS in each interval condition were reported and a 3 (interval condition) by 2 (sex) ANOVA (SPSS, Chicago, IL) was conducted to examine differences in METS across groups and sex. Post hoc Bonferroni analyses were conducted to examine differences across condition and sex and a Bonferroni adjustment of the alpha level was made to account for any increase in type-1 error associated with multiple comparisons. Thus, an alpha level of $p < .01$ was used to determine significance. *Eta squared* was calculated and reported as a measure of effect size. SPSS Statistics for Windows, Version 23.0 (Chicago, IL: IBM Corp.) was used for data analysis.

**Results**

Data indicated a main effect between interval conditions ($F(5, 114) = 187.02$, $\eta^2 = 0.766$). Post hoc analyses demonstrated that decreasing interval times between performance trials yielded significantly ($p < .001$) and progressively higher metabolic expenditure across the three conditions. (Table 2).

There also was a main effect for sex ($F(5,114) = 187.02$, $p < .001$, $\eta^2 = 0.76$) with men demonstrating higher METS than women. Post hoc tests also indicated men yielded higher METS ($p<.001$) at each performance trial interval. MET data differences within intervals by sex are shown in Table 2.

Finally, there was an interaction for sex by interval condition ($F(5, 114) = 35.39$, $p < .001$, $\eta^2 = 0.05$) indicating men had higher METS with faster performance trial intervals at a rate higher than that of women.

**Discussion**

The purpose of this study was to examine energy expenditure, as assessed by indirect calorimetry (METS), during object projection motor skill performance at 6, 12, and 30-second trial intervals in young adults. Results from this study demonstrated that the average METS associated with the repetitive performance of object projection skill performance in both sexes during all trial intervals was greater than the value associated with moderate activity (3.0 METS). Further, men (9.14) and women (7.28) elicited METS associated with vigorous activity (>6.0 METS) during the 6-second interval condition and males (6.24) in the 12-second interval condition. This is the first study to demonstrate that motor skill performance, even at an interval of only two trials/minute, results in energy expenditure equating to the threshold of 3.0 METS required to achieve moderate-to-vigorous physical activity (MVPA). Logically, as the performance rest interval decreased, the metabolic demands placed on an individual would increase, which was demonstrated in this study as the shorter rest interval conditions dramatically increased energy expenditure demand (i.e., vigorous activity levels).

These data suggest that practicing object projection skills with at least two effortful trials per minute in settings such as games, and sports (i.e., practice and training) will provide enough of a metabolic response to be classified as MVPA. However, the noted limitations in how physical activity intensity levels are currently assessed (e.g., hip worn pedometers and accelerometers mainly assess repeated excursions of the center of mass) may lead to a drastic underestimation of energy expenditure in activities that include object control skills (e.g., soccer, overhand throwing and racquet games and sports) (Rowlands & Stiles, 2012). These data also suggest that practicing object projection skills with at a rate of at least 5-10 trials per minute could provide a metabolic response to be categorized as vigorous activity. An alternative to accumulating 150 minutes of moderate activity per week is the accumulation of 75 minutes of vigorous activity (Haskell et al., 2007). These data also have potential implications for children and warrants future research in children and adolescence.

Currently, no MET values for the repetitive practice of object projection motor skills have been established. These data indicate that the validity of accelerometry to accurately reflect the corresponding MET values in activities including these types of skills in isolation (i.e., specific skill practice) or in the context of game play (i.e., tennis, soccer, etc..) should be addressed. Further research is warranted to not only address questions surrounding the convergent validity of accelerometry with indirect calorimetry assessments, but also to determine the contribution of practice and performance of discrete motor skills on the achievement of recommended daily values of MVPA in activities performed by children as well as adults in games, leisure activities and sports that inherently involve object projection skills.

The role that skill level and/or actual effort level may play in the production of energy expenditure during discrete tasks is not yet fully understood and may play a role in metabolic expenditure during performance. While the impact of participant skill levels were not addressed in this study, perceived exertion levels as measured by 15 point RPE scale provided a general idea of effort levels. Overall, RPE decreased with increasing interval length, with the average RPE for each interval of 6s, 12s and 30s being 13 (±2), 11 (±2) and 9 (±2) respectively. Participants perceived exertion at each level corresponded with ratings of "somewhat hard" (6-second interval), "Light" (12-second interval), and "Very light" (30-second interval). These data suggest that more effort was required to perform more trials per minute and align with the MET data with respect to decreasing energy expenditure associated with increasing rest intervals between trials. However, it does not align with the actual MET data at each level. For example, the "Very light" RPE rating at the 30-second interval does not align with MET values of over 3.0 at the 30-second interval, which indicate a "moderate" level of energy expenditure. This was interesting in that overall, 18 out of 20 men and 17 out of 20 women participants averaged at least 3.0 METS required to achieve moderate PA. Thus, while participants performed skills with high effort levels, the rest intervals between trials seem to have been more influential on their relative perceptions of exercise intensity as well as their objective energy expenditure, which also did not align at any of the three interval conditions.

Overall, participants' metabolic expenditure while performing object control skills with high effort at three different intervals was moderate to vigorous, but their relative perceptions of exertion ranged from "very light – somewhat hard." With further study, this relative difference in perception of effort and actual energy expenditure may provide insight for the practice of object projection skills as an enjoyable alternative to continuous activities, specifically with older adults, as a medium for the achievement of MVPA.

***Limitations***

As previously noted, one limitation of this study includes a lack of understanding of the relative contribution of each skill toward the total production of energy expenditure.

The protocol utilized in this study alternated the performance of all three skills in blocked fashion (i.e., repeating five kick trials, then five throw trials, then five strike trials) across interval settings to reduce potential acute overuse and joint-related injury risk (e.g., throwing shoulder and elbow injury) as a result of high levels of repeated high effort trials of independent motions. Thus, this protocol limits the ability to make inferences of the metabolic contribution of each skill performance to total energy expenditure. All three skills are multi-joint ballistic skills with similar gross neuromuscular involvement and kinetic chain mechanisms. Thus; the individual energy expenditure contribution relative to each skill performance should be similar (Langendorfer, Roberton, & Stodden, 2011). Furthermore, no data was collected relating each participant's prior experiences or participation in the sports and physical education activities (e.g,. kicking – soccer/football; throwing – handball, baseball; striking – tennis, baseball) contained within this study. As a result, it is unknown how each participant's level of prior experience or technical skill may have contributed to total energy expenditure during each trial session. A second limitation of this study relates to the mass of each implement used for each object projection skill performance. Each type of ball used in this study (e.g., kicking - foam ball (185g), throwing – tennis ball (56g), striking – plastic ball (42g) had masses that were lower than some examples of commonly used counterparts in sport (e.g., kicking – football (420g), throwing – handball (425g), striking – baseball (142g). A third limitation of this study is the possibility that diet-induced thermogenesis may have altered MET values during the performance of interval trials if suggested procedures were not followed by participants prior to testing. Finally, a contributing factor that may influence MET values is an individual's motivation to perform with maximal effort. Although instructions to perform with maximal effort were continually provided to individuals throughout the sessions, 'maximal effort' performance is relative to each performer.

***Implications for instruction and practice***

At this time, the most recent version of the Compendium for Energy Expenditures for Youth (CEEY) does not contain MET measures that align with the practice of object projection motor skills (Lyden, Keadle, Staudenmayer, Freedson, & Alhassan, 2013; Ridley & Olds, 2008; Sasaki et al., 2016). Although the majority of the MET data (65%) presented in the current CEEY for activities are based on the adult data provided in the adult (Ridley, Ainsworth, & Olds, 2008), the authors recommend that the validity of these data only apply to adults. This parallels the CEEY recommends that the validity of energy expenditure in physical activities in children should be based on measures derived from children's data (Ridley et al., 2008). Thus, while these data on young adults is interesting with respect to understanding the relative exercise intensity when performing object projection skills, understanding children's energy expenditure when performing these skills in children is even more intriguing. In an effort to achieve recommended values of MVPA in accordance with guidelines set forth by various governing bodies, the potential contribution to daily energy expenditure that motor skill performance can provide via practice/training, leisure games physical education and sport activities should not be overlooked. The practice and promotion of developmentally appropriate skill development activities is a critical aspect of child development that is integrated into various games, sports, as well as leisure recreation activities. These skills also are integrated into various activities that are promoted across the lifespan (Breuer & Wicker, 2009).

Activities such as walking, running and cycling are well documented for their ability to yield energy outputs equivalent to MVPA; however, these data indicate that the practice of object control skills provide an alternative means to contribute to the achievement of recommended levels of MVPA. This alternative may be preferred by many who have previously developed the skill required for participation in activities that require object control skills to achieve recommended levels of MVPA throughout their lifespan (Breuer & Wicker, 2009). If activities that integrate object control skills require the execution of those skills at a rate of two/minute (with relatively high effort), regardless of any other simultaneous locomotor activity, these data indicate they will be demonstrating MVPA. From a learning or training perspective, the practice of object control skills at a rate of no less that two repetitions every minute provides ample time for PE teachers, coaches or trainers to instruct a performer and provide feedback that is critical to skill development while allowing for the attainment of energy expenditure to reach a threshold in accordance with recommended values of MVPA.

**Conclusion**

This study is the first study to measure energy expenditure levels during fundamental motor skill performance using indirect calorimetry. Results indicate skill practice with a maximum of one trial every 30 seconds resulted in the equivalent of at least moderate PA and intervals of 12 and 6 seconds demonstrated vigorous PA for most individuals. These data have the potential to impact physical activity intervention strategies by informing curricular content of interventions attempting to promote moderate to vigorous PA. Trial intervals used in this study represent varying levels of practice intervals which may be utilized by practitioners when designing movement interventions.

Information gleaned from this study provides evidence that the practice of fundamental motor skill performance can aid in the achievement of recommended levels of MVPA that are health enhancing from a metabolic expenditure (i.e., PA intensity) perspective.

***Disclosure of interest***

The authors report no conflicts of interest.

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TABLE 3.1. Descriptive characteristics of the study participants (mean ± SD).

| | Female (N = 20) | Male (N = 20) | Total (N = 40) |
|---|---|---|---|
| Body mass (kg) | 71.2 ± 14.0 | 82.6 ± 16.7 | 77.3 ± 16.2 |
| Height (cm) | 166.7 ± 5.7 | 176.0 ± 5.3 | 171.4 ± 7.2 |
| Age (years) | 23.6 ± 2.4 | 23.9 ± 3.2 | 23.7 ± 2.9 |
| Body mass index ($kg \cdot m^{-2}$) | 25.7 ± 4.8 | 27.4 ± 3.3 | 26.7 ± 4.1 |

TABLE 3.2. Measured gross energy expenditure (METS)

| Interval Condition | Female Mean | Female SD | Male Mean | Male SD | Total Mean | Total SD |
|---|---|---|---|---|---|---|
| 6 seconds | 7.28 | 1.41 | 9.14 | 1.33 | 8.21 | 1.03 |
| 12 seconds | 5.13 | 1.03 | 6.24 | 1.30 | 5.69 | 1.28 |
| 30 seconds | 3.14 | 0.43 | 3.76 | 0.77 | 3.45 | 0.69 |

Measured MET (metabolic equivalent of task) values represent the mean of minutes 4-8 of each session

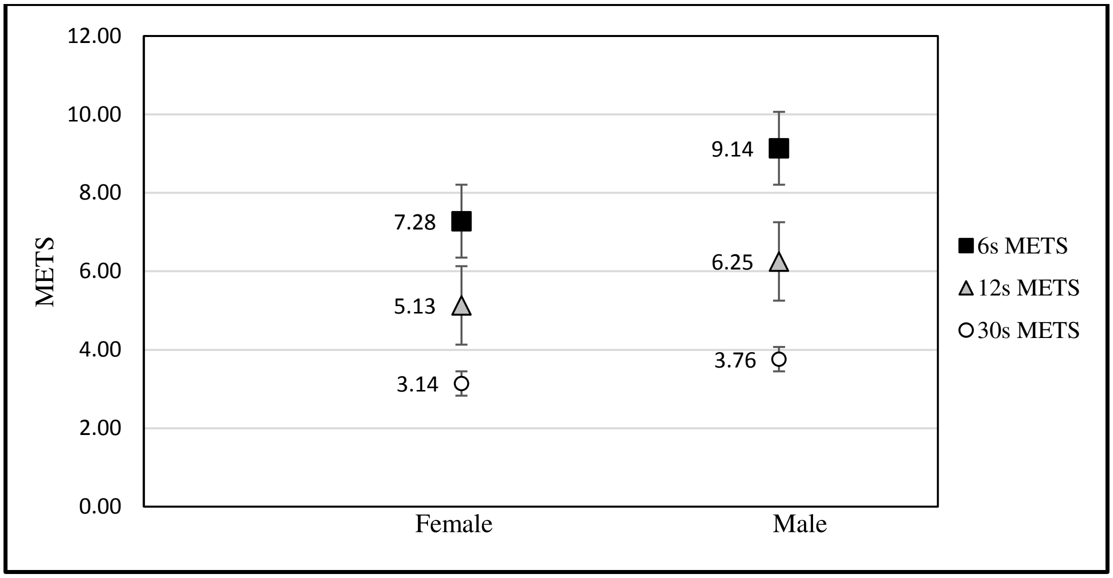


*Figure 3.1*. Measured mean MET (metabolic equivalent of task) values measured during 6, 12, and 30 second trial intervals.

# CHAPTER 4: STUDY 2

## COMPARISON OF INDIRECT CALORIMETRY- AND ACCELEROMETRY-BASED ENERGY EXPENDITURE DURING OBJECT PROJECTION SKILL PERFORMANCE[1]

[1]**Sacko, R.S.,** Brazendale, K., Brian, A., McIver, K., Nesbitt, D., Pfeifer, C., Stodden D.F. (in-review). Comparison of Indirect Calorimetry- and Accelerometry-based Energy Expenditure During Object Project Skill Performance. (*Measurement in Physical Education and Exercise Science.)*

**Introduction:**

Accelerometers were developed to address the need for accurate, objective, and versatile assessment of time spent in, and intensity levels of, physical activity (PA) in large scale epidemiological studies (Chen & Bassett, 2005; Melanson Jr & Freedson, 1995). Since their inception, the wide spread use of accelerometers has influenced our understanding of PA levels by revealing the lack of adequate PA levels in adults and children. Adults should accumulate a minimum of 150 minutes of moderate intensity PA (30 minutes a day, five times a week) per week or 75 minutes of vigorous intensity PA (15-20 minutes a day, four times per week) for the associated health benefits (Haskell et al., 2007), with aerobic types of PA (e.g., brisk walking or running) being suggested to meet these goals (Haskell et al., 2007; Nelson et al., 2007). Although numerous accelerometer calibration studies have been published to provide "cut-points" for the estimation of PA levels (e.g., moderate, vigorous), accurately quantifying PA intensities, (e.g. light, moderate and vigorous) remains a challenge to researchers and clinicians (Ainsworth et al., 2011; P. S. Freedson, Melanson, & Sirard, 1998; Kim, Beets, & Welk, 2012).

Cut-points are developed in calibration studies in which participants simultaneously wear an accelerometer and a standardized device (e.g., COSMED K4b2) used for estimation of energy expenditure (e.g., indirect calorimetry) while executing various forms of PA (e.g., walking, running, skipping) (Kim et al., 2012). The usefulness of accelerometers are dependent upon the selection of cut-points generally developed from studies that utilized similar types of movements. For example, cut-points derived from continuous activities (e.g., walking, running, skipping) should be used to evaluate physical activities that are also continuous. Objection projection skills (e.g., kicking, throwing, and striking), which are an integral part of many games, sports and physical activities, are classified as discrete skills (i.e., having a distinct beginning and end). At this time, cut-points developed from object projection skill performance (OPSP) do not exist. Thus, accelerometers may prove to be limited in their ability to accurately categorize PA intensity levels (e.g., light, moderate, and vigorous) when cut-points derived from continuous activities are applied to the evaluation of PA that involves the performance of discrete skills.

Many studies have attempted to validate accelerometers in laboratory and free-living conditions in order to estimate energy expenditure (EE). Such validation studies have examined different populations across various types of activities with algorithms that transform accelerometer activity “counts” (output unit of accelerometers) to METS (metabolic-equivalence of task) (Lyden, Kozey, Staudenmeyer, & Freedson, 2011). Accelerometers measure variations in movement and have been associated with the movement of an individual’s center of mass, as accelerometers have most often been worn close to an individual’s center of mass (i.e., hip) (Trost, McIver, & Pate, 2005). The movement signal is filtered, rectified, and integrated through a user-specified time interval called an “epoch” (Trost et al., 2005). Activity “counts” converted from the accelerations over a given “epoch” (e.g., 60 seconds, 15 seconds, 10 seconds), are the numerical representation of the total number of accelerations recorded to the accelerometers internal memory (Kim et al., 2012). The most commonly used adult cut-points (accelerometer worn on the hip) were developed by Freedson et al. (1998), which were based on the linear relationship that exists between measured vertical accelerations of the body and EE during locomotion (P. S. Freedson et al., 1998). Since 1998, researchers have attempted to develop sophisticated regression techniques to address the inaccuracies of PA measurement, which exist, in part, based on the fact that this linear relationship (i.e., vertical accelerations of the body and EE during continuous skill performance) is not as robust during discrete skill performance (Crouter, Clowers, & Bassett, 2006; Lyden et al., 2011). Regression models predict EE by expressing average counts during a period of time (i.e., epoch, 60 seconds, (P. S. Freedson et al., 1998) in categorical form (i.e., light, moderate, vigorous), or by translating them into a universal unit such as METS. Activities that require at least 3 METS are classified as moderate intensity activity in adults, with > 6 METS being classified as vigorous activities (Ainsworth et al., 2011).

Current recommendations for activities that promote adequate EE (i.e., Moderate-to-Vigorous Physical Activity - MVPA) levels include OPSP (e.g., soccer, tennis), but the contribution of OPSP performance to the total EE during these activities has not been assessed. OPSP involves complex multi-joint movements that demand high neuromuscular involvement during performance (Ainsworth et al., 2011; Butte et al., 2017; Haddock & Wilkin, 2006; Mazzetti, Douglass, Yocum, & Harber, 2007) as they activate large muscle groups and are generally produced with high effort levels. Neuromuscular demands associated with OPSP (e.g., kicking, throwing, striking) are substantially higher than repetitive (i.e., continuous) cardiorespiratory activities of moderate intensity (e.g., brisk walking or running) suggesting that EE would also be high when OPSP is repeated in a play, practice or training context (Campbell, Stodden, & Nixon, 2010; Duffield, Dawson, Pinnington, & Wong, 2004; Escamilla & Andrews, 2009; Holfelder & Schott, 2014). In fact, EE levels during the repetitive practice of OPSP has recently been shown to be equivalent to MVPA (≥ 3 METS) in adults when performed at intervals of as few as two trials per minutes (Sacko, McIver, Brian, & Stodden, In-press).

Evaluation of EE associated with OPSP is important as the development of skilled performance relies on repetitive practice with high levels of effort. Specifically, MET levels associated with OPSP performance have recently been calculated to be between 3.4 and 8.1 METS, depending on the rate of performance trials (Sacko et al., In-press). However, due to periods of relative inactivity that occur between high effort activity trial repetitions, it may be possible that commonly used accelerometer cut-points underestimate EE levels associated with OPSP (Hooker et al., 2011; Trost et al., 2005). If accelerometry-based MVPA values are assumed to be correlated with actual MET values, then many OPSP activities that require high amounts of energy to perform may be greatly undervalued; specifically in their ability to contribute to the accumulation of MVPA based on repetitive trials produced during practice and play. Thus, the purpose of this study was to compare energy expenditure (EE) levels during object projection skill performance (OPSP) as assessed by indirect calorimetry and accelerometry.

**Methods:**

***Participants***

A convenience sample of thirty-four adult aged (18-30 year-old) individuals volunteered for the purposes of this study (18 females; *M-age*: 23.5 yrs., *SD* = 2.5). The study was approved by the University of South Carolina's Institutional Review Board and ethical treatment of participants was followed. Participants provided consent and completed a Health History Questionnaire to determine eligibility for participation (see

Sacko et al., In-press for a review of procedures). Participants self-identified their race/ethnicity as 83% Caucasian, 14% African-American, and 3% Asian/Pacific Islander. Testing occurred in an indoor research laboratory that accommodated unrestricted skill performance (12.19 x 6.10 x 6.10 meters).

A within-subjects crossover design was used to examine EE during three nine-minute sessions of varying intervals (6, 12, and 30 seconds) of OPSP (kicking, throwing and striking) and one session of running at a self-selected pace. Anthropomorphic measures (i.e., mass, height) were collected prior to testing by trained staff with participants (presented in Table 1) wearing light workout clothing without shoes. Participants performed a general warm-up prior to testing which included dynamic flexibility exercises related to the specific assessments and a self-determined number of repetitions performing each specific skill. Each participant completed four experimental sessions (i.e., 3 motor skill interval sessions, 1 self-selected running) in a randomized order over two sessions separated by no less than 48 hours to minimize likelihood of fatigue induced alterations in performance. Participants were instructed to consume normal meals on testing days and to avoid the consumption of food or caffeinated beverages at least two hours prior to testing to reduce diet-induced thermogenesis.

***Procedures***

In each of the three object projection skill interval sessions, participants were asked to repeatedly perform five maximum effort trials of three skills (kicking, throwing and striking) in blocked fashion for nine minutes. Three different performance interval sessions were conducted (i.e., 6, 12, or 30-second rest interval schedules) to examine the differential metabolic responses to each interval schedule. The interval schedules were chosen to cover a spectrum of potential trial schedules that range from more intense (i.e., 6 second intervals) to less intense intervals (i.e. 30 second intervals) that would be expected in different practice, training, or physical education environments.

On the first day of testing, participants were familiarized with all testing procedures, and the following were collected: anthropometric data, resting state EE and two of the four interval sessions (randomized order). On the second day of testing, participants completed the remaining two randomized interval session conditions. During OPSP sessions, participants performed five kicks, five throws, and five strikes (blocked fashion of all three skills) at the selected time interval (i.e., perform once every 6, 12, or 30 seconds), which were repeated until the completion of a nine-minute interval. During the running session, participants were asked select a pace which they "could perform comfortably without stopping for 9 minutes." Participants were allowed to self-adjust the speed of the treadmill during the first 3 minutes of testing. For OPSP and running sessions, a rest period of no less than 10 minutes was allocated between each session to allow for appropriate recovery to resting metabolic rate (Sedlock, Fissinger, & Melby, 1989). A foam ball (diameter = 21.6 cm, weight =185 g; Rainbow® DuraCoat Squeeze™, Gopher, MN), a regulation size tennis ball (diameter = 6.7 cm, weight = 56 g; QuickStart® 78, Gopher MN) and a softball size plastic ball (diameter = 10.2 cm, weight = 42 g; ResisDent Ball, Gopher, MN) with an 'oversized' plastic bat (diameter = 11.4 cm, length = 71.1 cm, weight = 90.7 g; Phenom™ bat, Gopher, MN) were used for kicking, throwing and striking respectively. These implements were chosen with a consideration for the safety of participants and lab constraints. Participants were prompted to begin their performance for each trial using a prerecorded set of instructions created by the authors. Participants were instructed to perform each OPSP trial with maximum effort and were periodically reminded to perform maximally throughout the duration of each nine minute OPSP session. Participants were allowed to approach each performance trial movement in a manner of their choosing (e.g., stepping approach). Immediately following the instructions the recording gave a 3-second count down prior to the sound of a beep that was set at intervals of 6, 12, or 30 seconds, depending on the specific interval session.

***Indirect Calorimetry***

A COSMED K4b2 portable system for pulmonary gas exchange was used to collect expired respiratory gases on a breath-by-breath basis to measure oxygen consumption ($VO_2$ $kg^{-1} \cdot min^{-1}$) and METS (Bielinski, Schutz, & Jequier, 1985). The K4b2 unit was calibrated with standard gases prior to each measurement session and was worn according to product specifications (Cosmed, 1998). METS were averaged using data collected during minutes 4-8 of each nine-minute skill performance session. A nine-minute interval is long enough to allow for the participant to reach a steady state metabolism and is consistent with calibration of standards for the COSMED K4b2 in MVPA testing (Bielinski et al., 1985; Duffield et al., 2004; Lay, Sparrow, Hughes, & O'Dwyer, 2002; Lucia, Fleck, Gotshall, & Kearney, 1993; McLaughlin, King, Howley, Bassett Jr, & Ainsworth, 2001; Melby, Scholl, Edwards, & Bullough, 1993; Pinnington, Wong, Tay, Green, & Dawson, 2001; Sedlock et al., 1989)

***Accelerometry***

EE was estimated using an accelerometer (ActiGraph GT3X+, ActiGraph, Pensacola, FL) worn on the right hip. METS were calculated using cut points that delineated various intensities of PA (e.g., light, moderate, vigorous) and were established for adults (i.e., Freedson et al., 1998). The accelerometer was initialized using the sampling rate of 100 Hz and downloaded in epoch lengths of 1 second. The results were downloaded using ActiLife (Pensacola FL Version 6.11.2) software. The accelerometry evaluation time of each trial interval was matched with the same period of time (i.e., minutes 4-8) used for MET evaluation. All data was converted to average counts per one minute and transformed to METS using the equation developed by Freedson et al., (1998).

$$\text{METS} = 1.439008 + (0.000795 \text{ x counts min}^{-1})$$

Data was classified as light (100-1951counts $\text{min}^{-1}$, < 3 METS), moderate (1952-5724 counts $\text{min}^{-1}$, 3-6 METS), vigorous (5725-9498 counts $\text{min}^{-1}$, > 6 METS), or very vigorous (> 9499 counts $\text{min}^{-1}$, > 9 METS).

***Data Analysis***

Participant descriptive statistics were calculated for the total sample and by sex and reported as means (+/- SD) in Table 1. One samples t-tests were conducted to examine whether accelerometry estimated METS were significantly different than METS derived from indirect calorimetry. METS estimated by indirect calorimetry were used as the criterion measure for comparison to METS predicted by accelerometry. We used Bland-Altman plots to analyze the agreement between accelerometry (estimated METS, Freedson et al., 1998) and indirect calorimetry (METS) (Bland & Altman, 1986). The agreement between accelerometry predicted METS and indirect calorimetry MET values were depicted by plotting the difference between two measures (e.g., accelerometry estimated METS minus indirect calorimetry METS) against the mean of the two measures (e.g., accelerometry estimated METS and indirect calorimetry METS). The mean error score (solid line) and the 95% prediction intervals (dashed line) are shown graphically. (Figures

1-4). An agreement between accelerometry estimated METS and indirect calorimetry METS are represented by data points clustered tightly around zero. Data points above zero indicate an overestimation of METS by accelerometry while data points below zero indicate an underestimation. All statistical procedures were conducted using IBM SPSS software (Version 23.0; IBM, Armonk, NY USA) with a significance level of alpha $\leq$ .05.

**Results**

The average EE estimated by accelerometry and by indirect calorimetry can be seen in Table 2.

One sample t-tests (Table 3) indicated statistically significant differences between accelerometry-based MET estimations and indirect calorimetry derived MET levels during object projection skill performance. One sample t-tests indicated no statistically significant differences between accelerometry and indirect calorimetry MET levels during the running interval.

Bland-Altman plots (Figures 1 - 4) illustrate the lack of agreement between accelerometry-based MET estimations and METS measured via indirect calorimetry. Accelerometers did not reach the thresholds of MVPA (1952-5724 counts $min^{-1}$) set by Freedson et al., (1998) cut-points; 30s ($r = 0.94$, $P < .001$), 12s ($r = 0.96$, $P < .001$) and 6s ($r = 0.96$, $P < .001$). Overall, EE of OPSP estimated by accelerometry was dramatically less than assessed via indirect calorimetry at all three levels. Accelerometry-based MET estimations were $\leq$ 1.7 METS for all skill conditions, which indicates minimal activity above resting metabolic rate (1.0 METS). However, accelerometry and indirect calorimetry were in agreement during the self-selected running condition ($r = 0.02$, $P < 0.05$).

The categorization of exercise intensity levels (e.g., light, moderate, vigorous) by indirect calorimetry (METS) and accelerometry (counts per min) was compared and presented in Table 3. The categorization of PA level by accelerometery failed to demonstrate concurrent validity with the criterion EE assessment (indirect calorimetry) during all OPSP intervals. The underestimation of METS by accelerometry increased exponentially as the performance interval decreased from 30 second interval sessions (-1.7 METS) to 6 second intervals (-5.6 METS). Accelerometry categorized the level of activity as 'light' for each OPSP trial while the METS measured by indirect calorimetry indicated 'moderate' intensity PA during the 30s and 12s intervals and 'vigorous' during the 6 second trial. Accelerometry and indirect calorimetry during the running session were aligned (difference in METS = -0.04). PA during the running session was categorized as 'vigorous' intensity by both accelerometery and indirect calorimetry.

**Discussion**

The purpose of this study was to compare energy expenditure (EE) levels during object projection skill performance (OPSP) as assessed by indirect calorimetry and accelerometry. MET levels predicted from accelerometry were drastically lower compared to METS derived from indirect calorimetry (criterion measure) during all three OPSP interval conditions. Specifically, the discrepancy in mean differences in predicted MET levels between accelerometry and indirect calorimetry increased as the performance trial interval time decreased (i.e., 30s < 12 < 6s) (see Table 2). In alignment with the MET comparisons, the lack of agreement between the two assessments in predicting activity intensity levels (i.e., light, moderate and vigorous) also was clearly discernible (See Figure 5). Indirect calorimetry indicated that OPSP yielded an activity intensity level of ‘moderate’ during the 30s and 12s intervals and ‘vigorous’ during the 6 second trial, yet hip worn accelerometers predicted that only ‘light’ activity levels were accumulated. To better understand the consistency in MET levels reached by participants during OPSP, indirect calorimetry indicated that 31 of the 34 participants achieved the 6.0 METS needed obtain a ‘vigorous’ level of activity during the 6 second trial interval. Accelerometry also was consistent, but its consistency was noted in not being able to accurately predict OPSP intensity levels during the 6 second interval via MET prediction extrapolations and with cut-points. Accelerometry did not predict that any of the 34 subjects were above a ‘light’ activity level in either measurement. During the 30 second trial interval, indirect calorimetry also indicated that 31 of the 34 participates achieved the 3 METS required for classification of a ‘moderate’ activity level. Again, accelerometers did not place any of the 34 participants in the ‘moderate’ PA category. These global findings note the lack of impact that gender has on the comparisons between indirect calorimetry-based and accelerometry-based assessment of EE and PA intensity levels. This finding also illustrates the gross underestimation of accelerometry-based activity and EE levels during OPSP at different intensity levels as well as its inability to predict higher activity intensities (e.g., moderate, vigorous) during OPSP.

The initial comparison of calorimetry and accelerometry revealed that the assessment of activity intensity by both devices (COSMED K4b2, ActiGraph GT3X+) were in agreement during the continuous task of running. This was expected as Freedson et al., (1998) cut points were developed using a sample of adults of similar age (24.8 ± 4.2 years) at three different treadmill speeds (4.8, 6.4, and 9.7 $km \cdot h^{-1}$). An important reason for the gross underestimation estimation of intensity levels by accelerometry during OPSP is that the volume of accelerations associated with OPSP worn at the hip is far smaller than the volume of accelerations associated with a continuous activity during an equivalent amount of time (i.e., nine-minutes). In essence, oscillations occur continuously during the locomotor activities, thus producing a high accumulation of accelerations (i.e., counts). In contrast, oscillations produced during the repetitive practice of OPSP are intermittent (i.e. producing limited oscillations), producing limited oscillations (i.e., counts), yet are representative of high neuromuscular demand (high intensity) and thus, necessitates high levels of EE. It is therefore not surprising that this lower quantity of accelerations measured by accelerometers worn at the hip does not demonstrate MVPA, specifically when rates of OPSP are only two (30 second interval) or five (12 second interval) trials per minute.

While accelerometers used in this study did not fail to measure what they are intended to measure (i.e., number of movement accelerations at different intensities during nine-minute trials) they did fail to capture the EE associated with the neuromuscular demand of OPSP. Repetitive OPSP performed with high levels of effort involves repeated high eccentric/concentric muscular contractions in large muscle groups during total body, sequential kinetic chain movements. High neuromuscular demand is facilitated not only by volitional effort, but it is increased via the effective passive exploitation of neuromuscular mechanisms that are facilitated by high ground reaction forces and high segmental velocities produced through the kinetic chain high ground reaction forces (Campbell, Stodden, & Nixon et al., 2010; Cattuzzo et al., 2016; Croix & Korff, 2013; Girard, Micallef, & Millet, 2005; Langendorfer, Roberton and Stodden, 2011; MacWilliams, Choi, Perezous, & McFarland, 1998; Girard et al., 2005; Pandy & Zajac, 1991; Rodacki, Fowler, & Bennett, 2002; Stodden, Langendorfer, Fleisig, & Andrews, 2006a; Stodden et al., 2006b). The neuromuscular demands associated with OPSP also are substantially higher than repetitive cardiorespiratory activities of moderate intensity (e.g., brisk walking or running) (Girard et al., 2005; Reid & Schneiker, 2008). Thus, the importance of promoting activities that involve OPSP would seem to be beneficial, not only to impact acute levels of health-enhancing PA in adults, but also for children and adolescence, as there is strong evidence that the development of OPSP positively influences not only physical activity levels (Rodrigo A Lima et al., 2017) but also multiple aspects of health-related physical fitness (Cattuzzo et al., 2016; Rodrigo Antunes Lima et al., 2017; Rodrigues, Stodden, & Lopes, 2016) and body weight status (Cattuzzo et al., 2016; D'Hondt et al., 2013; D'Hondt et al., 2014; Rodrigo Antunes Lima et al., 2017; Lopes, Stodden, & Rodrigues, 2014; Martins et al., 2010; Rodrigues et al., 2016) in youth and health related fitness and body weight status in adults (Stodden & Brooks, 2013; Stodden, Langendorfer, & Roberton, 2009).

However, research has suggested historically that the contribution of intermittent repetitions of OPSP to the total EE recorded during game play has been noted as minimal (Botton, Hautier, & Eclache, 2011; Castagna et al., 2007; Ebine et al., 2002; Mohr, Krustrup, & Bangsbo, 2003; Potteiger, Blessing, & Wilson, 1992). In light of these findings, repetitive OPSP (performed in practice, training, or leisure activities) may provide an alternative, to continuous activities (brisk walking or running) to assist in accumulating recommended doses of MVPA associated with health-enhancing benefits. Monitoring activity accumulation with accelerometers worn on the wrist has been suggested as a method to increase accelerometer PA observation validity in children over that of hip-worn accelerometers (Evenson, Catellier, Gill, Ondrak, & McMurray, 2008; P.

Freedson, Pober, & Janz, 2005) due to the wrists association with upper body movement (Chandler, Brazendale, Beets, & Mealing, 2016). This same recommendation for using wrist-worn accelerometers may also be useful to test for adults; however, cut-points associated with MVPA for wrist-worn accelerometers (moderate ≥ 6360 counts $min^{-1}$ [Chandler et al., 2016]) are significantly higher than those of hip-worn accelerometers (moderate ≥ 2296 counts $min^{-1}$ [Evenson et al., 2008]) in children. Thus, the lack of validity in the measurement of EE or intensity levels during OPSP by accelerometers may, instead, still be a result of the neuromuscular demands of OPSP rather than a result of the wear location. Future research to develop cut-points, specifically for the use during OPSP, in both adults and children is warranted to address these measurement issues.

The authors would like to acknowledge some of the potential limitations of the current study. First, this study applied only the Freedson et al., (1998) cut-points for accelerometer validation. Although, these cut-points are widely used in adult literature and there is accessibility to transformation equations, the Freedson et al., (1998) cut-points represent a threshold for moderate (1952 ≥ counts $min^{-1}$) and vigorous (5725 ≥ counts $min^{-1}$) PA which are lower than more recently developed adult hip cut-points (Troiano et al., 2008) (moderate ≥ 2020 counts $min^{-1}$, vigorous ≤ 5999 counts $min^{-1}$). Thus, the use of cut-points with higher thresholds of categorization for PA would result in a greater disparity between accelerometry and indirect calorimetry. Second, a contributing factor that may influence MET values is an individual's motivation to perform. Participants were prompted to perform 'with maximal effort' throughout each interval session to maintain adherence to testing protocol. However, the instruction to perform 'with maximal effort' is relative to each performer. Third, as EE and counts were assessed via the combination of all three skills, the relative contribution of each skill to EE and counts were not addressed. However, all three skills (kicking, throwing, and striking) are multi-joint ballistic skills with similar gross neuromuscular involvement and kinetic chain mechanisms; thus, individual skill performance contribution relative to energy expenditure should be similar (Langendorfer, Roberton, & Stodden, 2011). Finally, this study did not examine the potential influence of individual skill level as it may relate to differences in the accumulation of accelerometer counts per minute. Participants were allowed to approach each performance trial movement in a manner of their choosing (e.g., no-step approach or stepping approach) therefore, performances associated with higher skill levels (i.e., stepping approach) may significantly increase individual counts per minute related to an increase in hip perturbations that resemble brisk-walking or running. Future research should address the potential influence of skill level on EE estimated by indirect calorimetry and categorical levels of PA estimated by accelerometry.

**Conclusions**

This study demonstrates that hip-worn accelerometers fail to adequately predict EE and thus, physical activity intensity (as assess by both METS and counts) during OPSP compared to indirect calorimetry. The allure of accelerometry for use in large scale PA studies is grounded in their perceived ability to provide an accurate and objective estimate of an individual's PA. However, the disparity in levels of PA measured by indirect calorimetry and accelerometry during OPSP in this study was considerably large. Results indicated skill practice with a minimum of just 2 trials per minute, as measured by indirect calorimetry, resulted in the equivalent of at least moderate PA, yet was only categorized as light activity by accelerometry. These data demonstrate that hip-worn accelerometer cut-points lack prediction validity of EE and physical activity intensity level (via accelerometry counts) during OPSP. As life-long PA begins at an early age with promotion of, and participation in a variety of activities that require the OPSP (e.g., soccer, tennis, kickball, handball, racquetball, basketball, softball, pickleball), the importance placed on developing object projection skills may impact physical activity participation well into adulthood (Breuer & Wicker, 2009). As such, the health-enhancing high levels of EE during repetitive OPSP represent an alternative to continuous activities (brisk walking or running) which may be utilized by adults for the accumulation of recommended amounts of moderate-to-vigorous physical activity.

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TABLE 4.1: *Descriptive characteristics of study participants (mean ± SD)*

| | Female ($n$ = 18) | | | Male ($n$ = 16) | | | Total ($N$ = 34) | | |
|---|---|---|---|---|---|---|---|---|---|
| Age (years) | 23.2 | ± | 2.4 | 23.8 | ± | 2.7 | 23.5 | ± | 2.5 |
| Body mass (kg) | 72.0 | ± | 14.4 | 82.0 | ± | 17.7 | 76.7 | ± | 16.8 |
| Height (cm) | 166.9 | ± | 6.1 | 175.5 | ± | 5.7 | 170.9 | ± | 7.3 |

TABLE 4.2: *Physical activity levels measured by indirect calorimetry and accelerometry during nine-minute sessions of running (self-selected pace) and object projection skill performance (30, 12, and 6 second intervals)*

| | Indirect Calorimetry | | Accelerometry | | |
|---|---|---|---|---|---|
| Interval | METS | PA Category | METS | PA Category | CPM |
| Running | 8.6 ± 1.0 | Vigorous | 8.6 ± 1.8 | Vigorous | 8955 ± 2327 |
| 30s | 3.4 ± 0.7 | Moderate | 1.8 ± 0.2 | Light | 396 ± 291 |
| 12s | 5.8 ± 1.2 | Moderate | 2.2 ± 0.4 | Light | 941 ± 480 |
| 6s | 8.3 ± 1.6 | Vigorous | 2.7 ± 0.6 | Light | 1628 ± 768 |

METS, metabolic equivalent of task; PA, physical activity; CPM, counts per minute;
SD, standard deviation
Categorical ranges for METS; < 3.0 METS = Light, 3.0-6.0 METS = Moderate,
> 6.0 METS = Vigorous
Categorical ranges for accelerometry; 100-1951 counts $min^{-1}$ = light, 1952-5724 counts $min^{-1}$ = moderate, 5725-9498 counts $min^{-1}$, = vigorous
*Note: All data is presented as an average per minute*

TABLE 4.3: *One-sample t-test difference of means, indirect calorimetry vs hip-worn accelerometry*

| | | | | | | | | 95% Confidence Interval of the Difference | |
|---|---|---|---|---|---|---|---|---|---|
| Interval | N | Mean Diff | Std. Deviation | *t* | *df* | Sig. (2-tailed) | Cohens *d* | Lower | Upper |
| Running | 34 | -0.04 | 1.65 | -0.13 | 33 | 0.90 | -0.05 | -0.61 | 0.54 |
| 30s | 34 | 1.69 | 0.64 | 15.31 | 33 | 0.001 | 5.33 | 1.46 | 1.91 |
| 12s | 34 | 3.59 | 1.06 | 19.64 | 33 | 0.001 | 6.84 | 3.22 | 3.96 |
| 6s | 34 | 5.63 | 1.59 | 20.69 | 33 | 0.001 | 7.2 | 5.08 | 6.19 |

*Note: Physical activity levels measured by indirect calorimetry and accelerometry (mean ± SD) during nine-minute sessions of running (self-selected pace) and object projection skill performance (30, 12, and 6 second intervals)*

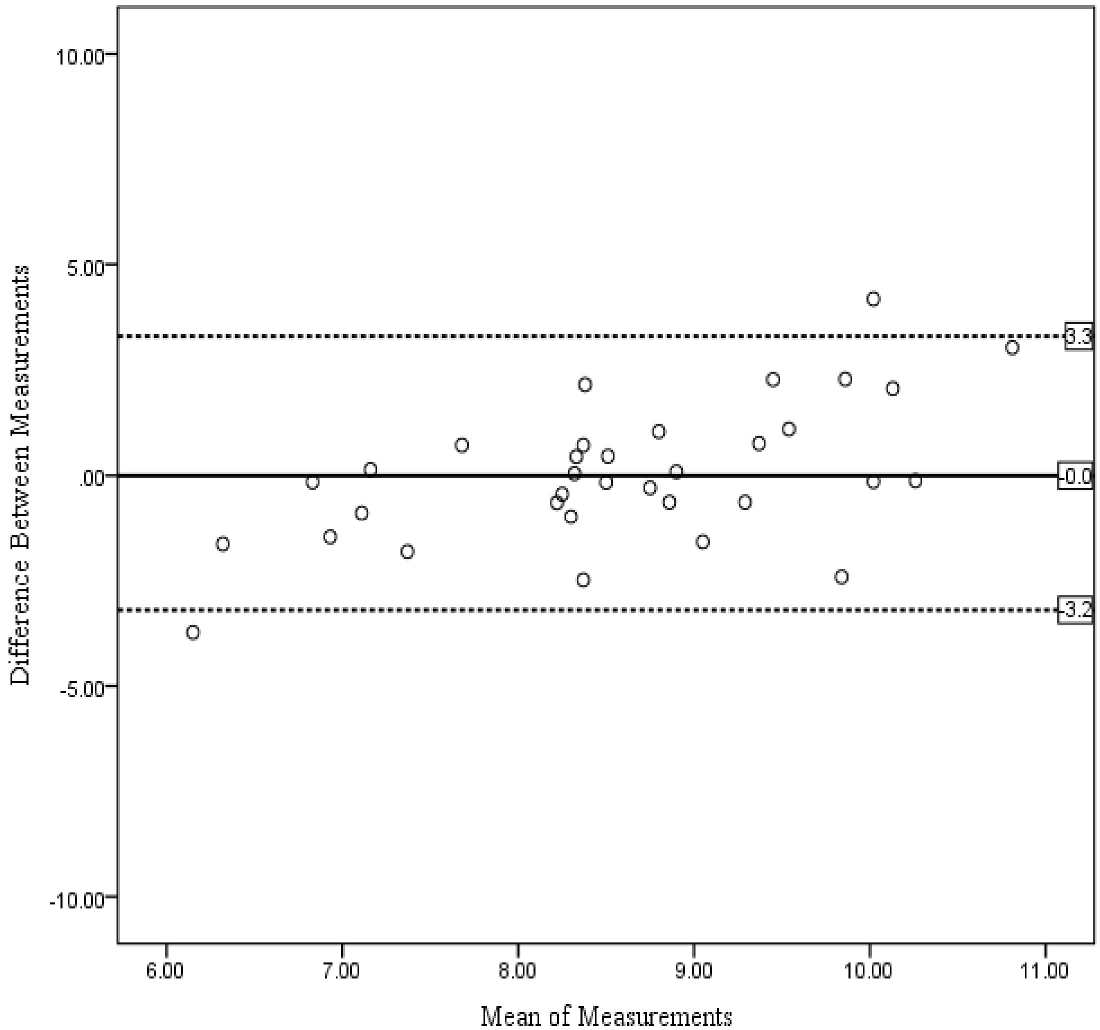


*Figure 4.1. Bland-Altman plot depicting error scores of METS estimated by hip-worn accelerometers (Freedson MET equation) vs indirect calorimetry (criterion measure) during the self-selected running interval session.*

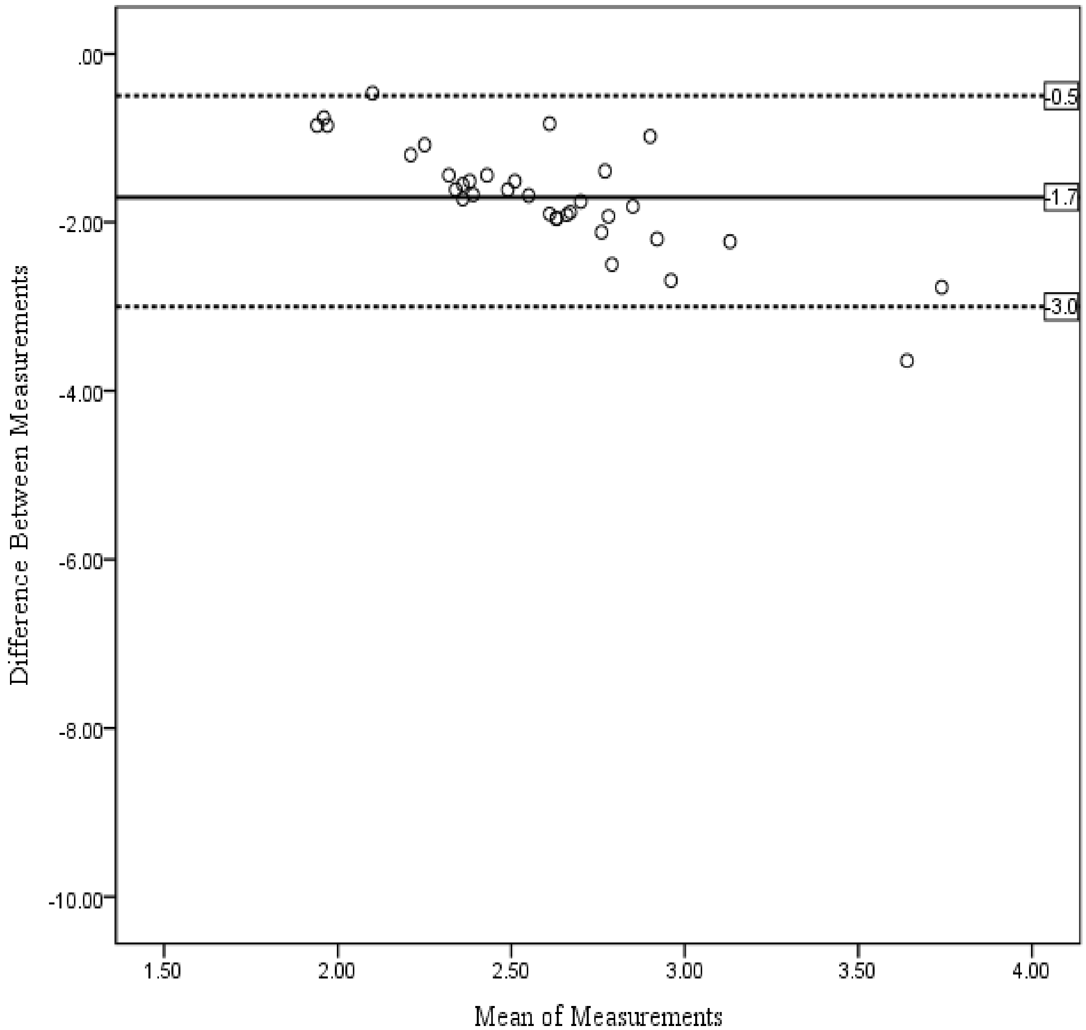


*Figure 4.2. Bland-Altman plot depicting error scores of METS estimated by hip-worn accelerometers (Freedson MET equation) vs indirect calorimetry (criterion measure) during the 30 second interval session.*

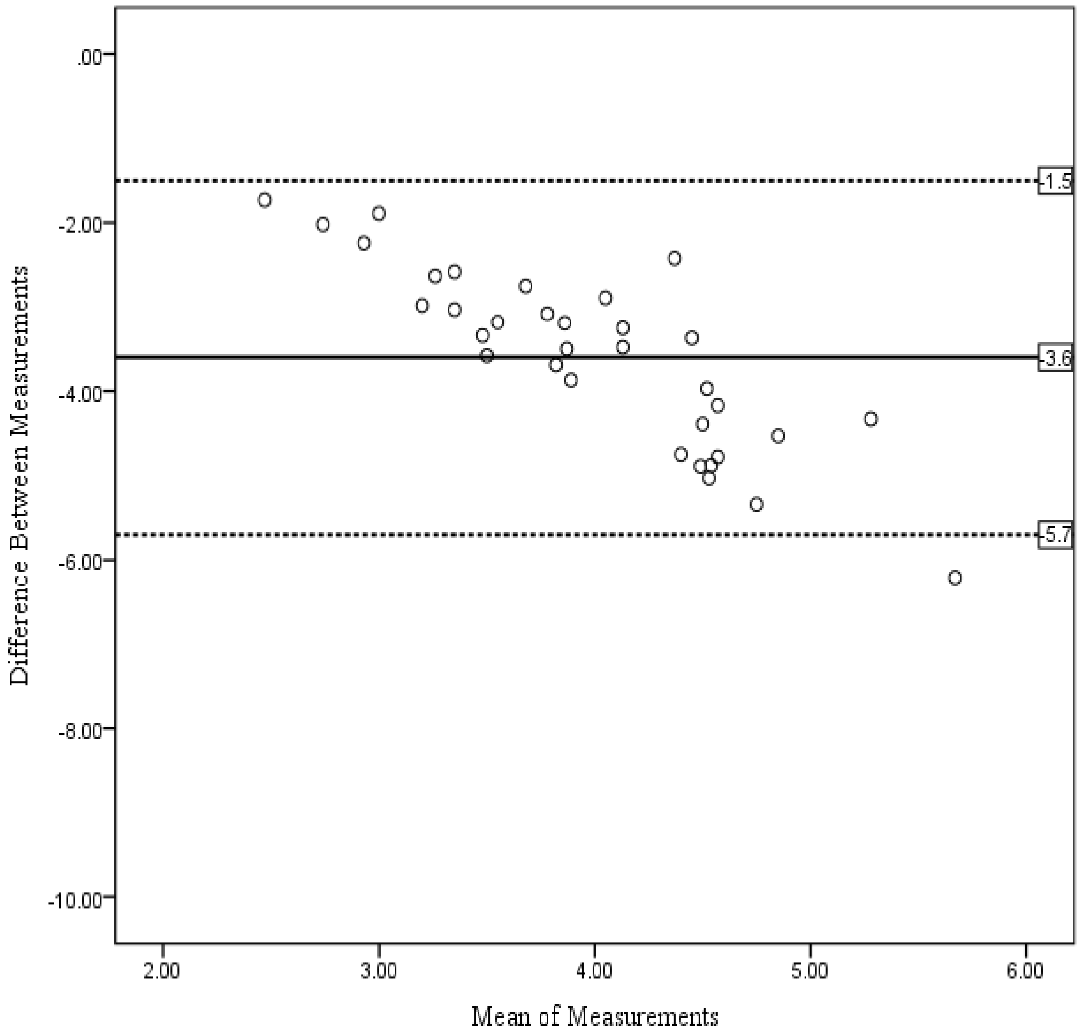


*Figure 4.3. Bland-Altman plot depicting error scores of METS estimated by hip-worn accelerometers (Freedson MET equation) vs indirect calorimetry (criterion measure) during the 12 second interval session.*

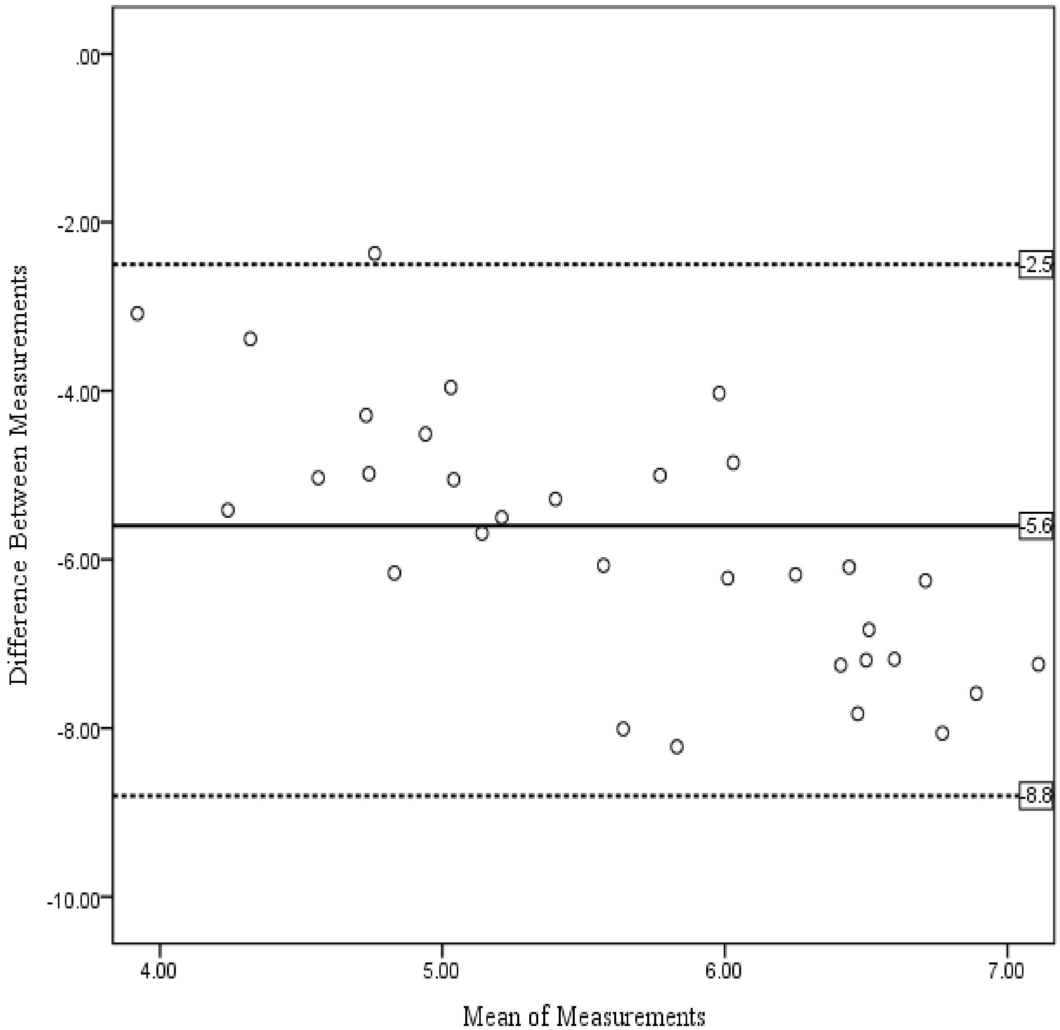


*Figure 4.4. Bland-Altman plot depicting error scores of METS estimated by hip-worn accelerometers (Freedson MET equation) vs indirect calorimetry (criterion measure) during the 6 second interval session.*

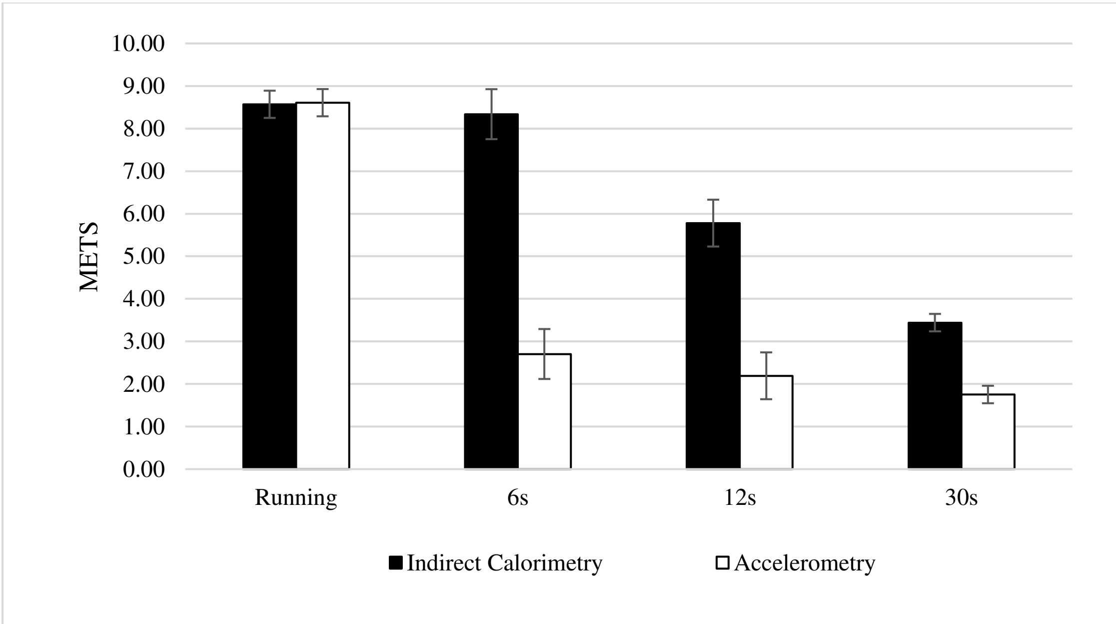


*Figure 4.5: Indirect calorimetry estimated METS (criterion measure) vs Accelerometry estimated METS during a nine-minute bout of running at a self-selected pace and object projection skill performance intervals (kicking, throwing, and striking) of one repetition every 6, 12, and 30 seconds.*

# CHAPTER 5: STUDY 3

## CHILDREN'S METABOLIC EXPENDITURE DURING OBJECT PROJECTION SKILL PERFORMANCE: NEW INSIGHT FOR ACTIVITY INTENSITY RELATIVITY[1]

[1]**Sacko, R.S.,** McIver, K., Brian, A., Nesbitt, D., Stodden D.F. (in-preparation). Children's Metabolic Expenditure During Object Projection Skill Performance: New Insight for Activity Intensity Relativity. (*Journal of Motor Learning and Development).*

## Introduction

Participation in physical activities enhance health and reduce chronic diseases related to sedentary behavior and obesity (Larouche, Boyer, Tremblay, & Longmuir, 2013; Laukkanen, Pesola, Havu, Sääkslahti, & Finni, 2014; Lloyd, Saunders, Bremer, & Tremblay, 2014) Physical Activity Guidelines recommend that children participate in a minimum of 60 minutes of moderate-to-vigorous physical activity (MVPA) every day to achieve substantial health benefits (C. Ogden, Carroll, Fryar, & Flegal, 2015; C. L. Ogden, Carroll, Kit, & Flegal, 2012). As much as 80% of children do not accumulate these recommended amounts of physical activity (PA) (Hallal et al., 2012; C. L. Ogden et al., 2012; Prevention & Promotion, 2011). The early childhood years are a critical time for the development of PA habits and the development of motor skills as they are the building blocks for more complex movements (Clark & Metcalfe, 2002; D. F. Stodden et al., 2008). Performing activities that involve continuous locomotor skills such as walking or running and participating in activities like soccer or tennis have been recommended to achieve Physical Activity Guidelines (Ainsworth et al., 2011) as the energy expenditure (EE) during these activities generally is high (Jette, Sidney, & Blümchen, 1990; Pinnington, Wong, Tay, Green, & Dawson, 2001) However, understanding how the performance of object projection motor skills (e.g., kicking, throwing, and striking) contributes to EE in children, either during specific practice or when integrated in game play, is not known. This is important as these skills are specifically practiced on their own (e.g., playing catch, physical education, sport practice) or within the context of many activities (e.g., ball games) in which children routinely participate.

Object projection skill performance (OPSP) involves complex multi-joint movements that demand high neuromuscular involvement (Gabbard, 2011; Laukkanen et al., 2014; Molina, 2015) as they activate large muscle groups and are generally produced with high effort. Neuromuscular demands associated with OPSP are substantially higher than repetitive cardiorespiratory activities of moderate intensity (e.g., jogging) suggesting that EE would also be high when these type of skills are repeated in a play, practice or skill training context (Campbell, Stodden, & Nixon, 2010; Duffield, Dawson, Pinnington, & Wong, 2004; Escamilla & Andrews, 2009). The development of competence in OPSP requires repetitive practice, which generally involves low work to rest intervals, as they are discrete skills that have a defined beginning and ending. Promoting high effort levels also is a prerequisite to developing advanced levels of object projection skills as the emergence of more advanced coordination patterns inherently includes the exploitation of neuromuscular mechanisms that necessitate high effort eccentric/concentric muscular contractions (Cattuzzo et al., 2016; Croix & Korff, 2013; Girard, Micallef, & Millet, 2005; Langendorfer, Roberton, & Stodden, 2011) that produce high GRFs and power (MacWilliams, Choi, Perezous, Chao, & McFarland, 1998; Orloff et al., 2008)

Children perform object projection skills with a wide range of skill levels; however, no research has addressed the impact that differing levels of skill has on EE in children. Higher performance levels of discrete skills are associated with improved coordination and more effective transfer of energy through the body (Lloyd et al., 2014; D. Stodden, Langendorfer, & Roberton, 2009). As a result, there are higher accelerations and limb speeds throughout OPSP and greater forces are required to not only accelerate, but also decelerate (i.e., eccentric loading, increased ground reaction forces) limbs and the performers center of mass during the completion of each individual OPSP (Girard et al., 2005; Langendorfer et al., 2011; MacWilliams et al., 1998; Orloff et al., 2008; Pandy & Zajac, 1991; Pfeifer, 2015; Roberton & Konczak, 2001; Tveter & Holm, 2010). These higher accelerations and decelerations are associated with high neuromuscular demand, necessitating high effort levels. Thus, it may be plausible that more highly skilled individuals demonstrate higher EE during OPSP as they may require greater EE, not only to effectively produce the performance outcome (i.e., accelerate limb segments), but also to effectively decelerate multiple limbs and their center of mass at the end of each OPSP.

The Youth Compendium for Physical Activity was developed to provide stakeholders with normative EE values for common physical activities (Butte et al., 2017) with specific consideration to children’s maturational differences (e.g., muscle mass to total mass ratio, pubertal changes) (Malina, Bouchard, & Bar-Or, 2004; Rowland, 2005). The Youth Compendium uses pediatric data exclusively to address limitations of The Compendium for Physical Activity (Ainsworth et al., 2011) , that is informed by adult specific data. An important difference in the compendia is that children’s metabolic equivalent of task (METS) values are higher (4.0 METS = moderate, ≥ 7.0 METS = vigorous) than those of adults (3.0 METS = moderate, ≥ 6.0 METS = vigorous) (Butte et al., 2017).

Current research referenced within the Youth Compendium; however, offers little insight into the EE associated with OPSP (Butte et al., 2017). The only specific example of EE during OPSP suggests that “playing catch” is categorized as a “light” intensity activity (3.5 METS) in 6-9 year-old children. EE levels during the repetitive practice of OPSP has recently been shown to be equivalent to adult MVPA (≥ 3 METS) when performed at intervals of as few as two trials per minutes (Sacko, McIver, Brian, Stodden In-press a), but EE data on children's OPSP is not available. Furthermore, the Youth Compendium does not offer insight into the variability in performance (i.e., cadence and effort levels) at which these skills should be performed to illicit a desired level of EE (i.e., MVPA) (Butte et al., 2017).

Understanding the EE during OPSP also has the potential to inform physical activity interventions by understanding the EE associated with performing these types of skills during developmentally appropriate activities. Activities that require at least 4.0 METS are classified as moderate intensity PA in children, with > 7.0 METS being classified as vigorous intensity PA (Butte et al., 2017). Thus, if OPSP is associated with high EE, then promoting their development during PA interventions and physical education (PE) will have both an acute and long-term (Cattuzzo et al., 2016; Logan et al., 2014; Robinson et al., 2015) health-enhancing benefit. In addition, this study may offer the first insight into the role skill level may have on EE associated with OPSP. Thus, the purpose of this study was to examine boys and girls EE during object projection skill performance at three different intensity intervals.

**Methods**

A convenience sample of 42 elementary school-aged (7-9 year-old) children were recruited for this study (22 boys; *M* = 8.1 yrs., *SD* = 0.8). The study was approved by the University of South Carolina's Institutional Review Board and ethical treatment of participants was followed. Parents of participating children provided consent and children provided assent. Children with physical disabilities or medical conditions which prevented them from completing testing were excluded from this sample. Disqualifying conditions included those: (a) who were under the care of a physician that excluded them from physical activity (e.g., heart condition, chest pain, injury, chronic illness, limb deformity) (b) who were taking prescription or non-prescription medications or used an inhaler (c) who had high blood pressure or cholesterol (d) who had suffered a seizure, asthma, lung disease, vertigo, and diabetes. The parent of each participant self-identified the race/ethnicity of their child as 88% Caucasian, 8% African-American, 2% Hispanic, and 2% Asian/Pacific Islander.

*Procedures*

Children participated in three nine-minute experimental sessions where participants performed rounds of five kicks, five throws, and five strikes in blocked fashion, at three different trial intervals (i.e., 6, 12, and 30 second intervals). Each participant completed the three experimental sessions in a randomized order. Participants were instructed to perform all trials with maximum effort. The interval schedules ranged from more intense (i.e., 6 second intervals to less intense intervals (i.e., 30 second intervals) that could be expected in different practice, training, or physical education environments.  Each interval session was followed by a cool down period in a seated position that lasted a minimum of 10 minutes to allow a return to resting state metabolism (Melby, Scholl, Edwards, & Bullough, 1993).

Maximal kicking and throwing ball speeds (Table 1) were recorded during the 30 second trial by radar gun (STALKER Inc. Plano, TX) to assess skill levels (Roberton & Konczak, 2001; D. F. Stodden, Gao, Goodway, & Langendorfer, 2014) and its potential influence on METS (R. M. Sacko et al., In-press a). Maximal effort throwing and kicking (five trials each) speeds for the total sample and by sex were *z*-transformed, summed and used to control for skill level. Speeds also were recorded intermittently during the 6 and 12 second trial intervals to estimate participants' continued effort levels. Children were instructed during each round of trials for each skill to provide maximum effort (e.g., "throw as hard as you can") and were periodically reminded to perform maximally throughout each trial. A foam ball (diameter = 21.6cm, weight =185g; Rainbow® DuraCoat Squeeze™, Gopher, MN), a regulation size tennis ball (diameter = 6.7cm, weight = 56g; QuickStart® 78, Gopher MN) and a softball size plastic ball (diameter = 10.2cm, weight = 42g; ResisDent Ball, Gopher, MN) with an 'oversized' plastic bat (diameter = 11.4cm, length = 71.1cm, weight = 90.7g; Phenom™ bat, Gopher, MN) were used for kicking, throwing and striking respectively. These implements were chosen with a consideration to their similarity to a wide range of implements which may be used in physical education settings, for the safety of participants, and with consideration to limiting laboratory damage.

Anthropomorphic measures (i.e., mass, height) were collected prior to each day of testing in accordance to standardized measurement procedures (Trost, 2001). (Table 1) Anthropometric measurements were assessed by trained staff with the participants wearing light (≤ 90 g) weight workout clothing without shoes. Height was measured using a portable stadiometer (ShorrBoard® Portable Height-Length Measuring Boards, Weight and Measure LLC, Olney, MD) to the nearest 0.1 cm. Mass was measured using an electronic scale (TANITA, SC-331S, Itabashi-ku, Tokyo) (Kelly & Metcalfe, 2012).

On the first of two days of testing, each participant was familiarized with all testing equipment and procedures. Children were allowed to complete as many practice trials of OPSP as they desired to be familiarized with the testing process. During the second day of testing, which was separated from day one by no less than 48 hours to allow recovery from the day one practice session, each participant completed three experimental OPSP sessions (i.e., 3 motor skill interval sessions) in a randomized order. Participants performed a general warm-up prior to testing which included dynamic flexibility exercises related to the specific assessments and a self-determined number of repetitions performing each specific skill. Participants were prompted to begin their performance for each trial using a prerecorded set of instructions created by two of the authors (RSS, DN). Immediately following the instructions the recording gave a 3-second count down prior to the sound of a beep that was set according to the interval trials of 6, 12, or 30 seconds. Participants were allowed to approach each performance trial movement in a manner of their choosing (e.g., no-step approach or stepping approach). No visual instructions were given prior to testing to ensure that participants' performance would not be influenced by instructional modeling.

*Indirect Calorimetry*

The estimation EE during OPSP trials was measured using a COSMED K4b2 portable gas exchange system, which is used to collect expired respiratory gases on a breath-by-breath basis to measure oxygen consumption ($VO_2$ $kg^{-1}\cdot min^{-1}$) and calculate METS (Duffield et al., 2004). The K4b2 unit was calibrated with standard gases prior to each measurement session and worn according to product specifications. METS were averaged using data collected during minutes 4-8 of each nine-minute OPSP session (Pinnington et al., 2001) of each nine-minute OPSP session (Sacko et al., In-press a). Resting state $VO_2$ measurements were collected prior to the start of interval sessions to establish baseline values of METS. Baseline values were used to ensure a sufficient amount of rest had been provided between trial sessions.

*Data Analysis*

Participant descriptive statistics and skill levels were calculated and reported as means (+/- SD) for the total sample and by sex (see Table 1). Average METS in each interval condition were reported and a 3 (interval condition) by 2 (sex) ANOVA was conducted to examine differences in METS across condition and sex. Post hoc Bonferroni analyses were conducted to examine differences across condition and sex and a Bonferroni adjustment of the alpha level was made to account for any increase in type-1 error associated with multiple comparisons. Thus, an alpha level of $p < .01$ was used to determine significance. *Eta squared* was calculated and reported as a measure of effect size. In addition, $z$-transformed performance speeds were used to control for skill level in the ANOVAs at each interval. SPSS Statistics for Windows, Version 23.0 (Chicago, IL: IBM Corp.) was used for data analysis.

**Results**

The average energy expenditure for boys and girls for the three different interval conditions (6, 12, and 30 seconds) by sex is reported in Table 2.

Data indicated a main effect for EE between interval conditions ($df = 2{,}123$, $F = 94.36$, $p <.001$, $\eta 2 = 0.605$) (Table 2). Post hoc analyses demonstrated that shorter performance intervals yielded significantly ($p < .001$) and progressively higher metabolic expenditure (i.e., interaction) across the three conditions (e.g., 6s > 12s > 30s). There also was a main effect for sex ($df = 1{,}120$, $F = 52.28$, $p < .001$ $\eta 2 = 0.305$) with boys demonstrating higher METS than girls. Post hoc tests indicated boys yielded higher METS ($p < .001$) at each performance trial interval.

Results also indicated an interaction for sex by interval condition (*df* = 1, 120, $F$ = 35.39, $p < .001$, $\eta^2 = 0.05$) indicating differences in average METS between boys and girls increased with shorter intervals.

Finally, the influence of skill on METS was examined further by performing three separate 3 (interval) x 2 (sex) ANCOVAs, controlling for skill. Results revealed a significant impact of skill on METS for each trial condition; 6 second ($F$ (1, 40) = 582.72, $p < 0.01$), 12 second ($F$ (1, 40) = 351.11, $p < 0.01$), and 30 second ($F$ (1, 40) = 158.13, $p < 0.01$), but no significant effect of sex when METS were controlled for skill at the of 12 second and 30 second intervals. Thus, skill was the main determinant (and not sex) in differences in METS in the 12 and 30 second interval sessions. However, sex remained a significant predictor of METS when controlling for skill during the 6 second session ($F$ (1, 40) = 6.67, $p < 0.01$). Thus, although skill still influenced METS in the 6 second interval (i.e., boys more highly skilled than girls), there was still a significant effect of sex on METS.

**Discussion**

The purpose of this study was to examine boys and girls EE during object projection skill performance at three different intensity intervals. Results of repetitive OPSP at 6, 12, and 30-second trial intervals demonstrated that average METS in both sexes during all trial intervals were greater than the value associated with the threshold for children's MVPA (4.0 METS). Overall, 21 of 22 boys and 16 of 20 girls averaged the 4.0 METS required to achieve MVPA during the 30 second trial interval. Thus, OPSP at an interval of only two trials/minute resulted in MVPA in almost all children. In addition, the average MET levels of both boys (9.3) and girls (7.2) demonstrated EE associated with vigorous activity (> 7.0

METS) during the 6-second interval condition and boys (7.0) in the 12-second interval condition. As expected, trial intervals with shorter rest intervals elicited higher values of EE (METS) as metabolic demands during these shorter trial intervals were higher.

However, when controlling for skill, gender differences during the 12 and 30 second intervals were not significant. Skill performance as measured by product (speed) during the 30s interval, provided a general idea of motor developmental levels. Although boys demonstrated significantly higher OPSP speeds and METS than girls ($p < .001$), only EE during the 6 second interval corresponded with these higher speeds. Thus, production of higher speeds (i.e., skill) resulted in higher MET levels giving rise to significance skill level plays toward the production of EE over that of gender in children. Furthermore, sex characteristics are not yet apparent in this age band (7-9) indicating that skill level (increased ranges of motion, higher developmental approach to performance) may play an increased role in the production of EE. What is not yet fully understood is the possible role self-perception and motivation, as it pertains to actual effort level, may have in the production of EE during discrete tasks. With further study, this relative difference in skill and EE may provide insight for the practice of OPSP as an enjoyable alternative to continuous activities, specifically with children, as a medium for the achievement of MVPA.

***Implications for instruction and practice***

The early childhood years are a critical time for the development of OPSP as they are the building blocks for more complex movements (Clark & Metcalfe, 2002). A recent meta-analysis (Logan et al., 2014) reported that motor skill competence does not develop naturally, motor skills need to be taught, practiced, and reinforced through developmentally appropriate movement programs. The practice and promotion of developmentally appropriate OPSP is a critical aspect of child development that are integrated into various games, sports, as well as leisure recreation activities. These skills also are integrated into various activities that are promoted across the lifespan (Breuer & Wicker, 2009). This study informs the work to rest ratios which may be ideal for practice of OPSP in a PE setting. The achievement of MVPA during the practice of OPSP can be achieved when performed at a rate of at least 2 trials per minute performed with ‘maximal’ effort. The time between trials performed at a rate of one performance every 30 seconds allows for instruction of skilled performance from a trained practitioner. These data suggest that practicing OPSP with at a rate of at least 5-10 trials per minute could provide a metabolic response to be categorized as vigorous activity.

Research demonstrates that the percentage of time in MVPA in physical education classes or recess (as measured by accelerometers or pedometers) rarely meet the recommended guidelines of 50% of time in those activities nor of 60 minutes per day (Health & Services, 2008; Nadeau, Maahs, Daniels, & Eckel, 2011; Prevention & Promotion, 2011). Thus, an implication of these data may be that MVPA levels in PE, leisure games, and sports may be higher than previously thought, specifically if the curriculum and/or activities inherently include the repetitive practice of OPSP. Furthermore, PE and PA motor interventions which have previously been observed by accelerometry may have failed to accurately ascertain EE due to the intermittent nature of OPSP (Sacko et al, 2018 In-press b; Sacko et al In-press a). Noted limitations in how PA intensity levels are currently assessed (e.g., hip worn pedometers and accelerometers mainly assess repeated excursions of the center of mass) may lead to a drastic underestimation of EE in activities that include OPSP (e.g., soccer or racquet sports) (Rowlands & Stiles, 2012; Sacko et al., In-press b). Further research is warranted to not only address questions surrounding the convergent validity of accelerometry with indirect calorimetry assessments, but also to determine the contribution of practice and performance of OPSP on the achievement of recommended daily values of MVPA in activities performed by children in games, leisure activities and sports that inherently involve object projection skills.

*Limitations*

A limitation of this study includes a lack of understanding of the relative contribution of each skill (kicking, throwing, or striking) toward the production of EE. The design of the trial sessions utilized in this study alternated the performances of all three skills in blocked fashion (i.e., repeating 5 kick trials, then 5 throw trials, then 5 strike trials) to reduce potential acute overuse and joint-related injury risk (e.g., hip flexor injury during kicking and little league elbow injury during throwing) as a result of repeated high effort trials of independent motions. Thus, this study's design limits the ability to make inferences based on the EE contribution of each independent skill performance. Furthermore, all three skills involve similar physical (i.e., multi-joint ballistic skills), physiological (i.e., gross neuromuscular involvement), and mechanical (i.e., kinetic chain) mechanisms. Thus; the individual EE contribution relative to each skill performance should be similar (Langendorfer et al., 2011). A second contributing factor that may influence EE is a child's motivation to perform with maximal effort. To mediate the impact of any potential decrease in motivation on individual performances, instructions to perform with maximal effort were continually provided to individuals throughout each session. Individual trial speeds also were recorded intermittently during the 6 and 12-second trial intervals to estimate participants' continued effort levels and periodic.

**Conclusions**

This study is a significant addition to the literature as it is the first study to measure EE levels during OPSP using indirect calorimetry in children. Results indicate skill practice with a maximum of one trial every 30 seconds resulted in the equivalent of at least moderate PA and intervals of 12 and 6 seconds demonstrated vigorous PA for most individuals. This is the first study to demonstrate that skill level has a significant role in the production of EE during OPSP in children. These data have the potential to significantly impact physical activity intervention strategies and the implementation of PE curricula by informing specific trial intervals which promote health-enhancing physical activity levels (i.e., MVPA). Information gleaned from this study provides evidence that the practice of OPSP can aid in the achievement (acute) of recommended health-enhancing levels of EE (i.e., MVPA), as well as promote a foundation for skill development that promotes lifelong physical activity.

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***Disclosure of interest***

The authors report no conflicts of interest.

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TABLE 5.1. *Physical characteristics of participants.*

| | Boys ($n$ = 22) | Girls ($n$ = 20) | All Participants ($N$ = 42) |
|---|---|---|---|
| Age, years | 8.1 ± 0.8 | 8.0 ± 0.8 | 8.1 ± 0.8 |
| Height, cm | 139.3 ± 6.3* | 135 ± 8.8 | 134.4 ± 7.6 |
| Body mass, kg | 33.2 ± 4.3* | 30.0 ± 6.6 | 29.1 ± 5.6 |
| Kick, mph | 42.0 ± 6.9* | 28.3 ± 8.3 | 27.8 ± 7.6 |
| Throw, mph | 37.9 ± 8.7* | 25.7 ± 5.5 | 30.7 ± 8.7 |

Values presented as means ± SD; $n$, number of subjects; METS, metabolic equivalent of task; *Significantly different from girls $p < .01$.

TABLE 5.2. *Measured gross energy expenditure (METS)during object projection skill performance*

| | 6 second (METS) | 12 second (METS) | 30 second (METS) |
|---|---|---|---|
| Total | 8.3 ± 1.6 | 6.3 ± 1.3 | 4.5 ± 0.7 |
| Boys | 9.3 ± 1.3* | 7.0 ± 1.1* | 4.8 ± 0.7* |
| Girls | 7.2 ± 1.1 | 5.6 ± 1.1 | 4.1 ± 0.7 |

*Values presented as means ± SD; METS, metabolic equivalent of task;*
**Significantly different from girls $p < .01$.*

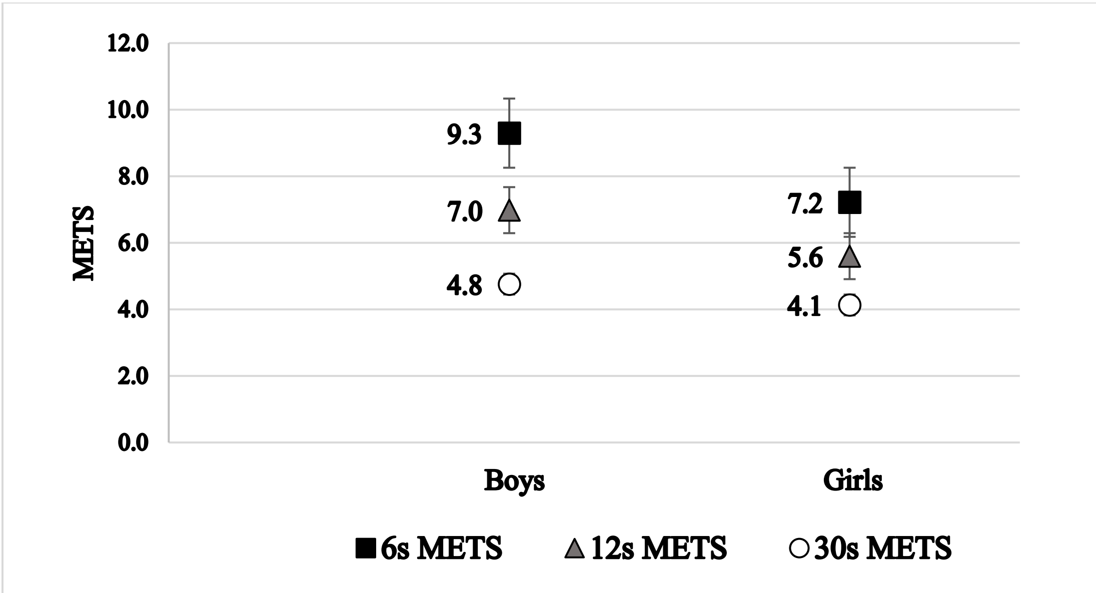


*Figure 5.1. Measured mean MET (metabolic equivalent of task) values measured during 6, 12, and 30 second trial intervals.*

# CHAPTER 6: STUDY 4

## COMPARISON OF INDIRECT CALORIMETRY- AND ACCELEROMETRY-BASED ENERGY EXPENDITURE DURING CHILDREN'S OBJECT PROJECTION SKILL PERFORMANCE[1]

[1]**Sacko, R.S.,** McIver, K., Brazendale, K., Brian, A., Nesbitt, D., Stodden D.F. (in-preparation) Estimation of Energy Expenditure Using Hip and Wrist Worn Accelerometers During Object Projection Skill Performance in Children. (*Measurement in Physical Education and Exercise Science).*

**Introduction**:

Participation in a minimum of 60 minutes of moderate-to-vigorous physical activity (MVPA) every day by children is recommended to achieve substantial health benefits and to reduce chronic diseases related to sedentary behavior and obesity (Larouche, Boyer, Tremblay, & Longmuir, 2013; Laukkanen, Pesola, Havu, Sääkslahti, & Finni, 2014; C. Ogden, Carroll, Fryar, & Flegal, 2015; Riddoch et al., 2004; van Grieken, Ezendam, Paulis, van der Wouden, & Raat, 2012). However, as much as 80% of children do not accumulate these recommended amounts of physical activity (PA) (Hallal et al., 2012; C. L. Ogden, Carroll, Kit, & Flegal, 2012; Prevention & Promotion, 2011). Physical activities that have been promoted for the achievement of recommended levels of PA (e.g., sports, games, leisure activities) include movements that are both continuous (e.g., brisk-walking, jogging, or running) and discrete (e.g., kicking, throwing, or striking) in nature (Prevention & Promotion, 2011). These wide range of movement types impose significant methodological and logistical challenges to researches seeking to measure MVPA in children (Butte et al., 2017; Kim, Beets, & Welk, 2012; Ridley, Ainsworth, & Olds, 2008). The wide range of methods currently available for the measurement of PA levels in children include self-report, systematic observation, and accelerometry (Sirard & Pate, 2001). It is critical to obtain precise estimates of energy expenditure (EE) produced by children during all forms of PA to advance research relating to the promotion of lifelong health.

Limitations exist for all forms of PA measurement. For example, self-report PA assessments are limited in their accuracy due to the validity of parental recall of their child's

PA behavior (Machado-Rodrigues et al., 2011) and self-assessments questionnaires are not recommended for distribution to children due to the child's lack of cognitive ability to accurately recall their PA behavior (Kohl III, Fulton, & Caspersen, 2000). Difficulties in the use of systematic observation include the requirement of large amounts of researcher time to measure PA (McKenzie, 1991; McKenzie et al., 1991) and results may be altered due to interactions between observers and children (Bailey et al., 1995). The usefulness of accelerometers are dependent upon the selection of cut-points generally developed from studies that utilized similar types of movements.( e.g.,) and upon the choice of wear location (e.g., hip, wrist) on the study participant (Crouter, Flynn, & Bassett Jr, 2015; Kim et al., 2012; Sacko, et al., in-press b). Furthermore, universal agreement among researchers regarding cut-points and the optimal wear location or cut-points does not exist (Kim et al., 2012).

Accelerometers were developed to address the need for an accurate, objective, and versatile assessment of time spent in, and intensity levels of, PA (Chen & Bassett, 2005; Melanson Jr & Freedson, 1995). Since their inception and due in-part to their inclusion in large epidemiological studies, accelerometers have most significantly impacted our understanding of PA levels by revealing the lack of adequate PA levels children. The development of accelerometer cut-points occurs in calibration studies in which participants simultaneously wear an accelerometer, on a specified location on the body (e.g., hip, wrist), and a standardized device (e.g., COSMED K4b2) used as a criterion measure for the estimation of energy expenditure (e.g., indirect calorimetry) while executing various forms of PA (e.g., walking, running) (Kim et al., 2012). Validation studies have utilized algorithms that transform accelerometer activity “counts” (output unit of accelerometers) to METS (metabolic-equivalence of task) (Lyden, Kozey, Staudenmeyer, & Freedson, 2011). Accelerometers worn on the hip measure variations in movement and have been associated with the movement of an individual's center of mass, while accelerometers worn on the wrist are associated more closely with arm movement independent from the hip or lower extremity (Evenson, Catellier, Gill, Ondrak, & McMurray, 2008; P. Freedson, Pober, & Janz, 2005; P. S. Freedson, Melanson, & Sirard, 1998; Trost, McIver, & Pate, 2005). The two most commonly used children's cut-points (accelerometer worn on the hip) were developed by Evenson et al., (2008) and Freedson et al., (2005) which were based on the linear relationship that exists between measured vertical accelerations of the body and EE during locomotion. Monitoring activity accumulation with accelerometers worn on the wrist has been suggested as a method to increase accelerometer PA observation validity in children over that of hip-worn accelerometers (Evenson, Catellier, Gill, Ondrak, & McMurray, 2008; Freedson, Pober, & Janz, 2005) due to the wrists association with upper body movement (Chandler, Brazendale, Beets, & Mealing, 2016). Researchers have attempted to develop regression techniques to address the inaccuracies of accelerometer PA measurement which exist due to in part the intermittent performance nature of discrete skill performance (Lyden et al., 2011; R. B. Sacko et al., in-press b) and differences in movement when accelerometers are placed on different anatomical positions (i.e., wrist) (Crouter, Clowers, & Bassett, 2006; Crouter et al., 2015). Regression models predict EE by expressing average counts during a period of time (i.e., 5, 15, or 60 seconds, (P. Freedson et al., 2005; Pate, Almeida, McIver, Pfeiffer, & Dowda, 2006; Trost et al., 2005) in categorical form (i.e., sedentary, light, moderate, vigorous), or by translating them into a universal unit such as METS. Activities that require at least 4 METS are classified as moderate intensity activity in children, while > 7 METS are classified as vigorous activities (Butte et al., 2017).

Recently, there has been a movement away from the traditional placement of accelerometers on the hip, to locations such as the dominant and non-dominant wrists (Chandler, Brazendale, Beets, & Mealing, 2016; Crouter et al., 2006; Crouter et al., 2015). This change was brought about, in part, due to the lack of validity of hip worn accelerometry to correctly classify sedentary PA during seated activities such as video games where wrist movement is high and hip movement is low (Kim, Lee, Peters, Gaesser, & Welk, 2014). Advantages to the wrist location included increased wear time compliance (van Hees et al., 2011) and the ability to assess movement during activities where hip movement is limited (e.g., discrete skills) (Sacko, et al., in-press b). Cut-points and regression equations to estimate EE in children using accelerometer placement on the dominant wrist were recently established (Crouter et al., 2006; Crouter et al., 2015). An advantage to dominant wrist accelerometer placement in children over that of the non-dominant wrist is the increased use of the dominant hand during PA when movements such as throwing or striking take place. In contrast, a concern with using an accelerometer on the dominant hand is the possibility of increased activity counts, and thus overestimation of PA, during sedentary activities, such as drawing, coloring, and video games. In response to this assumption Chandler et al., 2015 published cut points for accelerometers worn on the non-dominant wrist. Although numerous accelerometer calibration studies have been published to provide “cut-points” for the estimation of PA levels (e.g., sedentary, light, moderate, vigorous) and to provide suggestions for the optimal wear location (e,g., hip, wrist), during activities such as walking, running or activities of daily living (Troiano,

2006) accurately quantifying PA intensities during discrete skill performance (e.g. kicking, throwing, and striking) remains a challenge to researchers and clinicians (Butte et al., 2017; Kim et al., 2012; Sacko, et al., in-press b; Sacko, Nesbitt, Brian, McIver, & Stodden, in-press c; Sacko, McIver, Brian, Stodden, & Stodden, in-press a).

Discrete skills, specifically object projection skill performance (OPSP), involve complex multi-joint movements that demand high neuromuscular involvement (Gabbard, 2011; Laukkanen et al., 2014; Molina, 2015). Movements, such as kicking, throwing and striking, activate large muscle groups and are generally produced with high effort. Neuromuscular demands associated with OPSP are substantially higher than continuous activities of moderate intensity (e.g., brisk-walking, jogging) suggesting that EE would also be high when discrete skills are repeated in a play, practice or skill training context (Campbell, Stodden, & Nixon, 2010; Duffield, Dawson, Pinnington, & Wong, 2004; Escamilla & Andrews, 2009; Pinnington, Wong, Tay, Green, & Dawson, 2001). Discrete skills, defined as having a defined beginning and ending, requires repetitive practice, which generally involves low work to rest intervals. Promoting high effort levels also is a prerequisite to developing advanced levels of OPSP as the emergence of more advanced coordination patterns inherently includes the exploitation of neuromuscular mechanisms that necessitate high effort eccentric/concentric muscular contractions (Cattuzzo et al., 2016; Croix & Korff, 2013; Girard, Micallef, & Millet, 2005; Langendorfer, Roberton, & Stodden, 2011) that produce high GRFs and power (MacWilliams, Choi, Perezous, Chao, & McFarland, 1998; Orloff et al., 2008).

Evaluation of EE associated with OPSP is important as the development of skilled performance relies on repetitive practice with high levels of effort. Objection projection skills (e.g., kicking, throwing, and striking), which are an integral part of many games, sports and physical activities, are classified as discrete skills (i.e., having a distinct beginning and end). At this time, cut-points developed from object projection skill performance (OPSP) do not exist. Thus, accelerometers may prove to be limited in their ability to accurately categorize PA intensity levels (e.g., light, moderate, and vigorous) when cut-points derived from continuous activities are applied to the evaluation of PA that involves the performance of discrete skills. Specifically, MET levels associated with OPSP performance have recently been calculated to be between 4.5 and 8.3 METS, depending on the rate of performance trials in children (Sacko et al., in-press c). However, due to periods of relative inactivity that occur between high effort activity trial repetitions, it may be possible that commonly used hip- and wrist-worn accelerometer cut-points underestimate EE levels associated with OPSP (Chandler et al., 2016; Crouter et al., 2015; Sacko et al., in-press c; Trost et al., 2005). If accelerometry-based MVPA values are assumed to be correlated with actual MET values, then many OPSP activities that require high amounts of energy to perform may be greatly undervalued; specifically in their ability to contribute to the accumulation of MVPA based on repetitive trials produced during practice and play. Thus, the purpose of this study was to compare energy expenditure (EE) levels during object projection skill performance (OPSP) as assessed by hip- and wrist-worn accelerometry.

**Methods:**

***Participants***

A convenient sample of 42 elementary school-aged children (age: 8.01 ± 0.8 years, height: 134.4 ± 7.6 cm, mass: 29.1 ± 5.6 kg, body mass index: 16.0 ± 2.3) were recruited for the purposes of this study. The study was approved by the University of South Carolina's Institutional Review Board and ethical treatment of participants was followed. The parent/guardian of each participant completed informed consent and each child proved assent before participating in the study Participants provided consent and completed a Health History Questionnaire to determine eligibility for participation (see Sacko et al., in-press c) for a review of procedures).The physical characteristics of the participants are shown in Table 1. The parent of each participant self-identified the race/ethnicity of their child as 88% Caucasian, 8% African-American, 2% Hispanic, and 2% Asian/Pacific Islander.

***Procedures***

Children participated in three nine-minute experimental sessions where participants performed rounds of five kicks, five throws, and five strikes in blocked fashion, at three different trial intervals (i.e., 6, 12, and 30 second intervals). Each participant completed the three experimental sessions in a randomized order. Participants were instructed to perform all trials with maximum effort. The interval schedules ranged from more intense (i.e., 6 second intervals to less intense intervals (i.e., 30 second intervals) that could be expected in different practice, training, or physical education environments. Each interval session was followed by a cool down period in a seated position that lasted a minimum of 10 minutes to allow a return to resting state metabolism (Melby, Scholl, Edwards, & Bullough, 1993).

Maximal kicking and throwing ball speeds (Table 1) were recorded during the 30 second trial by radar gun (STALKER Inc. Plano, TX) to assess skill levels (Roberton & Konczak, 2001; D. F. Stodden, Gao, Goodway, & Langendorfer, 2014) and its potential influence on METS (Sacko et al., in-press a). Speeds also were recorded intermittently during the 6 and 12 second trial intervals to estimate participants' continued effort levels. Children were instructed during each round of trials for each skill to provide maximum effort (e.g., "throw as hard as you can") and were periodically reminded to perform maximally throughout each trial. A foam ball (diameter = 21.6cm, weight =185g; Rainbow® DuraCoat Squeeze™, Gopher, MN), a regulation size tennis ball (diameter = 6.7cm, weight = 56g; QuickStart® 78, Gopher MN) and a softball size plastic ball (diameter = 10.2cm, weight = 42g; ResisDent Ball, Gopher, MN) with an 'oversized' plastic bat (diameter = 11.4cm, length = 71.1cm, weight = 90.7g; Phenom™ bat, Gopher, MN) were used for kicking, throwing and striking respectively. These implements were chosen with a consideration to their similarity to a wide range of implements which may be used in physical education settings, for the safety of participants, and with consideration to limiting laboratory damage.

Anthropomorphic measures (i.e., mass, height) were collected prior to each day of testing in accordance to standardized measurement procedures (Trost, 2001) (Table 1). Anthropometric measurements were assessed by trained staff with the participants wearing light (≤ 90 g) weight workout clothing without shoes. Height was measured using a portable stadiometer (ShorrBoard® Portable Height-Length Measuring Boards, Weight and Measure LLC, Olney, MD) to the nearest 0.1 cm. Mass was measured using an electronic scale (TANITA, SC-331S, Itabashi-ku, Tokyo) (Kelly & Metcalfe, 2012).

On the first of two days of testing, each participant was familiarized with all testing equipment and procedures. Children were allowed to complete as many practice trials of OPSP as they desired to be familiarized with the testing process. During the second day of testing, which was separated from day one by no less than 48 hours to allow recovery from the day one practice session, each participant completed three experimental OPSP sessions (i.e., 3 motor skill interval sessions) in a randomized order. Participants performed a general warm-up prior to testing which included dynamic flexibility exercises related to the specific assessments and a self-determined number of repetitions performing each specific skill. Participants were prompted to begin their performance for each trial using a prerecorded set of instructions created by two of the authors (RSS, DN). Immediately following the instructions the recording gave a 3-second count down prior to the sound of a beep that was set according to the interval trials of 6, 12, or 30 seconds. Participants were allowed to approach each performance trial movement in a manner of their choosing (e.g., no-step approach or stepping approach). No visual instructions were given prior

***Indirect Calorimetry***

Energy expenditure during skill performance was measured using the criterion measure of indirect calorimetry. A COSMED K4b2 portable system for pulmonary gas exchange was used to collect expired respiratory gases on a breath-by-breath basis to measure oxygen consumption ($VO_2$ $kg^{-1} \cdot min^{-1}$) and METS (Duffield et al., 2004; Melby et al., 1993; Pinnington et al., 2001). The K4b2 unit was calibrated with standard gases prior to each measurement session and worn according to product specifications. METS were averaged using data collected during minutes 4-8 of each nine-minute OPSP session (Pinnington et al., 2001) of each nine-minute OPSP session (Sacko et al., in-press a; Sacko et al., in-press b; Sacko et al in-press c). Resting state $VO_2$ measurements were collected prior to the start of interval sessions to establish baseline values of METS. Baseline values were used to ensure a sufficient amount of rest had been provided between trial sessions.

***Accelerometry***

Accelerometers (ActiGraph GT3X+, ActiGraph, Pensacola, FL) were worn on three locations: a) waist level at the right anterior axillary line attached to a belt, b) posterior side of the non-dominant wrist, and c) posterior side of the dominant wrist. The accelerometers were synchronized with the COSMED K4b2 (indirect calorimetry) for data analysis purposes. The accelerometers were initialized using the sampling rate of 100 Hz and downloaded in epoch lengths of 1 second. The results were downloaded using ActiLife (Pensacola FL) software. Measurements from accelerometry were matched with the corresponding time period collected by indirect calorimetry (i.e., minutes 4-8) and used for EE prediction evaluation.

METS were calculated using two sets of cut points that delineated various intensities of PA (e.g., light, moderate, vigorous) and were established for children ages 7-9 for the hip (i.e., Freedson et al., 1998) and dominant wrist-worn (i.e., Crouter et al., 2015) accelerometers. All data was converted to average counts min-1. Accelerometer data from the hip was transformed to METS using the equation developed by Freedson et al., (2005) and from the dominant wrist using the equation developed by Crouter et al., (2015).

Freedson et al., (2005) Hip-worn Regression Model:

METS = 2.757 + (0.0015 · cnts per min) – (0.08957 · age (yr)) – (0.000037 · cnts per minute · age (yr))

Crouter et al., (2015) Dominant Wrist-worn Regression Model

1. If the vertical axis counts per 5 sec are ≤ 35, energy expenditure = 1.0 child – MET
2. If the vertical axis counts per 5 sec are > 35, energy expenditure (child-MET)

METS = 1.592 + (0.0039 · ActiGraph vertical axis counts per 5 second)

MET transformation could not be performed for Evenson et al., (2008) or Chandler et al., (2016) because no regression equation was provided.

The inclusion criteria for the cut-points used within this study were accelerometer studies published through December of 2015. The criteria used for identification were: (a) sample age range included children 7-9 years of age. (b) use of ActiGraph accelerometers to establish cut-points (c) used an appropriate biological standard (4.0 METS = moderate), and (d) used an EPOCH length less than 60s, and (e) the study was validated in sample sizes of at least 10 per age group (P. S. Freedson et al., 1998). The following four cut-points and their respective wear location were identified for inclusion into this study (1) Freedson et al., (2005), hip; (2) Evenson et al., (2008), hip; (3) Crouter et al., (2015), dominant wrist; and (4) Chandler et al., (2016), non-dominant wrist. All data was classified as light, moderate, or vigorous by the cut-points that corresponded to their wear location and are presented in Table 2.

***Data Analysis***

To examine time spent in moderate (>4.0 METS), and vigorous (>7.0 METS) physical activity, the minute-by-minute values for the COSMED K4b2 (criterion) and each accelerometer regression formula (estimate) were downloaded and used for comparison. Agreement between estimated METS (i.e., accelerometer) and actual METS (i.e., indirect calorimetry) was analyzed to examine the prediction accuracy of hip worn accelerometry and wrist-worn accelerometry during OPSP. A one-way repeated measures ANOVA was used to detect differences between the COSMED K4b2 and each accelerometer regression formula. Pairwise comparisons with Bonferroni adjustments were used to locate significant differences when necessary. We evaluated the agreement between accelerometer (counts per min) and indirect calorimetry (METS) to categorize moderate and vigorous PA.

We used Bland-Altman plots to analyze the agreement between accelerometry (estimated METS, Freedson et al., 1998) and indirect calorimetry (METS) (Bland & Altman, 1986). The agreement between accelerometry predicted METS and indirect calorimetry MET values were depicted by plotting the difference between two measures (e.g., accelerometry estimated METS minus indirect calorimetry METS) against the mean of the two measures (e.g., accelerometry estimated METS and indirect calorimetry METS). The mean error score (solid line) and the 95% prediction intervals (dashed line) are shown graphically. (Figures 1-4). An agreement between accelerometry estimated METS and indirect calorimetry METS are represented by data points clustered tightly around zero. Data points above zero indicate an overestimation of METS by accelerometry while data points below zero indicate an underestimation.

To examine the prediction of validity of accelerometry to accurately categorize PA (e.g., light, moderate, vigorous) during OPSP (Chandler et al., 2016; Crouter et al., 2015; Evenson et al., 2008; P. Freedson et al., 2005) accelerometer cut-points were applied to the data downloaded from each session (6, 12, and 30 second intervals) of OPSP. Average counts-per minute from each wear location (hip, dominant-wrist, non-dominant wrist) and the corresponding categorical representation of PA (light, moderate, vigorous) from each application of cut-points OPSP (Chandler et al., 2016; Crouter et al., 2015; Evenson et al., 2008; P. Freedson et al., 2005) are presented in Table 2.

Finally, we conducted 3 X 3 chi-square test of goodness of fit to examine if accelerometry (categorical PA derived from cut-points) were equivalent to the criterion measure of indirect calorimetry (categorical PA derived from METS) for each of the OPSP sessions. All statistical procedures were conducted using IBM SPSS software (Version 23.0; IBM, Armonk, NY USA) with a significance level of alpha $\leq .05$.

**Results**

The average energy expenditure for boys and girls respectively were 9.3 (± 1.4) and 7.2 (± 1.2) METS during the six second intervals, 7.0 (± 1.1) and 5.6 (± 1.1) METS during 12 second intervals and 4.8 (± 0.7) and 4.1 (± 0.7) during 30 second intervals. Data indicated a main effect for EE between interval conditions ($df = 2{,}123$, $F = 94.36$, $p < .001$, $\eta 2 = 0.605$). Post hoc analyses demonstrated that shorter performance intervals yielded significantly ($p < .001$) and progressively higher metabolic expenditure across the three conditions (e.g., 6s > 12s > 30s). There also was a main effect for sex ($df = 1{,}120$, $F = 52.28$, $p < .001$ $\eta 2 = 0.305$) with boys demonstrating higher METS than girls. Post hoc tests indicated boys yielded higher METS ($p < .001$) at each performance trial interval. Results also indicated an interaction for sex by interval condition ($df = 1, 120$) = 35.39, $p < .001$, $\eta^2 = 0.05$) indicating the difference in METS between boys and girls increased with shorter intervals.

One sample t-tests (Table 2) indicated a lack of agreement between hip-worn accelerometry (P. Freedson et al., 2005) and indirect calorimetry during OPSP. One sample t-tests also indicated a lack of agreement between dominant-wrist-worn accelerometry (Crouter et al., 2015) and indirect calorimetry during OPSP.

Bland-Altman plots (Figure 1) show a lack of agreement between accelerometry-based predicted METS and METS assessed via indirect calorimetry. Hip- and wrist-worn accelerometers did not observe an adequate amount of accelerations from origin to accurately estimate EE during OPSP; Hip = 30s (r = 0.94, P < 0.00), 12s (r = 0.96, P < 0.00) and 6s (r = 0.96, P < 0.00); Wrist = 30s (r = 0.94, P < 0.00), 12s (r = 0.96, P < 0.00) and 6s (r = 0.96, P < 0.00). Movement was virtually unobserved by hip-worn accelerometry. Movement values predicted were 0.9 METS or less above resting (2.5 METS) for all skill conditions. EE values estimated by wrist-worn accelerometry were higher than those estimated by hip-worn accelerometry, however, wrist-worn accelerometry failed to accurately categorize PA in any of the interval conditions.

The categorization of exercise intensity levels (e.g., light, moderate, vigorous) by indirect calorimetry (METS) and accelerometry (counts per min) was compared and presented in Table 3. Accelerometry failed to accurately predict METS during all object projection skill intervals. Accelerometry categorized the level of activity as light for each of object projection skill performance trials while the values indicated by indirect calorimetry were moderate, moderate, and vigorous during the 30s, 12s, and 6 second trials respectively.

Categorical PA levels derived by accelerometery underestimated the PA levels derived from the criterion measure of indirect calorimetry in all conditions during the 6 second and 30 second interval sessions. Furthermore, Evenson et al., (2008) cut-points underestimated PA levels of OPSP during all three interval conditions (i.e., 6, 12, and 30 seconds). Chi-square analysis from the remaining 12 second interval sessions (Freedson et al., 2005 Crouter et al., 2015 Chandler et al., 2016) indicated the following statistically significant predictive qualities of accelerometry: 1) categorical PA derived from Freedson et al., hip-worn cut-points for the total sample $\chi^2$ (2, $N$ = 42) = 9.46, $p < .01$ and for the boys $\chi^2$ (2, $N$ = 22) = 12.36, $p < .01$, 2) categorical PA derived from Crouter et al., dominate-wrist-worn cut-points for the total sample $\chi^2$ (2, $N$ = 42) = 20.77, $p < .01$ and for both boys $\chi^2$ (2, $N$ = 22) = 19.00, $p < .01$ and girls $\chi^2$ (2, $N$ = 20) = 9.82, $p < .01$, 3) and for categorical PA derived from Chandler et al., non-dominate-wrist-worn cut-points for boys $\chi^2$ (2, $N$ = 22) = 5.45, $p < .05$.

**Discussion**

The purpose of this study was to compare energy expenditure (EE) levels during object projection skill performance (OPSP) as assessed by hip- and wrist-worn accelerometry. Previous studies have calibrated both hip- and wrist-worn AcitGraphGT3X+ OPSP (Chandler et al., 2016; Crouter et al., 2015; Evenson et al., 2008; P. Freedson et al., 2005), however, recent insight into the EE of OPSP in children (Sacko, in-press c) has bought into question the validity of accelerometry to accurately predict PA levels of OPSP. Data from this study illustrates that MET levels predicted from accelerometry were drastically lower compared to METS derived from indirect calorimetry (criterion measure) during all three OPSP interval conditions for both hip- and wrist worn accelerometers. Specifically, the discrepancy in mean differences in predicted MET levels between hip- and dominant-wrist-worn accelerometry and indirect calorimetry increased as the performance trial interval time decreased (i.e., 30s < 12 < 6s) (see Table 2). Furthermore, the lack of agreement between hip- and wrist-worn accelerometry and indirect calorimetry in predicting activity intensity levels (i.e., moderate < 4 METS and vigorous < 7 METS) utilizing METS also was clearly discernible (See Figure 7). Although, dominant-wrist-worn accelerometers predicted a higher value of METS over that of hip-worn accelerometers, the EE values as expressed in METS did not surpass the thresholds needed to accurately predict PA levels as determined by the criterion measure of indirect calorimetry.

Indirect calorimetry indicated that OPSP yielded an activity intensity level of 'vigorous' during the 6 second sessions and 'moderate' during the 12s and 30s intervals sessions. Evenson et al., (2008) hip worn cut-points predicted that only 'light' activity levels were accumulated during all interval conditions. All cut-point OPSP (Chandler et al., 2016; Crouter et al., 2015; Evenson et al., 2008; P. Freedson et al., 2005)) and wear location variations (hip, dominant-wrist, and non-dominant-wrist) failed to accurately predict PA levels during both the 6 second (i.e., highest intensity EE condition) and the 30 second (i.e., lowest intensity EE condition) interval sessions. However, there was agreement between Freedson et al., (2005) hip-worn accelerometry and indirect calorimetry, as well as between Crouter et al., (2015) dominant wrist worn accelerometry and indirect calorimetry, for the total sample during the 12 second interval sessions. Thresholds for Freedson et al., (2005) cut-points (see table 2) for moderate PA (>500 counts per minute - cpm) are lower than those of Evenson et al., (2008) (>2296 cpm), thus, it is not surprising that Evenson et al., (2005) cut-points failed to accurately categorize PA levels during the 12 second interval condition where children averaged just 681 cpm. Surprisingly, thresholds for dominant-wrist (Crouter et al., 2015) cut-points for moderate PA (> 4321 cpm) are lower than those of non-dominant-wrist worn (Chandler et al., 2016) cut-points for moderate PA (> 6349 cpm). Though, cut-points applied to both wrists failed accurately categorize PA in the 6 and 30 second interval sessions, cut-points applied to the dominant wrist (Crouter et al., 2015) accurately predicted PA levels during the 12 second interval session. In reference of wrist movement during OPSP as it relates to play, it is logical to assume that the dominant wrist would be used more often that of the non-dominant wrist. Results from this study (see table 3) demonstrate that average counts per minute for the dominant wrist were higher than the non-dominant wrist in all conditions as performed by all study participants. Thus, with further study, dominant wrist cut-points may prove to be a stronger location of accelerometry for the prediction of PA levels during OPSP. Furthermore, recent research by Sacko et al., (in-press c) has brought to light skill the effect of skill differences on EE in children. Due to the limited use- and motion-of the non-dominant wrist in children with lower skill levels, non-dominant wrist cut-points representing thresholds of MVPA higher than those of the dominant wrist, should not be considered for use in the measurement of PA levels during OPSP.

To better understand the consistency in EE required by children to perform object project skills at 6 second intervals, indirect calorimetry indicated that 38 of the 42 participants achieved the 7.0 METS needed obtain a 'vigorous' level of PA. In contrast, hip- and wrist-worn accelerometers consistency was noted in the inability to accurately predict OPSP PA intensity levels during the 6 second interval via METS prediction extrapolations and with cut-points. This same underestimation occurred throughout the 30 second OPSP where 38 of 42 participants achieved the > 4 METS required for classification of moderate PA as measured by indirect calorimetry, yet, hip- or wrist-worn accelerometry failed to classify any participant above a 'light' PA intensity level. These global findings reemphasis the lack of impact that gender has on the comparisons between indirect calorimetry-based and accelerometry-based assessment of EE and PA intensity levels reported by Sacko et al., (in-press b). These findings also illustrate the consistent underestimation of PA intensity levels by accelerometers worn on the hip, dominant wrist, and the non-dominant wrist, during OPSP at varying practice intervals.

It is important to note that the development of Freedson et al., (2005), Evenson et al., (2008) Crouter et al., (2015) and Chandler et al., (2016) cut-points for children were all developed without using any variation of OPSP as a criterion measure of PA. An important reason for the consistent and drastic underestimation estimation of PA intensity levels by all tested variations of accelerometry during OPSP is that the volume of accelerations associated with intermittent performances of object project skills is far smaller than the volume of accelerations associated with a continuous activity (e.g., brisk-walking, running) during an equivalent amount of time (i.e., nine-minutes). In essence, oscillations of the hips and wrists occur continuously during the locomotor activities (e.g., running), thus producing a high accumulation of accelerations (i.e., counts) that are captured by accelerometers. In contrast, oscillations of the hip and wrists produced during the repetitive practice of OPSP is limited by the total number of reputations which occur during a given time period (e.g., 1 OPSP every 30 seconds = 2 performances per minute), yet, OPSP require high levels of neuromuscular involvement (high intensity) and thus, necessitates high levels of EE. It is therefore not surprising that the lower volume of accelerations was represented by accelerometers worn at both the hip and wrists does not demonstrate MVPA.

The neuromuscular demands associated with OPSP are substantially higher than those of the repetitive cardiorespiratory activities of moderate intensity (e.g., brisk walking or running) (Girard et al., 2005; Reid & Schneiker, 2008) and of the ‘activities of daily living’ which were used during the cut-point validation studies featured in this study

(Freedson et al., 2005; Evenson et al., 2008; Crouter et al., 2015; Chandler et al., 2016). Accelerometers used in this study did not fail to measure what they are intended to measure (i.e., number of movement accelerations at different intensities during nine-minute trials), rather, they failed to capture the EE associated with the neuromuscular demand of OPSP. The high neuromuscular demand facilitated during repetitive OPSP, requires volitional effort, and is increased via the effective passive exploitation of neuromuscular mechanisms that are facilitated by high ground reaction forces and high segmental velocities produced through the kinetic chain high ground reaction forces (Campbell et al., 2010; Cattuzzo et al., 2016; Croix & Korff, 2013; Girard et al., 2005; Langendorfer et al., 2011; MacWilliams et al., 1998; Rodacki, Fowler, & Bennett, 2002; D. F. Stodden, Langendorfer, Fleisig, & Andrews, 2006a, 2006b). Thus, the importance of promoting activities that involve OPSP would seem to be beneficial, not only to impact acute levels of health-enhancing PA in children and adolescence, as there is strong evidence that the development of OPSP positively influences not only PA levels (Lima et al., 2017) but also multiple aspects of health-related physical fitness (Cattuzzo et al., 2016; Lima et al., 2017; Rodrigues, Stodden, & Lopes, 2016) (Cattuzzo et al., 2016; Rodrigo Antunes Lima et al., 2017; Rodrigues, Stodden, & Lopes, 2016) and body weight status (Cattuzzo et al., 2016; D'Hondt et al., 2014; Lima et al., 2017; Lopes, Stodden, & Rodrigues, 2014; Martins et al., 2010; Rodrigues et al., 2016) in youth.

The use of wrist-worn accelerometers has been promoted over those of hip-worn accelerometers for the measurement of PA levels in children (Evenson et al., 2008; Freedson et al., 2005) due to the wrists association with upper body movement (Chandler et al., 2016). For example, the cut-points associated with MVPA for wrist-worn accelerometers (moderate ≥ 6360 counts $min^{-1}$ [Chandler et al., 2016]) are significantly higher than those of hip-worn accelerometers (moderate ≥ 2296 counts $min^{-1}$ [Evenson et al., 2008]) in children. Furthermore, the cut-points associated with MVPA for non-dominant-wrist-worn accelerometers (moderate ≥ 6360 counts $min^{-1}$ [Chandler et al., 2016]) are significantly higher than those of the dominant-wrist-worn (i.e., more active limb during OPSP) accelerometers (moderate ≥ 4321 counts $min^{-1}$ [Crouter et al., 2008]) in children. Thus, the lack of validity in the measurement of EE or intensity levels during OPSP by accelerometers, as indicated by this study's findings, is a result of the neuromuscular demands of OPSP and lack of OPSP specific cut-points rather than a result of the wear location. Future research to develop cut-points, specifically for the use during OPSP, in both children and adults is warranted to address these measurement issues.

The early childhood years are a critical time for the development of PA habits and the development of motor skills as they are the building blocks for more complex movements (Clark & Metcalfe, 2002; Stodden et al., 2008). In light of these findings, repetitive OPSP (performed in practice, training, or leisure activities) may provide an alternative, to continuous activities (brisk walking or running) to assist in accumulating recommended doses of MVPA associated with health-enhancing benefits. These data also indicate that the repetitive practice of OPSP in physical education and physical activity intervention settings may have been severely undervalued as a means to provide recommended levels of MVPA.

This study is not without limitations. This study did not examine the potential influence of individual skill level as it may relate to differences in the accumulation of accelerometer counts per minute. Participants were allowed to approach each performance trial movement in a manner of their choosing (e.g., no-step approach or stepping approach) therefore, performances associated with higher skill levels (i.e., stepping approach) may significantly increase individual counts per minute related to an increase in hip perturbations that resemble brisk-walking or running. Future research should address the potential influence of skill level on EE estimated by indirect calorimetry and categorical levels of PA estimated by accelerometry. Another contributing factor that may influence MET values is an individual's motivation to perform. Participants were prompted to perform 'with maximal effort' throughout each interval session to maintain adherence to testing protocol. However, the instruction to perform 'with maximal effort' is relative to each performer. Finally, as EE and counts were assessed via the combination of all three skills, the relative contribution of each skill to EE and counts were not addressed. However, all three skills (kicking, throwing, and striking) are multi-joint ballistic skills with similar gross neuromuscular involvement and kinetic chain mechanisms; thus, individual skill performance contribution relative to energy expenditure should be similar (Langendorfer, Roberton, & Stodden, 2011).

**Conclusions**

This is the first study to evaluate the ability of hip- and wrist-worn accelerometry to predict physical activity (PA) levels during object projection skill performance (OPSP) in children. This study demonstrates that hip- and wrist-worn accelerometers fail to adequately predict EE and thus, PA intensity (as assessed by both METS and counts) during OPSP when compared to indirect calorimetry. The disparity in levels of PA measured by indirect calorimetry and both hip- and wrist-worn accelerometry during OPSP were considerably large. Results indicated skill practice at a rate of 2 trials per minute (as measured by indirect calorimetry), resulted in the equivalent of moderate PA, yet was only categorized as light activity by all measured forms (dominant-wrist, non-dominant-wrist, and hip) of accelerometry. These data demonstrate that hip- (Freedson et al., 2005; Evenson et al., 2008) and wrist- worn (Crouter et al., 2015; Chandler et al., 2016) accelerometer cut-points lack prediction validity of EE and PA intensity level (via accelerometry counts) during OPSP in children. These data may significantly impact PA intervention measurement strategies by revealing the lack of validity in accelerometers to accurately predict PA levels during OPSP in children.

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TABLE 6.1. *Physical characteristics of the participants*.

| | Boys ($n$ = 22) | Girls ($n$ = 20) | All Participants ($N$ = 42) |
|---|---|---|---|
| Age, years | 8.1 ± 0.8 | 8.0 ± 0.8 | 8.1 ± 0.8 |
| Height, cm | 139.3 ± 6.3* | 135 ± 8.8 | 134.4 ± 7.6 |
| Body mass, kg | 33.2 ± 4.3* | 30.0 ± 6.6 | 29.1 ± 5.6 |
| Resting METS, $ml \cdot kg^{-1} \cdot min^{-1}$ | 2.5 ± 0.3 | 2.5 ± 0.6 | 2.5 ± 0.5 |

Values presented as means (SD); n, number of subjects; BMI, body mass index; METS, metabolic equivalent of task; *Significantly different from girls $p < .01$.

TABLE 6.2: *Vertical axis cut-points associated with moderate-to-vigorous physical activity.*

| | | Range of accelerometer counts-per-minute | | | | |
|---|---|---|---|---|---|---|
| Cut-point | Wear location | Sedentary | Light | Moderate | Vigorous | Very-Vigorous |
| Freedson et al | Hip | 0-149 | 150-499 | 500-3999 | 4000-7599 | > 7600 |
| Evenson et al | Hip | 0-100 | 101-2295 | 2296-4011 | > 4012 | N/A |
| Crouter et al | Wrist (dominant) | 0-420 | 421-4320 | 4321-13548 | > 13560 | N/A |
| Chandler et al | Wrist (non-dominant) | 0-1932 | 1933-6348 | 6349-17532 | > 17554 | N/A |

All cut-points presented as measure of vertical axis;
N/A, non-applicable
*Note*: All cut-points presented in counts-per minute
[a]Originally published as counts per 5 seconds

TABLE 6.3: *Physical Activity Levels as Measured by Indirect Calorimetry and Accelerometry*

| | Device | Study | Location | Group | 6 Second Interval | | 12 Second Interval | | 30 Second Interval | |
|---|---|---|---|---|---|---|---|---|---|---|
| METS (Categorical PA, METS ± SD) | Cosmed | | N/A | Total | Vigorous | 8.3 ± 1.6 | Moderate | 6.3 ± 1.3 | Moderate | 4.5 ± 0.8 |
| | | | | Boys | Vigorous | 9.3 ± 1.4 | Moderate | 7.0 ± 1.1 | Moderate | 4.8 ± 0.7 |
| | | | | Girls | Vigorous | 7.2 ± 1.2 | Moderate | 5.6 ± 1.1 | Moderate | 4.1 ± 0.7 |
| | ActiGraph | Freedson et al. | Hip | Total | Light | 3.4 ± 0.7 | Light | 2.8 ± 0.5 | Light | 2.4 ± 0.2 |
| | | | | Boys | Light | 3.8 ± 0.6 | Light | 3.1 ± 0.4 | Light | 2.4 ± 0.3 |
| | | | | Girls | Light | 3.0 ± 0.5 | Light | 2.6 ± 0.4 | Light | 2.3 ± 0.2 |
| | | Crouter et al. | Wrist Dominant | Total | Moderate | 5.2 ± 0.9 | Light | 3.9 ± 0.6 | Light | 2.8 ± 0.8 |
| | | | | Boys | Moderate | 5.6 ± 0.9 | Light | 4.1 ± 0.5 | Light | 3.0 ± 0.5 |
| | | | | Girls | Moderate | 4.7 ± 0.5 | Light | 3.6 ± 0.5 | Light | 2.7 ± 0.3 |
| CPM (Categorical PA, counts ± SD) | ActiGraph | Freedson et al. | Hip | Total | Moderate | 1186 ± 583 | Moderate | 681 ± 394 | Light | 281 ± 195 |
| | | | | Boys | Moderate | 1490 ± 548 | Moderate | 861 ± 367 | Light | 342 ± 216 |
| | | | | Girls | Moderate | 834 ± 402 | Light | 471 ± 320 | Light | 212 ± 145 |
| | | Evenson et al. | Hip | Total | Light | 1186 ± 583 | Light | 681 ± 394 | Light | 281 ± 195 |
| | | | | Boys | Light | 1490 ± 548 | Light | 861 ± 367 | Light | 342 ± 219 |
| | | | | Girls | Light | 834 ± 402 | Light | 471 ± 320 | Light | 212 ± 145 |
| | | Crouter et al. | Wrist Dominant | Total | Moderate | 11025 ± 2700 | Moderate | 6916 ± 1790 | Light | 3876 ± 1283 |
| | | | | Boys | Moderate | 12232 ± 2845 | Moderate | 7657 ± 1573 | Light | 4226 ± 1471 |
| | | | | Girls | Moderate | 9628 ± 1709 | Moderate | 6057 ± 1667 | Light | 3472 ± 900 |
| | | Chandler et al. | Wrist Non-Dominant | Total | Moderate | 8609 ± 2728 | Light | 5614 ± 1792 | Light | 3379 ± 1225 |
| | | | | Boys | Moderate | 9913 ± 2705 | Moderate | 6429 ± 1686 | Light | 3780 ± 1319 |
| | | | | Girls | Moderate | 7099 ± 1876 | Light | 4670 ± 1437 | Light | 2914 ± 939 |

METS, metabolic equivalence of task; PA, physical activity; CPM, counts per minute; SD, standard deviation; N/A, non-applicable

Categorical ranges for METS; < 4.0 METS = Light, 4.0-7.0 METS = Moderate, >7.0 METS = Vigorous Categorical ranges for accelerometry; Freedson: 150-499 counts $min^{-1}$ = light, 500-3999 counts $min^{-1}$ = moderate, 4000-7599 counts $min^{-1}$, = vigorous; Evenson: 101-2295 counts $min^{-1}$ = light, 2296-4011 counts $min^{-1}$ = moderate, > 4012 counts $min^{-1}$, = vigorous; Crouter: 421-4320 counts $min^{-1}$ = light, 4321-13548 counts $min^{-1}$ = moderate, > 13550 counts $min^{-1}$, = vigorous; Chandler: 1933-6348 counts $min^{-1}$ = light, 6349-17532 counts $min^{-1}$ = moderate, > 17533 counts $min^{-1}$, = vigorous

Note: All data is presented as an average per minute.

TABLE 6.4: *One-sample t-test difference of means, indirect calorimetry vs accelerometry*

| Cut-point | Interval | *N* | Mean Diff | Std. Deviation | *t* | *df* | Sig. (2-tailed) | Cohens *d* | 95% Confidence Interval of the Difference | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | Lower | Upper |
| Freedson et al. | 6 Second | 41 | 5.85 | 1.08 | 34.64 | 40 | 0.001 | 10.96 | 5.51 | 6.20 |
| Freedson et al. | 12 Second | 41 | 4.56 | 0.84 | 34.93 | 40 | 0.001 | 11.05 | 4.29 | 4.82 |
| Freedson et al. | 30 Second | 41 | 3.41 | 0.47 | 46.72 | 40 | 0.001 | 14.77 | 3.26 | 3.56 |
| Crouter et al. | 6 Second | 41 | 6.74 | 1.11 | 38.90 | 40 | 0.001 | 12.30 | 6.39 | 7.09 |
| Crouter et al. | 12 Second | 41 | 5.07 | 0.84 | 38.64 | 40 | 0.001 | 12.22 | 4.80 | 5.33 |
| Crouter et al. | 30 Second | 41 | 3.65 | 0.51 | 45.67 | 40 | 0.001 | 14.44 | 3.49 | 3.81 |

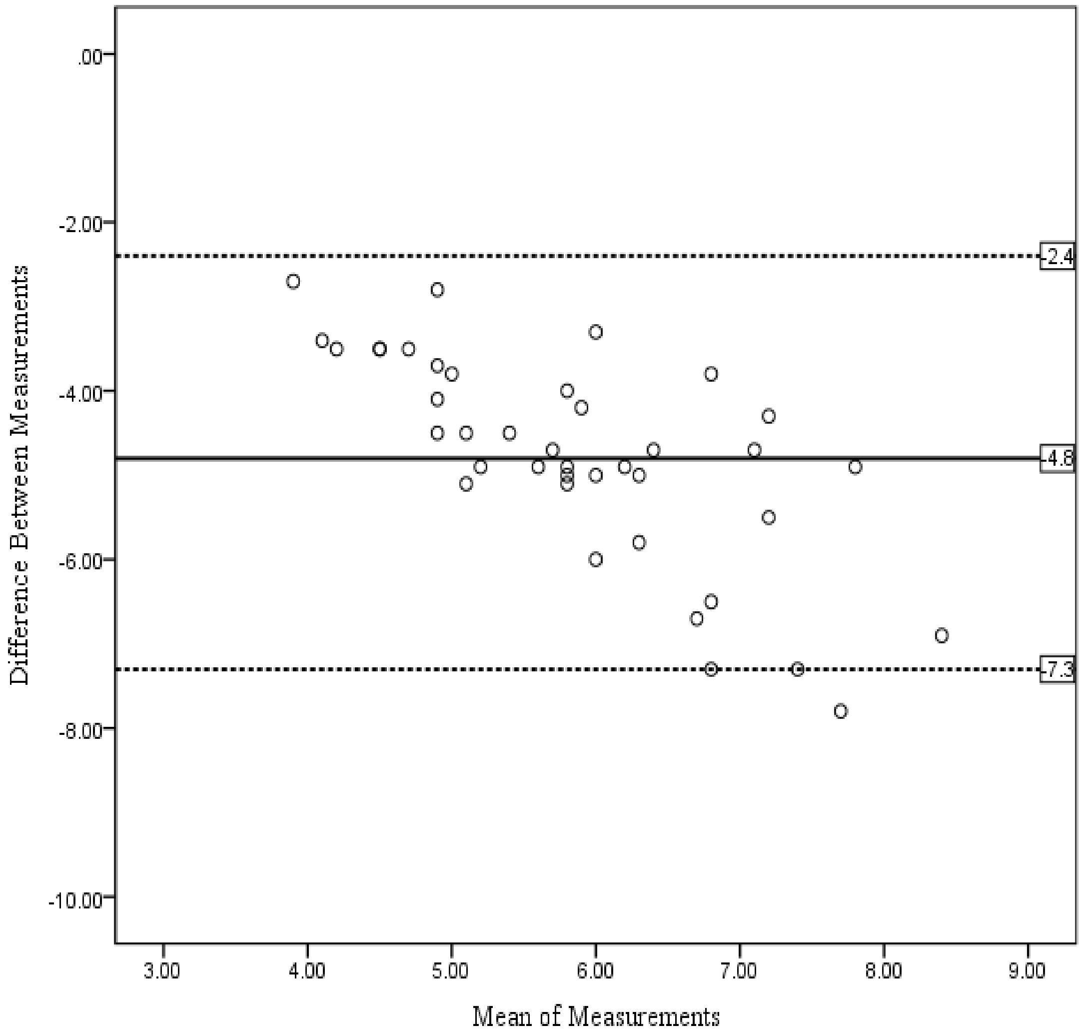


*Figure 6.1. Bland-Altman plot depicting error scores of METS estimated by hip-worn accelerometers (Freedson MET equation) vs indirect calorimetry (criterion measure) during the 6 second interval session.*

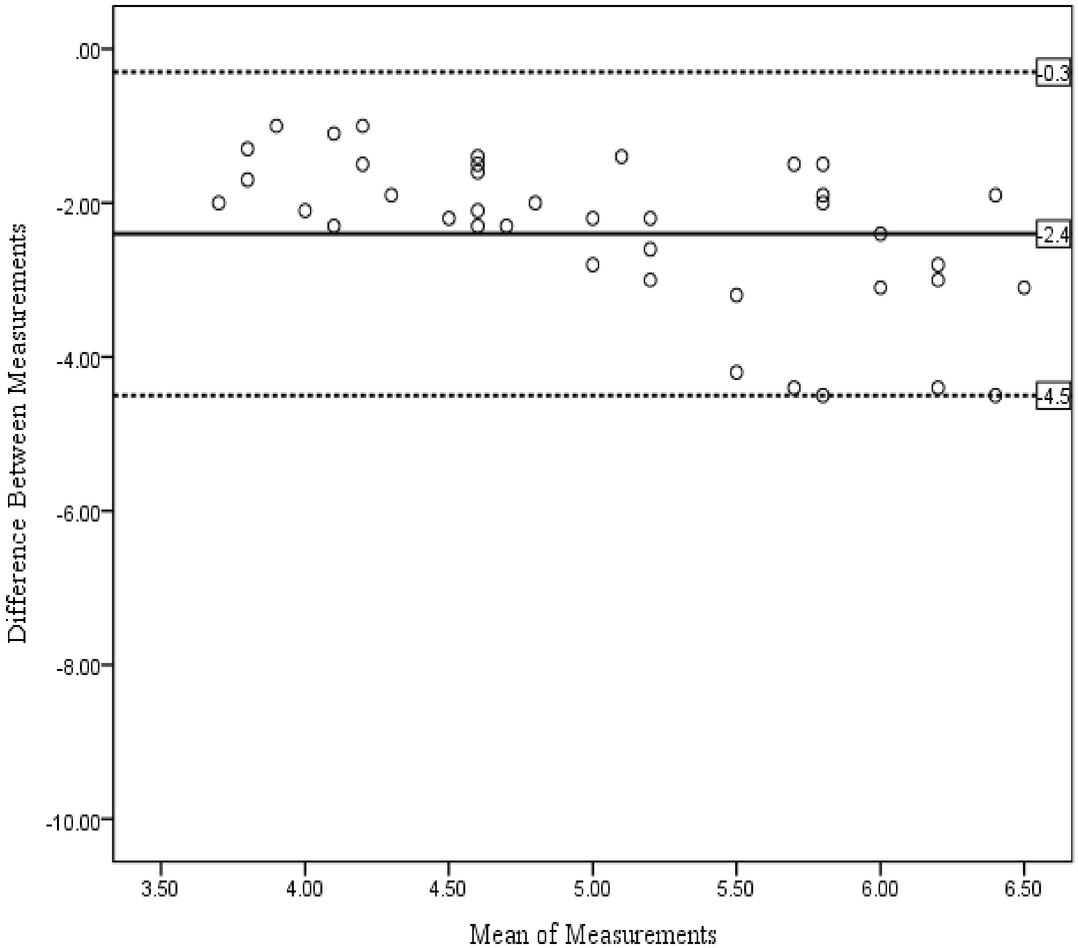


*Figure 6.2. Bland-Altman plot depicting error scores of METS estimated by hip-worn accelerometers (Freedson MET equation) vs indirect calorimetry (criterion measure) during the 12 second interval session.*

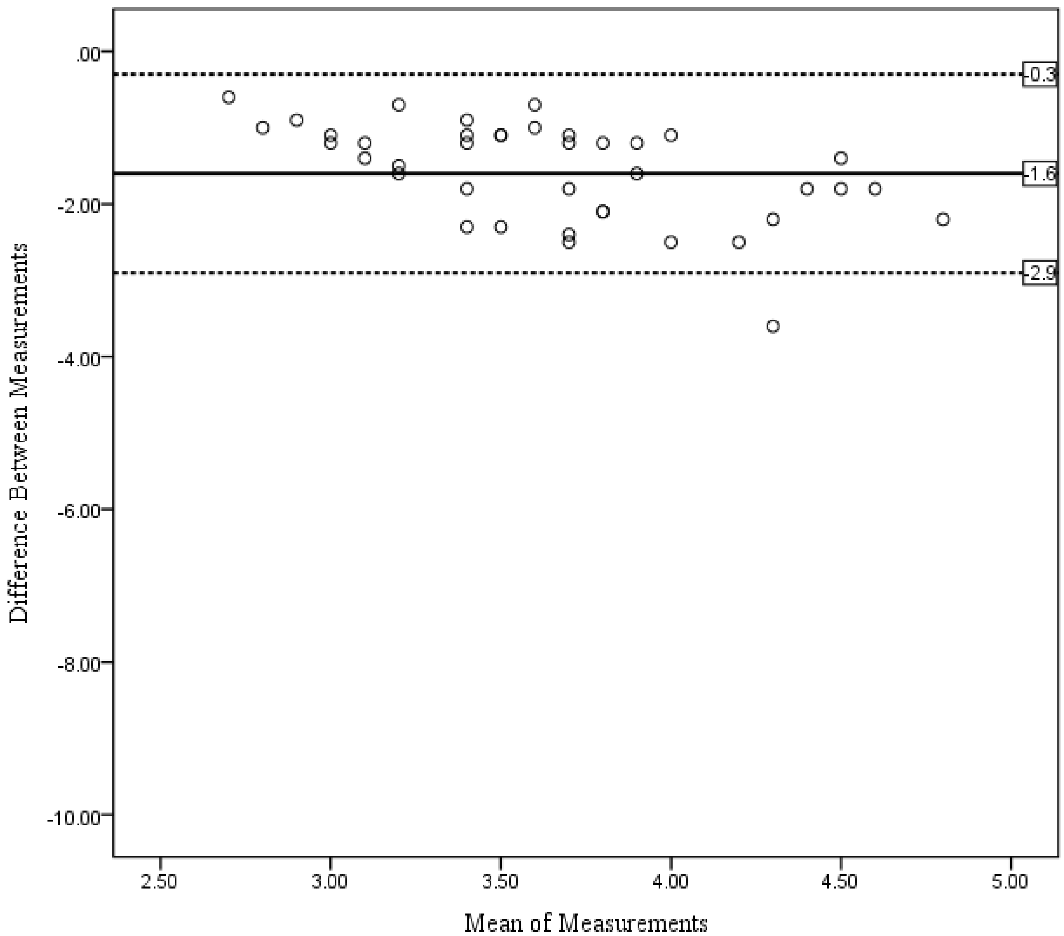


*Figure 6.3. Bland-Altman plot depicting error scores of METS estimated by hip-worn accelerometers (Freedson MET equation) vs indirect calorimetry (criterion measure) during the 30 second interval session.*

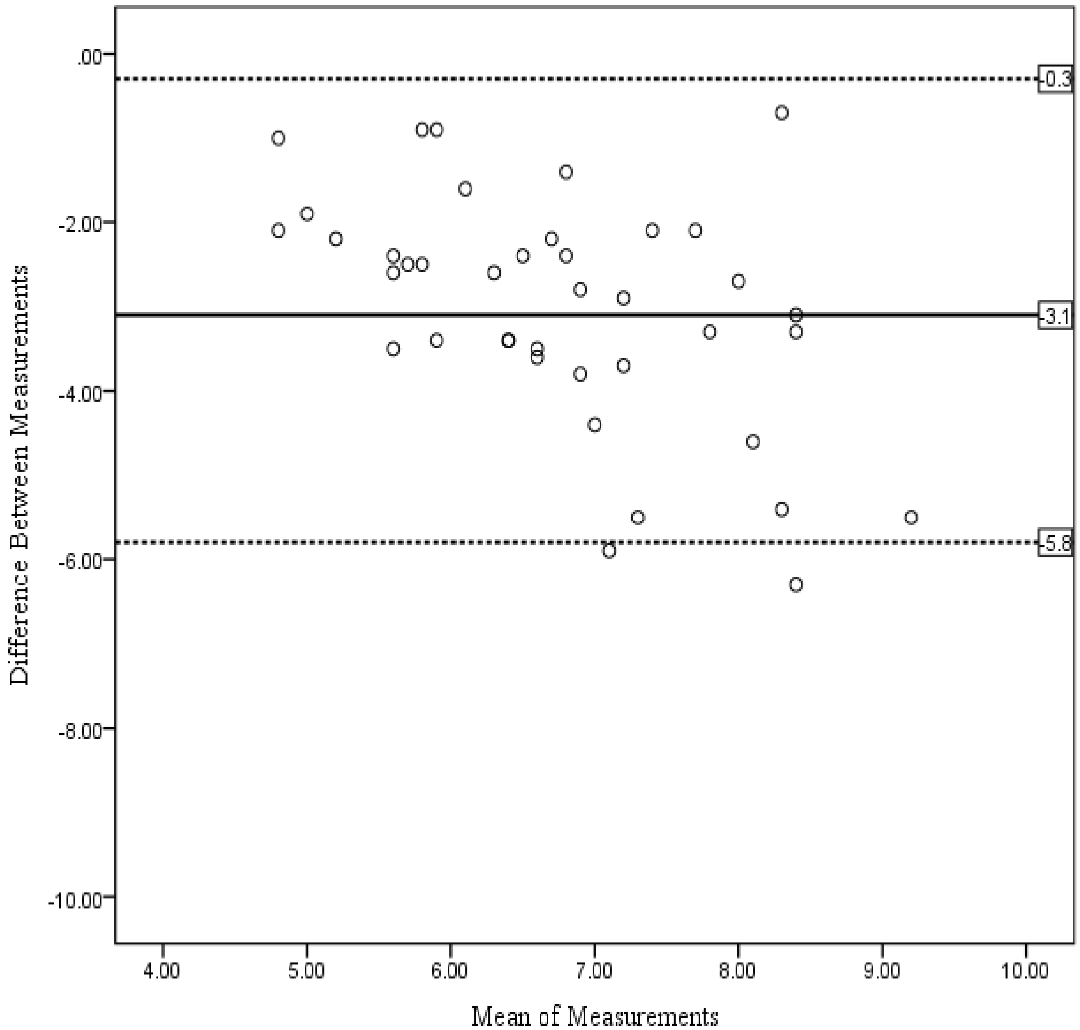


*Figure 6.4. Bland-Altman plot depicting error scores of METS estimated by dominant wrist-worn accelerometers (Crouter MET equation) vs indirect calorimetry (criterion measure) during the 6 second interval session.*

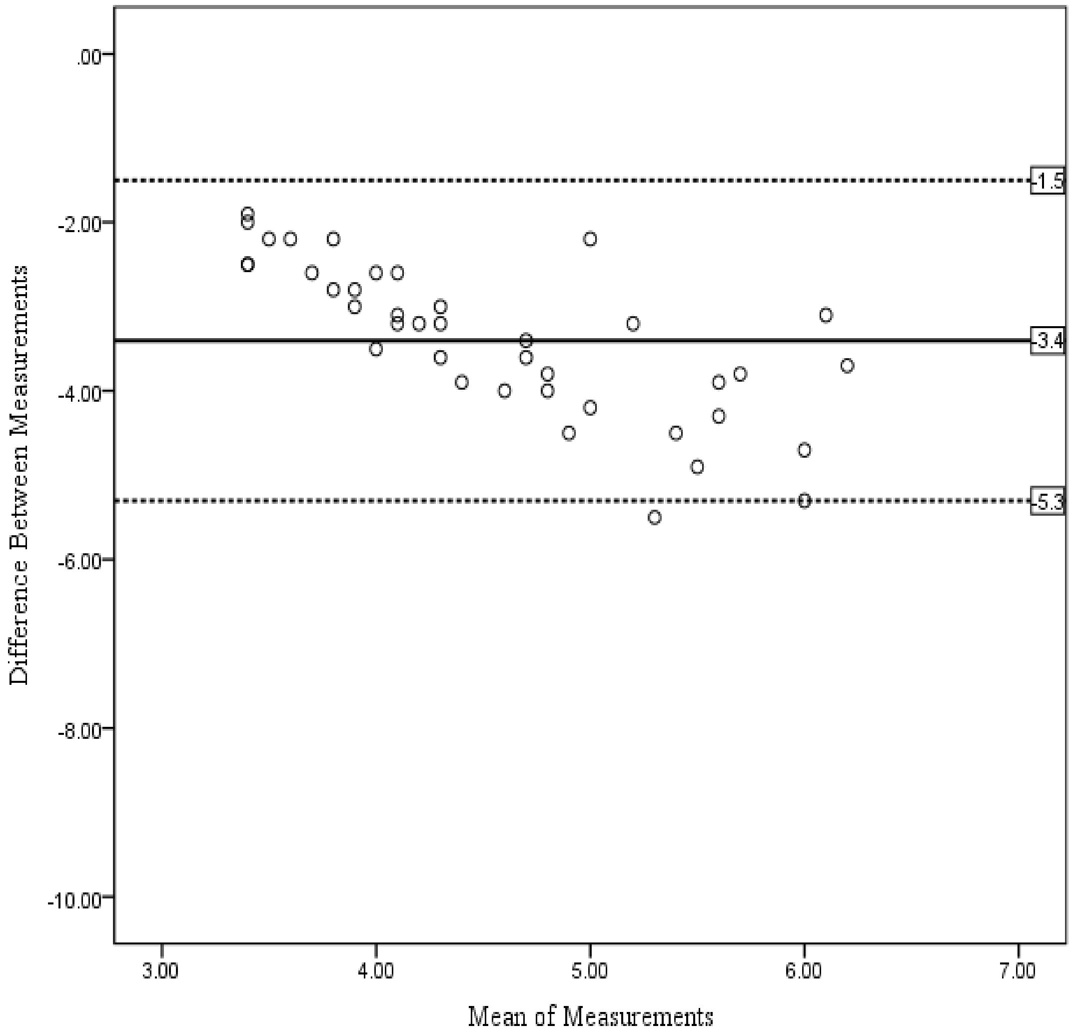


*Figure 6.5. Bland-Altman plot depicting error scores of METS estimated by dominant wrist-worn accelerometers (Crouter MET equation) vs indirect calorimetry (criterion measure) during the 12 second interval session*

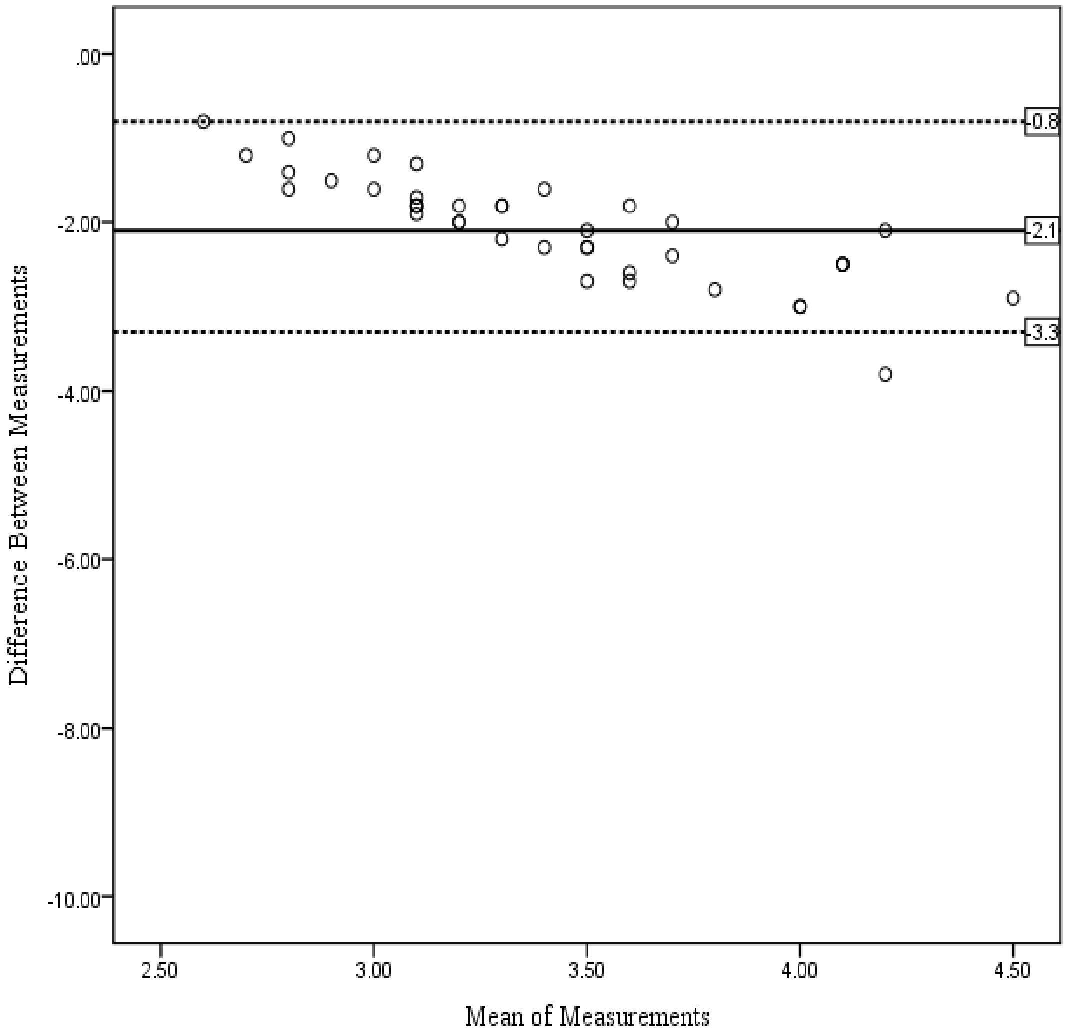


*Figure 6.6. Bland-Altman plot depicting error scores of METS estimated by dominant wrist-worn accelerometers (Crouter MET equation) vs indirect calorimetry (criterion measure) during the 30 second interval session.*

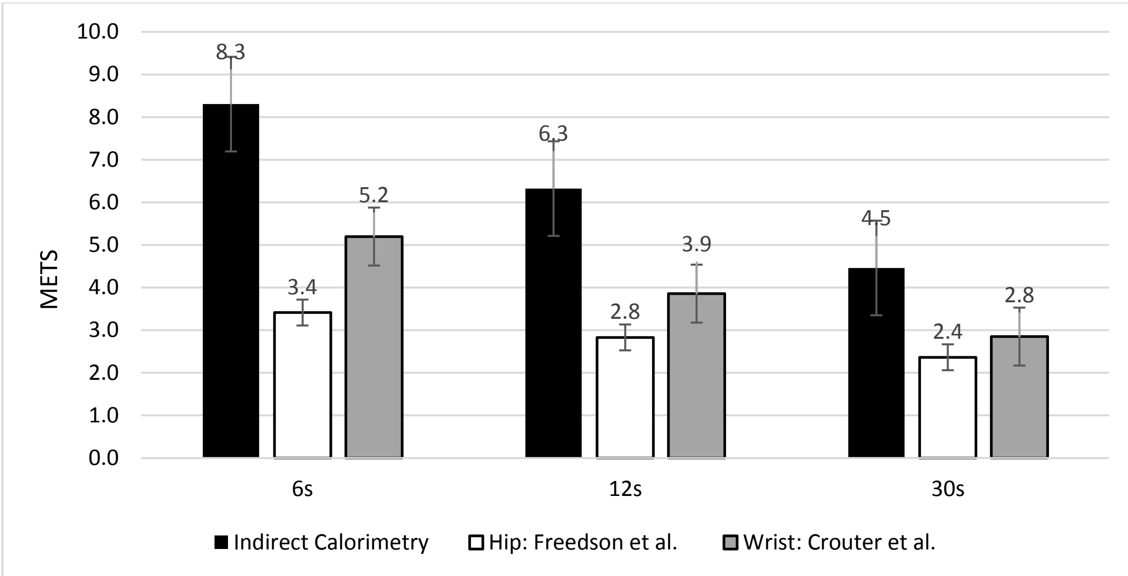


*Figure 6.7: Indirect calorimetry (criterion measure ) estimated METS (metabolic equivalent of task), Hip-worn accelerometer (Freedson et al.), and Dominant wrist-worn (Crouter et al.) accelerometer estimated METS during a nine-minute bout of running at a self-selected pace and object projection skill performance intervals (kicking, throwing, and striking) of one repetition every 6, 12, and 30 seconds.*

# CHAPTER 7

# DISSCUSSION

The four studies contained within this dissertation contribute to the understanding of the energy expenditure (EE) of object projection skill performance (OPSP) in adults and children. Overall, these studies addressed the gaps in the literature and informed physical activity (PA) research by examining EE, as measured by indirect calorimetry (i.e., criterion measure), during OPSP in adults (18-30 years of age) and children (7-9 years of age) and compared the intensity level of OPSP as assessed by indirect calorimetry with accelerometry. Specifically, study 1 examined EE, as assessed by indirect calorimetry, during OPSPS at 6, 12 and 30 second trial intervals in adults (18-30 years of age). Study 2 examined the level of agreement in assessment of activity intensity levels as measured via indirect calorimetry and accelerometry during OPSP in adults (18-30 years of age) at 6, 12 and 30 second intervals. Study 3 examined EE, as assessed by indirect calorimetry (METS) during OPSP at 6, 12 and 30 second trial intervals) in children (7-9 years of age). Study four examined the level of agreement in assessment of activity intensity levels (METS) as measured via indirect calorimetry (i.e., COSMED) and accelerometry during object projection skill performance in children (7-9 years of age) at 6, 12 and 30 second intervals.

**Energy Expenditure and Object Projection Skill Performance**

This study is a significant addition to the literature as it is the first study to measure EE levels during OPSP using indirect calorimetry in adults and children. These data have important short-term and long-term implications for promoting children's health. Physical Activity Guidelines recommend children participate in a minimum of 60 minutes or more of moderate-to-vigorous intensity physical activity (MVPA) every day to achieve substantial health benefits. Participating in activities (e.g., soccer, basketball or tennis) that have been noted to demonstrate high energy expenditure levels measured in "METS" have been shown to be health enhancing and aid in the reduction of obesity. The current "gold-standard" of field-based measurement of physical activities and their specific EE levels is based on accelerometry. Accelerometry measurement aligns with continuous cardiorespiratory activities (e.g., walking, running) because these types of activities are associated with consistent and repetitive center of mass movements. However, lifelong participation in activities such as soccer, basketball or tennis require the development of proficient object projection motor skills.

Understanding the EE of OPSP is critical to development of a foundation for future physical activity habits, health-related physical fitness and a healthy weight status. The neuromuscular demands associated with OPSP are substantially higher than those of the repetitive cardiorespiratory activities of moderate intensity (e.g., brisk walking or running) (Girard et al., 2005; Reid & Schneiker, 2008) and of the 'activities of daily living' which were used during the cut-point validation studies featured in this study (Freedson et al., 2005; Evenson et al., 2008; Crouter et al., 2015; Chandler et al., 2016). Accelerometers used in this study did not fail to measure what they are intended to measure (i.e., number of movement accelerations at different intensities during nine-minute trials), rather, they failed to capture the EE associated with the neuromuscular demand of OPSP. The high neuromuscular demand facilitated during repetitive OPSP, requires volitional effort, and is increased via the effective passive exploitation of neuromuscular mechanisms that are facilitated by high ground reaction forces and high segmental velocities produced through the kinetic chain high ground reaction forces (Campbell et al., 2010; Cattuzzo et al., 2016; Croix & Korff, 2013; Girard et al., 2005; Langendorfer et al., 2011; MacWilliams et al., 1998; Rodacki, Fowler, & Bennett, 2002; D. F. Stodden, Langendorfer, Fleisig, & Andrews, 2006a, 2006b). Thus, the importance of promoting activities that involve OPSP would seem to be beneficial, not only to impact acute levels of health-enhancing PA in children and adolescence, as there is strong evidence that the development of OPSP positively influences not only PA levels (Lima et al., 2017) but also multiple aspects of health-related physical fitness (Cattuzzo et al., 2016; Lima et al., 2017; Rodrigues, Stodden, & Lopes, 2016) (Cattuzzo et al., 2016; Rodrigo Antunes Lima et al., 2017; Rodrigues, Stodden, & Lopes, 2016) and body weight status (Cattuzzo et al., 2016; D'Hondt et al., 2014; Lima et al., 2017; Lopes, Stodden, & Rodrigues, 2014; Martins et al., 2010; Rodrigues et al., 2016) in youth.

**Future research**

This dissertation provides the first look into the potential contribution that skill level may provide to the level of EE during OPSPS. Children and adolescence perform object projection skills with a wide range of skill levels; however, no research has addressed the impact that differing levels of skill has on EE in children and adolescents. As both skilled and unskilled individuals may perform with high effort and similar musculature, EE during OPSP may be similar across all skill levels. The current understanding of skill level and EE indicates that as skill level is increased EE is decreased. Alternatively, higher levels of performance of discrete skills demonstrates improved coordination and more effective transfer of energy through the system. As a result, there are higher accelerations and speeds of limbs throughout the motion and greater forces are required to decelerate (i.e., eccentric loading, increased ground reaction forces) limbs and the center of mass during the completion of each individual skill performance. Thus, it may be plausible that more highly skilled individuals demonstrate higher EE during OPSP as their more effective movement may require greater EE to effectively decelerate multiple limbs and their center of mass (see preliminary studies). Thus, future research should examine differences in EE across skill levels in children and adolescents during OPSP.

It is suggested that the percentage of time in MVPA in physical education classes or recess (as measured by accelerometers or systematic observation assessments) rarely meet the recommended guidelines of 50% of time in those activities nor of the recommended 60 minutes per day.[23,24] Based on these data, the practice of OPSP is likely to substantially contribute to the accumulation of is MVPA, during physical education, recess or sports practice, where repetitive practice or performance of object projection skills may take place. However, this contribution may be severely underestimated as accelerometry and systematic observation tools do not have the capability to accurately assess exercise intensity (i.e., energy expenditure calculated as METS) during the repeated performance of object control skills. Future research should include the development of an inexpensive, objective, valid and unobtrusive measurement of EE that aligns with both cardiorespiratory activities (e.g., soccer, basketball, tennis) as well as the practice of OPSP required for proficient lifelong participation.

**Implications for instruction and practice**

Activities such as walking, running and cycling are well documented for their ability to yield energy outputs equivalent to MVPA; however, these data indicate that the practice of object control skills provide an alternative means to contribute to the achievement of recommended levels of MVPA. This alternative may be preferred by many who have previously developed the skill required for participation in activities that require object control skills to achieve recommended levels of MVPA throughout their lifespan (Breuer & Wicker, 2009). For example, if locomotor-based activities are prioritized over object control activities in a PE class because the former are perceived as a more effective means of meeting EE recommendations than the later, children and youth who might prefer certain activities (e.g., practicing penalty shots in soccer) may be discouraged from participation if they think (or are told) the only activities that count involve continuous activities (e.g., running). If activities integrate high effort object control skills at an execution rate of two trials per minute, regardless of any other simultaneous locomotor activity, these data indicate they will be obtain health enhancing levels of MVPA. From a learning or training perspective, the practice of object control skills at a rate of no less that two repetitions every minute provides ample time for PE teachers, coaches or trainers to instruct a performer and provide feedback that is critical to skill development while allowing for the attainment of energy expenditure to reach a threshold in accordance with recommended values of MVPA.

The practice and promotion of developmentally appropriate OPSP is a critical aspect of child development that are integrated into various games, sports, as well as leisure recreation activities. These skills also are integrated into various activities that are promoted across the lifespan (Breuer & Wicker, 2009). This study informs the work to rest ratios which may be ideal for practice of OPSP in a PE setting. The achievement of MVPA during the practice of OPSP can be achieved when performed at a rate of at least 2 trials per minute performed with 'maximal' effort. The time between trials performed at a rate of one performance every 30 seconds allows for instruction of skilled performance from a trained practitioner. These data suggest that practicing OPSP with at a rate of at least 5-10 trials per minute could provide a metabolic response to be categorized as vigorous activity.

While accelerometers used in this study did not fail to measure what they are intended to measure (i.e., number of movement accelerations at different intensities during nine-minute trials) they did fail to capture the EE associated with the neuromuscular demand of OPSP. The use of wrist-worn accelerometers has been promoted over those of hip-worn accelerometers for the measurement of PA levels in children (Evenson et al., 2008; Freedson et al., 2005) due to the wrists association with upper body movement (Chandler et al., 2016). For example, the cut-points associated with MVPA for wrist-worn accelerometers (moderate ≥ 6360 counts $min^{-1}$ [Chandler et al., 2016]) are significantly higher than those of hip-worn accelerometers (moderate ≥ 2296 counts $min^{-1}$ [Evenson et al., 2008]) in children. Furthermore, the cut-points associated with MVPA for non-dominant-wrist-worn accelerometers (moderate ≥ 6360 counts $min^{-1}$ [Chandler et al., 2016]) are significantly higher than those of the dominant-wrist-worn (i.e., more active limb during OPSP) accelerometers (moderate ≥ 4321 counts $min^{-1}$ [Crouter et al., 2008]) in children. Thus, the lack of validity in the measurement of EE or intensity levels during OPSP by accelerometers, as indicated by this study's findings, is a result of the neuromuscular demands of OPSP and lack of OPSP specific cut-points rather than a result of the wear location. Future research to develop cut-points, specifically for the use during OPSP, in both children and adults is warranted to address these measurement issues. Research demonstrates that the percentage of time in MVPA in PE classes or recess (as measured by accelerometers or pedometers) rarely meet the recommended guidelines of 50% of time in those activities nor of 60 minutes per day (Health & Services, 2008; Nadeau, Maahs, Daniels, & Eckel, 2011; Prevention & Promotion, 2011). Thus, an implication of these data may be that MVPA levels in PE, leisure games, and sports may be higher than previously thought, specifically if the curriculum and/or activities inherently include the repetitive practice of OPSP. Furthermore, PE and PA motor interventions which have previously been observed by accelerometry may have failed to accurately ascertain EE due to the intermittent nature of OPSP. Noted limitations in how PA intensity levels are currently assessed (e.g., hip worn pedometers and accelerometers mainly assess repeated excursions of the center of mass) may lead to a drastic underestimation of EE in activities that include OPSP (e.g., soccer or racquet sports).

In summary, this dissertation represents the first studies to: measure energy expenditure (EE) levels during object projection skill performance (OPSP) using indirect calorimetry, to measure EE levels during OPSP using indirect calorimetry in children, to demonstrate that skill level has a significant role in the production of EE during OPSP in children, to evaluate the ability of hip- and wrist-worn accelerometry to predict PA levels during OPSP in children and, to demonstrate that hip- and wrist-worn accelerometers fail to adequately predict PA intensity level during OPSP when compared to indirect calorimetry. Results indicate skill practice with a maximum of one trial every 30 seconds resulted in the equivalent of at least moderate PA and intervals of 12 and 6 seconds demonstrated vigorous PA for most individuals in both adults and children.

Life-long PA begins at an early age with promotion of, and participation in a variety of activities that require the OPSP (e.g., soccer, tennis, kickball, handball, racquetball, basketball, softball, pickleball), the importance placed on developing object projection skills may impact PA participation well into adulthood (Breuer & Wicker, 2009). As such, the health-enhancing high levels of EE during repetitive OPSP represent an alternative to continuous activities (brisk walking or running) which may be utilized by adults for the accumulation of recommended amounts of moderate-to-vigorous physical activity. The allure of accelerometry for use in large scale PA studies is grounded in their perceived ability to provide an accurate and objective estimate of an individual's PA. However, the disparity in levels of PA measured by indirect calorimetry and accelerometry during OPSP in this study was considerably large. These data demonstrate that hip-worn accelerometer adult cut-points (Freedson et al., 1998) as well as hip- (Freedson et al., 2005; Evenson et al., 2008) and wrist- worn (Crouter et al., 2015; Chandler et al., 2016) accelerometer cut-points lack prediction validity of EE and PA intensity level (via accelerometry counts) during OPSP in adults and children.

The early childhood years are a critical time for the development of PA habits and the development of motor skills as they are the building blocks for more complex movements (Clark & Metcalfe, 2002; Stodden et al., 2008). In light of these findings, repetitive OPSP (performed in practice, training, or leisure activities) may provide an alternative, to continuous activities (brisk walking or running) to assist in accumulating recommended doses of MVPA associated with health-enhancing benefits. These data have the potential to significantly impact physical activity intervention strategies and the implementation of PE curricula attempting to promote moderate to vigorous PA by informing specific trial intervals which promote health-enhancing physical activity levels (i.e., MVPA). Information gleaned from this study provides evidence that the practice of OPSP can aid in the achievement (acute) of recommended health-enhancing levels of EE (i.e., MVPA), as well as promote a foundation for skill development that promotes lifelong physical activity

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