2018

Calibration of an Accelerometer for Measurement of Very Light Intensity Physical Activity in Children

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by

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Bachelor of Science
The College of New Jersey, 2014

Submitted in Partial Fulfillment of the Requirements

For the Degree of Master of Science in

Exercise Science

The Norman J. Arnold School of Public Health

University of South Carolina

2018

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ABSTRACT

Obesity prevalence is continuing to rise in children in the United States. Decreased physical activity has long been thought to be a cause of this trend. As such, much of the accelerometer study has been focused on moderate to vigorous physical activity (MVPA). More recently, time spent in sedentary behavior has received much attention as well. There is an abundance of time spent in light intensity physical activity, and yet comparatively little focus has been placed on it in the field of accelerometer study. The purpose of this study was to generate an accelerometer count cut-point for the ActiGraph GT3X+ monitor that distinguishes sedentary behaviors from very light intensity physical activity, and very light intensity physical activity from light intensity activity in 10-12-year old children.

Eighteen children wore accelerometers on the hip and non-dominant wrist, along with a COSMED portable metabolic system. Participants engaged in nine structured activities in a laboratory setting. Respiratory gases and oxygen consumption were measured on a breath by breath basis and accelerometer data was collected at 15 second intervals. ROC curve analyses were used to generate count cut-points for very light intensity physical activity at the hip and non-dominant wrist sites.

Correlation between VO_2 (ml/kg/min) and accelerometer counts was strong for both the hip (r=0.95) and non-dominant wrist (r=0.82) across all activities. Cut-points for the hip site were identified as 10 counts/15 seconds for sedentary and 131 counts/15 seconds for very light intensity activity. Cut-points for the non-dominant wrist site were identified as

180 counts/15 seconds and 305 counts/15 seconds for sedentary and very light intensity activity, respectively.

This study was the first to identify accelerometer count cut-points for very light intensity activity for this age range. Findings suggest that the non-dominant wrist site is more effective at differentiating between the sedentary and very light intensity activities performed in this study than the hip site. The very light activities performed in this study required little trunk movement, which limited the effectiveness of the hip site in differentiating between sedentary and very light intensity. These findings provide a starting point for the refinement of accelerometer-based study of light intensity activities.

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CHAPTER 1

OVERALL INTRODUCTION

Physical activity researchers are primarily concerned with the relationship between time spent in physical activity intensity categories and various health outcomes. To examine these relationships, methods for differentiating between intensity categories are necessary (1). Due to their ability to record activity counts in a given time interval, accelerometers are a widely used method of doing so (1). An accelerometer must first be calibrated against a criterion measure of physical activity intensity, such as oxygen consumption (VO_2), in a controlled experiment in order to accurately measure activity intensities (1). Identifying accelerometer count cut-points that define different intensity categories is advantageous for larger scale studies where criterion measures of physical activity are not feasible.

Indirect calorimetry is a commonly used criterion measure used in calibration studies. Indirect calorimetry involves measuring heat production through the amount of oxygen consumed and the amount of carbon dioxide expired during an activity (2), which is used to quantify the intensity of the activity (3). Technological advances have allowed for portable metabolic systems that measure VO_2 during activity (4). One such portable system is the COSMED K5 model, which can measure oxygen consumption and carbon dioxide production on a breath-by-breath basis (4). The COSMED K5 system has been shown to be a valid, reliable, and accurate method of measuring oxygen uptake over a wide range of exercise intensities (4). When measured simultaneously with accelerometer counts, it allows for the determination of prediction equations and accelerometer count cut-points to differentiate between intensity categories. The determination of these cut-points provides operational definitions for objective physical activity measurement that can be used for large scale epidemiological studies.

The prevalence of overweight and obesity has increased in the United States since the early 21st century in both adults and youth (5), which led to increased attention on potential etiologies, treatments, and preventions (6). Epidemiological investigations revealed a decline in the number of children who were accumulating the Physical Activity Guidelines recommended amount of at least 60 minutes per day of moderate to vigorous physical activity (MVPA) which mirrored the rise in childhood obesity (6). This discovery led to MVPA being the primary early focus of physical activity study. Many devices were calibrated to generate count cut-points for MVPA for use in adolescent children. Early calibration studies focused on activities such as walking, jogging, and running (7), and as accelerometer technology advanced (triaxial vs uniaxial devices), more dynamic, free living activities began to be assessed (8). Cut-points were identified and confirmed (8, 9, 10) for many devices for use in larger studies. The primary outcome of interest of many of these studies was the amount of time that youth spent in MVPA in relation to the Physical Activity Guidelines.

Initially, it was thought that physical activity and sedentary behavior were two sides of the same coin; however, that began to change as evidence started to accumulate suggesting that the amount of time children spend in sedentary pursuits is an independent risk factor, distinct from physical activity (11). As sedentary behavior continues to gain acceptance as an independent risk factor for negative health outcomes, interest has grown in objectively assessing how much sedentary time children accumulate as well (12). Investigations revealed that markers of adiposity and cardio-metabolic risk are positively associated with sedentary behavior (11). Additionally, reducing the time spent in 5-19-minute sedentary bouts may be beneficial for children (13). MVPA, and more recently sedentary behavior, have been major focuses of accelerometry study, while light intensity activity has been somewhat neglected; however, interest in light intensity activity is starting to grow.

Children spend an abundance of time in light intensity pursuits, and yet comparatively little accelerometry study has been focused on it. More work is needed to examine the role of light intensity physical activity in health (14). There is a need to more precisely measure this light intensity activity. Often light intensity physical activity was treated as a default intensity category, between sedentary and MVPA. It currently encompasses a wide array of sitting, standing, and ambulatory activities (15). The current definition of light intensity activity may be too broad, and in order to further advance the field of accelerometer based physical activity study in children, light intensity activity should be further refined. Additionally, as screen time becomes more diverse and more prominent there is a need to better understand its role in health outcomes (14). Different devices can be used with different postures (i.e. sitting or standing). There is a need to explore how these postures affect the metabolic cost of these screen-based activities (14). This underscores the growing interest in differentiating activities that fall on the low end of the current light intensity activity definition from sedentary behaviors in children (14).

To accomplish this, accelerometers must be calibrated to generate accelerometer count cut-points defining a ‘very light’ intensity category in adolescent children. To address the gaps in the literature, the purpose of this thesis is to identify accelerometer count cut-points distinguishing sedentary behaviors from very light intensity physical activity, and very light intensity activity from light intensity physical activity in 10-12-year-old children.

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CHAPTER 2

MANUSCRIPT – CALIBRATION OF AN ACCERLOMETER FOR MEASUREMENT OF VERY LIGHT INTENSITY PHYSICAL ACTIVITY IN CHILDREN[1]

[1] Gorab JS, McIver KL, Weaver RG, and Pate RR. To be submitted

Introduction

The prevalence of obesity has increased in the United States since the early 21st century in both adults and youth (1). Decreased physical activity is believed to be a major factor underlying the increase in childhood obesity (2). The negative effects of low childhood physical activity can follow children into adulthood, with increased risk for chronic conditions such as diabetes and cardiovascular disease (3). Independent of low levels of physical activity, high levels of childhood sedentary behavior are associated with these acute and chronic adverse health outcomes as well (4). Recently, it has been suggested that physical activity and sedentary behavior should be considered two distinct constructs, independent of one another (5). Physical activity and sedentary behaviors track from childhood into young adulthood, demonstrating the importance of studying both physical activity and sedentary behaviors (6).

Accelerometry is a widely used objective measure of physical activity. Accelerometers can measure free-living physical activity, expressed as activity counts, expressed in various time intervals, for substantial time periods (7). In order to translate accelerometry data to physical activity in terms of intensity categories, the device must be calibrated against a criterion measure, such as indirect calorimetry. Many devices have been calibrated for use in adolescents by developing cut-points defining sedentary, light, moderate, and vigorous intensity (8, 9, 10, 11). The field of accelerometry has been focused primarily on assessing the amount of moderate to vigorous physical activity (MVPA) that adolescents perform so that compliance with current physical activity guidelines can be assessed. As sedentary behavior continues to gain acceptance as an independent risk factor for negative health outcomes, interest has grown in objectively assessing how much time children spend in sedentary behavior (12). Light intensity activity, which falls between sedentary and MVPA, has been largely ignored; however, interest in it is beginning to grow.

Children spend a considerable amount of time in light intensity pursuits, and yet comparatively little accelerometry study has been focused on it. More work is needed to examine the role of light intensity physical activity in health (13). As such, there is a need to more precisely measure light intensity activity. Often light intensity physical activity was treated as a default intensity category, between sedentary and MVPA. It encompasses a wide array of sitting, standing, and ambulatory activities (14). The current definition of light intensity activity may be too broad, and in order to further advance the field of accelerometer-based physical activity research in children, light intensity activity should be further refined. Additionally, as screen time becomes more diverse and more prominent there is a need to better understand its role in health outcomes (13). Different devices can be used with different postures (i.e. sitting or standing). There is a need to explore how these postures affect the metabolic cost of these screen-based activities (13). This underscores the growing interest in differentiating activities that fall on the low end of the current light intensity activity definition from sedentary behaviors in children (13). To accomplish this, accelerometers must be calibrated to generate accelerometer count cut-points defining a 'very light' intensity category in adolescent children. Therefore, the purpose of this study is to identify accelerometer count cut-points distinguishing sedentary behaviors from very light intensity physical activity, and very light intensity activity from light intensity physical activity in 10-12-year-old children.

Methods

Subjects

Eighteen children, ages 10 to 12 years, were recruited through various organizations in South Carolina. None of the participants had any physical impairments that affected their ability to participate in physical activity. Demographic and anthropometric characteristics of the sample are summarized in Table 2.1.

Study Design

A cross-sectional design was used, and data were collected in a single session. During the session, the participant performed nine structured physical activities in a laboratory setting. The protocol for this study was approved by the University of South Carolina Institutional Review Board. Prior to participation in this study, written informed consent was provided by the parent or guardian of the child. The child provided written assent to be a subject in the study as well.

Operational Definitions of Intensity Categories

To our knowledge, very light intensity physical activity has not been operationally defined in the literature. In order to identify corresponding accelerometer count cut-points, the intensity category must be physiologically and descriptively defined. For the purposes of this study, we operationally defined sedentary, very light intensity physical activity, and light intensity physical activity. The intensity groups were defined physiologically as metabolic equivalent (MET) values. The MET is a widely used physiological concept used for expressing the energy cost of physical activity as a multiple of resting metabolic rate (RMR), expressed as a VO_2 value (15). In adults, resting VO_2 is defined as 3.5 ml/kg/min, which equates to 1 MET (16). Children tend to have a higher resting VO_2 than adults; however, the ratio of activity energy expenditure to resting energy expenditure is similar (17). 10-12-year old children have a resting VO_2 of 5.4 ml/kg/min (16, 18). Adjusted VO_2 values corresponding to sedentary, very light, and light intensity activity for children in this age range are reported below.

Sedentary behavior is defined physiologically as any activity that requires energy expenditure at a rate of ≤1.5 METs. In this study, that corresponds to a range of VO_2 values between 5.5 and 8.2 ml/kg/min. Activities that fall in this category are classified as any passive lying, passive reclining, passive sitting, or passive standing activities (14).

Very light intensity activity can be defined physiologically as any activity that requires energy expenditure at a rate between 1.6-2 METs. In this study, that corresponds to a range of VO_2 values between 8.3 and 12.5 ml/kg/min. Activities that fall in this category are classified as any active standing and active sitting activities, requiring limb movement or weight shifting.

Light intensity activity can be defined physiologically as any activity that requires energy expenditure at a rate between 2.1-3 METs. In this study, that corresponds to a range of VO_2 values between 12.6 and 16.6 ml/kg/min. Activities that fall in this category include ambulation at slow speeds, ambulation while carrying a light load, or some locomotor or object control skill practice.

Activities

The activities chosen for assessment in this study were considered representative of those performed by 10-12-year old children both during the school day and outside of school. Nine activities were performed, each for 5 minutes. The majority of the activities were predicted to be sedentary, very light, or light intensity in order to satisfy the purpose of this paper. All activities were performed in a laboratory setting. Participants performed the activities in a manner that they self-selected. Trained data collectors supervised the session and ensured that each activity was performed continuously throughout the entire 5 minutes. The participant was given time to rest between each activity if needed. The list of activities is provided in Table 2.2.

Accelerometry

The Actigraph GT3X+ accelerometer is a multi-axial accelerometer that is small (1.50 x 1.44 x 0.70 inches), light weight (28 grams), and unobtrusive to the participant. It records data in the vertical, horizontal, and perpendicular axes. The vector magnitude (VM) incorporates movement of the vertical, horizontal, and perpendicular axes, creating a composite of the three. We chose to use the VM for this analysis because, when compared with the other axes, it was the most highly correlated with VO_2 across all activities for each site. The vertical axis, horizontal axis, and VM have similar classification accuracy, and the use of the vertical axis or the VM is recommended for developing cut-points for children in this age group (8). For the present study, the monitors were initialized to save data in 15-second intervals (epochs). The average accelerometer counts from minutes 3-5 of each activity were used for analysis. Children wore two accelerometers, one at a site above the iliac crest over the right hip, secured with an elastic belt worn around the waist, and a second on the non-dominant wrist, secured with a wrist strap. We chose to use the wrist accelerometer site, in addition to the hip site, due to evidence suggesting that it may be a better location for measuring time spent in sedentary behavior and light intensity activity in children (9, 19). Monitors were initialized prior to each session.

Metabolic Measures

Expired respiratory gases and oxygen consumption (VO_2) were measured on a breath-by-breath basis using the Cosmed portable metabolic system (Model K5). The COSMED K5 system has been shown to be a valid, reliable, and accurate method of measuring oxygen uptake over a wide range of exercise intensities (20). The unit is a lightweight system (<800 grams) that is worn on the back of the participant with the support of a harness. A small face mask was fitted for each participant to ensure that no air escaped from the mask. Prior to each session the system was calibrated with standard gases according to standard protocols. The average VO_2 (ml/kg/min) from minutes 3-5 was used for analysis.

Statistical Analysis

Accelerometry data were summarized as activity counts per 15 seconds. When compared with the other axes, the VM had the highest Pearson correlation with VO_2 values across all activities for both the hip (r=0.95) and the non-dominant wrist (r=0.82). For this reason, the VM was selected for analyses. Minutes 3-5 of each activity were used for the calibration analysis. Accelerometer counts and VO_2 were averaged over those 3-minute periods for each of the nine activities. Descriptive statistics were calculated for VO_2, accelerometer counts at the hip, and accelerometer counts at the non-dominant wrist.

To define upper and lower bounds of accelerometer counts corresponding to sedentary, very light, and light intensity activity, we first placed each of the performed activities into an intensity category. To do this, we first identified energy expenditure ranges, expressed as VO_2 values, that corresponded to each intensity category (i.e.

sedentary, very light, light, MVPA). The VO_2 thresholds for sedentary and MVPA in 10-12-year old children were determined from the existing literature (16, 18). In addition, we identified a VO_2 threshold for very light intensity activity as well. To accomplish this, we split the VO_2 range corresponding to the previously identified light intensity activity in half, and identified the lower half as very light, and the upper half as light. VO_2 ranges for each intensity category are shown in Table 2.2. Based on the mean observed VO_2 value, each activity was placed in one of four intensity categories.

Next, receiver operating characteristic (ROC) curve analyses were conducted to determine accelerometer count cut-points at different levels of sensitivity and specificity for the intensity categories of sedentary, very light intensity, and light intensity for each accelerometer site. For identification of the upper bound of the sedentary cut-point (and lower bound of the very light cut-point), only sedentary and very light intensity activities were included in the ROC curve analysis. We then classified those activities as a "1" if the activity was sedentary or a "0" if the activity was not sedentary. This served as the dependent variable for the analysis. The averaged 15 second VM accelerometer value for each participant was the independent variable in the model. ROC analyses produced a number of cut-point values and ranked them based on sensitivity (rates of true positives) and specificity (rates of true negatives). The Youden index (J) was used to select the cut-point that maximized sensitivity and specificity at each accelerometer site, as it has proven to be a suitable method for determining a generalizable cut-point (21). Area under the ROC curve (AUC) was used to determine how well the cut-point predicted the classes. The same procedure was used to identify the upper bound of the cut-point for very light intensity and the upper bound for the cut-point of light intensity physical activity. For identification of the upper cut-point for very light intensity, only very light and light intensity activities were included in the analysis. For identification of the upper bound for the cut-point of light intensity, only light and moderate to vigorous intensity activities were included in the analysis. SAS software was used for all analyses.

Results

Data from 18 children were available for analysis, and 61% of the children were males and 83% were Caucasian. The average age of the sample was 10.9 years. The BMI values of the sample ranged from 15.1 to 24.7. Caucasian, African American, and Asian children were included in the sample. Descriptive characteristics of the sample are presented in Table 2.3.

Mean VO_2 values and corresponding accelerometer counts for the hip VM and the non-dominant wrist VM for each of the nine activities are shown in Table 2.4. No significant sex or race differences were observed for VO_2 or accelerometer counts at either site. The lowest mean VO_2 and counts for both accelerometer sites were observed during the DVD activity and the highest mean VO_2 and counts for both accelerometer sites were observed during the jogging activity. The highest standard deviation in counts occurred during jogging for each accelerometer site. Higher standard deviations were observed with the non-dominant wrist site compared to the hip site for each of the activities.

ROC curve analysis produced a range of cut-points with various sensitivity and specificity values for each accelerometer site. As evidenced by the AUC values, the hip site was unable to successfully discriminate between sedentary and very light intensity activity. Compared to the hip, discrimination between sedentary and very light intensity was better for the non-dominant wrist site; however, it was still considered poor. Both accelerometer sites provided excellent discrimination between very light and light intensity activities. Discrimination between light intensity and MVPA was considered excellent and good, for the hip and non-dominant wrist site, respectively. Results from the ROC analysis are presented in Table 2.5. Cut-point ranges at the hip site were identified as 0-10 for sedentary, 11-131 for very light, and 132-563 for light intensity physical activity. Cut-point ranges at the non-dominant wrist site were identified as 0-180 for sedentary, 181-305 for very light, and 306-829 for light intensity physical activity. Plots of the ROC curves are shown in Figures 2.1, 2.2 and 2.3 for the hip accelerometer site and Figures 2.4, 2.5, and 2.6 for the non-dominant wrist accelerometer site.

Discussion

This study was the first to derive accelerometer count cut-points for measurement of 'very light' physical activity intensity in 10-12-year old children for the hip and the non-dominant wrist accelerometer sites. The main finding was that the wrist-worn monitor is superior to the hip monitor in differentiating between sedentary and very light intensity physical activity. This is likely due to the nature of the very light intensity activities. Referring to our operational definitions, limb movement is a major distinguishing factor between sedentary and very light intensity activities. In order to effectively differentiate between the two, the increased limb movement performed during very light intensity physical activity must be detected by the accelerometer. Non-dominant wrist accelerometer placement is able to capture more of the accompanying limb movement and thus, more effectively differentiates between sedentary and very light intensity activity. This finding is consistent with other findings in the literature, suggesting that the non-dominant wrist accelerometer site performed as well as the hip site using the Actigraph GT3X+, particularly in identifying sedentary and light intensity activity (19, 9). The non-dominant wrist placement was also very effective at differentiating between very light and light intensity physical activity, as well as light intensity physical activity and MVPA, in the current study.

The hip has been the primary accelerometer site used in physical activity studies and its ability to differentiate between light intensity physical activity and MVPA has been well documented in the literature (22, 23, 24, 25), as well as the current study. As interest grows in studying and refining light intensity physical activity (13), it may be necessary to re-evaluate the effectiveness of the hip accelerometer site in that regard. Results of the present study suggest that the hip accelerometer site is unable to differentiate between sedentary behavior and very light intensity activity. This is a major finding, as it supports the continued exploration of other accelerometer sites, such as the non-dominant wrist, in effectively refining the current definition of light intensity activity.

Comparison across studies is only beneficial if the studies employ the same model of accelerometer at the same site with a similar age group. Comparison of our study with other studies is particularly challenging due to the nature of the present study. Our study was designed specifically to develop cut-points that distinguish a ‘very light’ intensity activity category from sedentary behavior and light intensity activity. Due to the novelty of this intensity category, activities that we classify as ‘very light’ in the present study would be classified as either sedentary or light in other calibration studies. For this reason, comparisons between this study and others are particularly difficult; however, it is still useful to compare results to previously generated cut-points using similar age groups. These are summarized in Table 2.6. Although comparisons to other studies are difficult to interpret, the cut-points identified in the current study for sedentary behavior were considerably lower than that of the established literature for both the hip site (26) and the non-dominant wrist site (8).

Screen based activities are becoming more and more prominent, particularly among children (13). Different devices can be used with different postures (i.e. sitting or standing), resulting in a need to explore how these postures affect the metabolic cost of these screen-based activities (13). Results from the current study suggest that performing screen time standing in an upright position, as opposed to sitting, increases energy expenditure to a point where the activity is no longer sedentary. The seated video game and standing video game were played on the same device, and the postural adjustment to standing changed the activity from sedentary to very light intensity. The effect of standing as opposed to sitting on energy expenditure has been demonstrated in classroom settings (27), and the results of this study suggest that the effect may be observed with screen time as well. Findings from this study also suggest that standing upright may be a major factor in distinguishing sedentary behavior from very light intensity physical activity. This warrants further investigation.

A major strength of this study is the advancement of accelerometer measurement of sedentary behavior and light intensity activity. To our knowledge, we were the first to derive non-dominant wrist and hip accelerometer count cut-points to define a very light intensity activity category in 10-12-year old children. The identification of this activity category will allow for further refinement of accelerometry study related to light intensity physical activity in children. This study has some limitations as well. The sample size was relatively small and predominantly comprised of Caucasian children. In addition, the majority of the participants identified themselves as physically active and were of healthy weight status. This may limit generalizability of the findings. Another potential limitation lies in our findings with the hip accelerometer site. The hip has been a traditionally used site for accelerometer based physical activity study; however, little trunk movement is involved in very light intensity activities, which appears to limit the effectiveness of a hip-worn accelerometer in differentiating very light intensity activities from sedentary activities. Results of this study suggest that the non-dominant wrist may be superior to the hip in that regard.

Future studies should include a measurement of resting VO_2. Children have higher resting energy expenditures than adults (16, 18), and having measured resting VO_2 values, rather than using estimates derived from the literature, may improve the identification of intensity thresholds. Additionally, future studies should include more activities in each intensity category. In the very light intensity category, it would be beneficial to have activities that encompass the entire range of associated VO_2 values. In the current study, all of the very light intensity activities (standing texting, standing video game, and standing drawing), had mean VO_2 values that fell on the lower end of the very light intensity boundaries (Table 2.2 and Table 2.4). Having a better distribution of VO_2 values may help to improve classification accuracy of the identified cut-point. Finally, this is the first time a very light intensity cut-point has been identified in this age group, thus it should be tested in different, more diverse samples of 10-12-year old children to validate our findings.

Conclusions

The major finding of the current study was the wrist accelerometer site is superior to the hip accelerometer site in differentiating between sedentary and very light intensity physical activity. Very light intensity activities can be characterized by limb movement that is not detected by the traditionally used hip accelerometer site. Additionally, results of this study suggest that a change in posture from sitting to standing upright may be a major distinguishing factor between sedentary behavior and very light intensity activity. This was the first study to derive accelerometer count cut-points for measurement of very light intensity physical activity in 10-12-year old children. Future investigations should test these cut-points on different samples of children and in a wide variety of activities in order to further refine accelerometer-based study of light and very light intensity physical activity.

Table 2.1: Description of activities and identified intensity categories based upon observed mean VO_2 values.

Activity	Description	Intensity
Watch DVD	Sit in chair, watch DVD on a handheld tablet	Sedentary
Seated Reading	Sit in chair, read a book	Sedentary
Seated Video Game	Sit in chair, play video game on a handheld tablet	Sedentary
Standing Texting	Stand upright, text on a cell phone	Very Light
Standing Video Game	Stand upright, play video game on a handheld tablet	Very Light
Standing Drawing	Stand upright, draw picture on a large white board	Very Light
Walking	Walk at 1.5 mph on a treadmill	Light
Kicking	Standing upright, kicking 8” foam soccer ball back and forth with a partner continuously	Moderate-Vigorous
Jogging	Jog at 4 mph on a treadmill	Moderate-Vigorous

Table 2.2: VO_2 ranges in 10-12-year old children for each intensity category

	Resting	Sedentary	Very Light	Light	MVPA
VO_2 (ml/kg/min)	5.4	5.5-8.2	8.3-12.5	12.6-16.6	>16.6

Table 2.3: Descriptive characteristics of study participants (*n=18*)

Variable	Mean (standard deviation) or percent (n)
Sex	
Male	61% (11)
Female	39% (7)
Race	
Caucasian	83% (15)
African American	11% (2)
Asian	6% (1)
Age (years)	10.9 (0.87)
Height (cm)	148.2 (7.1)
Weight (kg)	41.3 (8.0)
BMI (kg/m^2)	18.7 (2.5)

Table 2.4: VO_2 and accelerometer counts by activity. Mean (standard deviation)

		Counts/15s	
Activity	**VO_2 (ml/kg/min)**	**Non-dominant wrist VM**	**Hip VM**
Watch DVD	7.5 (1.4)	27.6 (38.1)	2.7 (5.0)
Seated Reading	7.8 (1.7)	87.6 (131.5)	3.8 (5.3)
Seated Video Game	7.9 (1.6)	48.1 (51.0)	7.0 (12.9)
Standing Texting	8.3 (1.8)	151.9 (150.6)	9.5 (11.7)
Standing Video Game	8.5 (1.6)	98.2 (93.0)	6.4 (5.4)
Standing Drawing	8.8 (1.3)	193.0 (134.6)	19.9 (14.2)
Walking	16.3 (2.0)	533.5 (174.2)	409.2 (133.0)
Kicking	23.5 (4.9)	1661.3 (743.1)	783.2 (255.9)
Jogging	37.5 (4.8)	2397.9 (1564.1)	1676.3 (527.7)

Table 2.5: Accelerometer count cut-points defining sedentary, very light, and light intensity activity for the hip and non-dominant wrist sites.

	VO_2 threshold		ROC curve analysis				
	(ml/kg/min)		**Counts /15s**	**Sensitivity**	**Specificity**	**∗ AUC**	**† J**
Hip VM							
Sedentary	8.2		0-10	0.79245	0.38776	0.5300	0.18021
Very Light	12.5		11-131	1.0000	0.98182	0.9989	0.98182
Light	16.6		132-563	0.90244	1.0000	0.9550	0.90244
NDW VM							
Sedentary	8.2		0-180	0.84906	0.57143	0.6687	0.42049
Very Light	12.5		181-305	1.0000	0.87273	0.9690	0.87273
Light	16.6		306-829	0.73171	1.0000	0.8856	0.73171

∗AUC= Area under the ROC curve
† J= Youden Index

Table 2.6: Summary of accelerometer cut-points from selected studies

			ROC analysis: Intensity specific cut-points		
Source	**Accelerometer (site)**	**Activities**	**Sedentary**	**Light**	**Participant age (n)**
Romanzini et al. (26) *	Actigraph GT3X VM (hip)	Rest, DVD, videogame, standing, walking, running, other activities	0-180	181-756	10-15 (79)
This study *	Actigraph GT3X+ VM (hip)	DVD, reading, standing video game, walking, other activities	0-18	206-533	10-12 (18)
Crouter et al. (9) **	Actigraph GTX3+ VM (dominant wrist)	Rest and many others	0-100	101-609	8-15 (181)
Chandler et al. (8) **	Actigraph GT3X+ VM (non-dominant wrist)	Rest, coloring, walking, PACER, other activities	0-305	306-817	8-12 (45)
This study *	Actigraph GT3X+ VM (hip)	DVD, reading, standing video game, walking, other activities	0-81	305-547	10-12 (18)

* Counts per 15 seconds
** Counts per 5 seconds

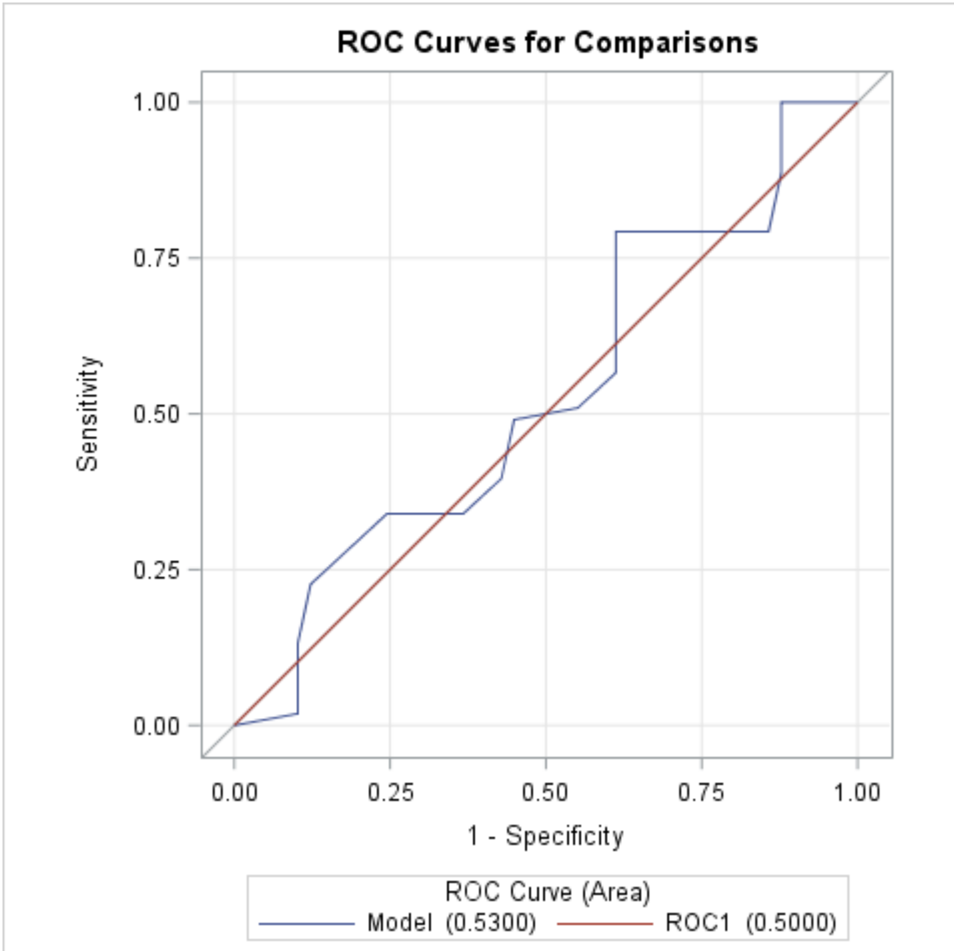

Figure 2.1: ROC curve for sedentary threshold at the hip site.

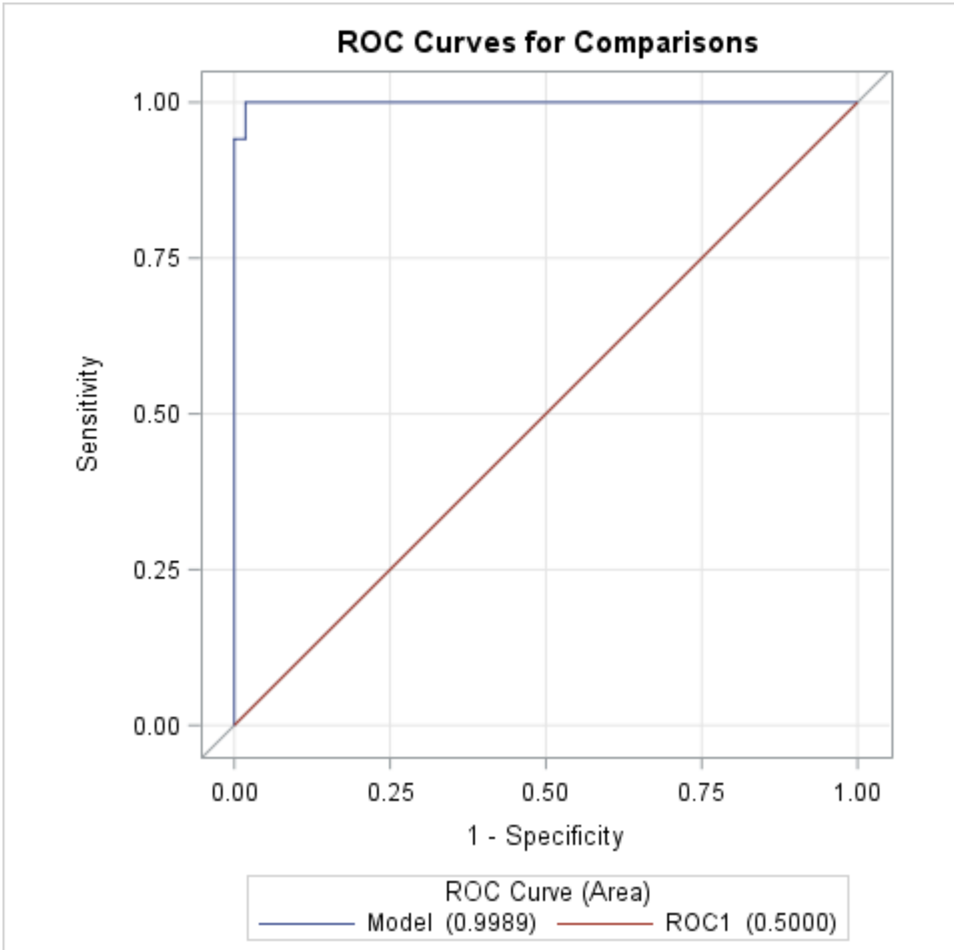

Figure 2.2: ROC curve for very light intensity threshold at the hip site

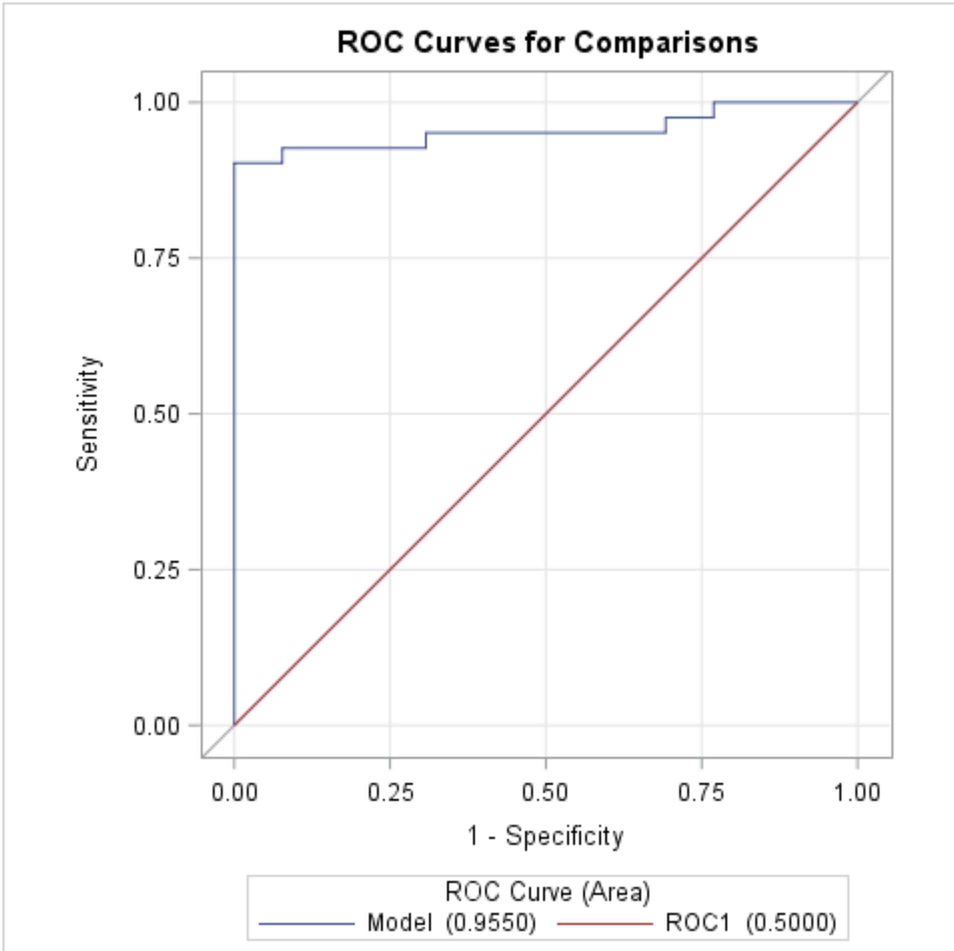

Figure 2.3: ROC curve for light intensity threshold at the hip site

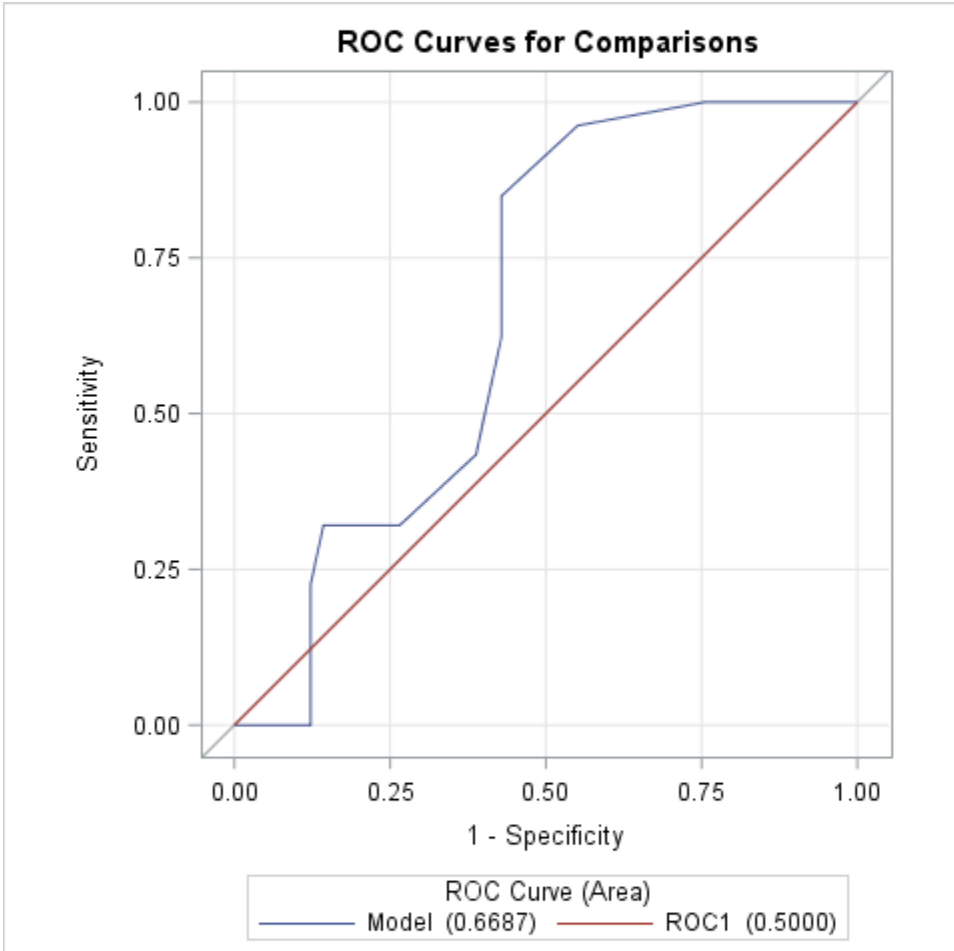

Figure 2.4: ROC curve for sedentary threshold at the non-dominant wrist site

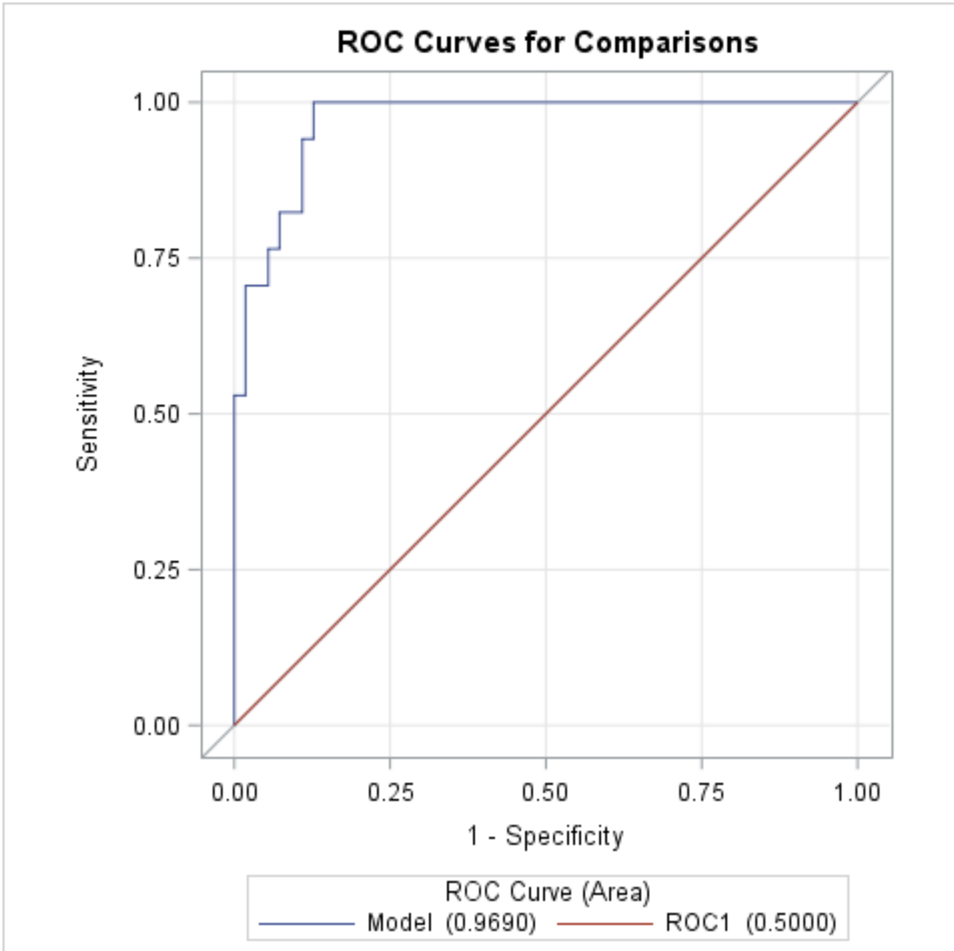

Figure 2.5: ROC curve for very light intensity threshold at the non-dominant wrist site

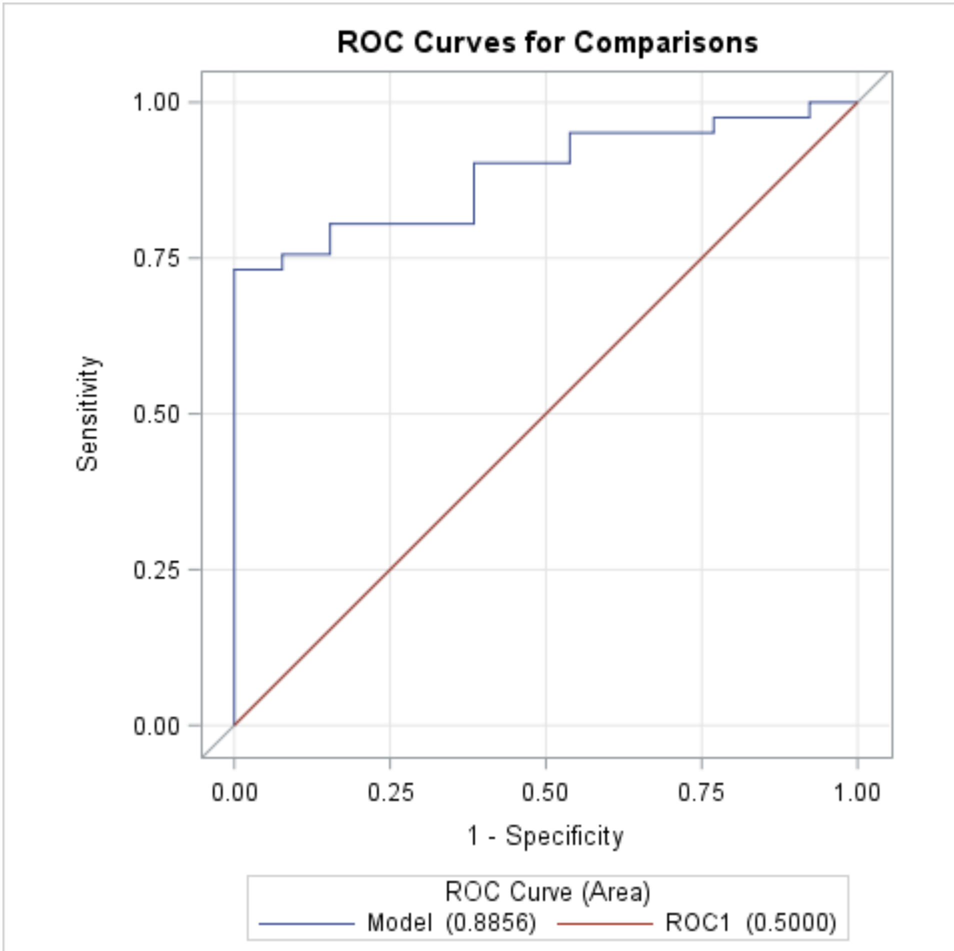

Figure 2.6 ROC curve for light intensity threshold at the non-dominant wrist site

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CHAPTER 3

OVERALL DISCUSSION

This study was the first to derive accelerometer count cut-points for measurement of 'very light' physical activity intensity in 10-12-year old children for the hip and the non-dominant wrist accelerometer sites. The main finding of the current study was that the wrist-worn monitor is superior to the hip monitor in differentiating between sedentary and very light intensity physical activity. This is likely due to the nature of the very light intensity activities. Referring to our operational definitions, limb movement is a major distinguishing factor between sedentary and very light intensity activities. In order to effectively differentiate between the two, the increased limb movement performed during very light intensity physical activity must be detected by the accelerometer. Non-dominant wrist accelerometer placement is able to capture more of the accompanying limb movement and thus, more effectively differentiates between sedentary and very light intensity activity. This finding is consistent with other findings in the literature, suggesting that the non-dominant wrist accelerometer site performed as well as the hip site using the Actigraph GT3X+, particularly in identifying sedentary and light intensity activity (1, 2). The non-dominant wrist placement was also very effective at differentiating between very light and light intensity physical activity, as well as light intensity physical activity and MVPA, in the current study.

The hip has been the primary accelerometer site used in physical activity studies and its ability to differentiate between light intensity physical activity and MVPA has been well documented in the literature (3, 4, 5, 6, 7), as well as the current study. As interest grows in studying and refining light intensity physical activity (8), it may be necessary to re-evaluate the effectiveness of the hip accelerometer site in that regard. Results of the present study suggest that the hip accelerometer site is unable to differentiate between sedentary behavior and very light intensity activity. This is a major finding, as it supports the continued exploration of other accelerometer sites, such as the non-dominant wrist, in effectively refining the current definition of light intensity activity.

Screen based activities are becoming more and more prominent, particularly among children (8). Different devices can be used with different postures (i.e. sitting or standing), resulting in a need to explore how these postures affect the metabolic cost of these screen-based activities (8). Results from the current study suggest that performing screen time in an upright position, as opposed to sitting, increases energy expenditure to a point where the activity is no longer sedentary. The seated video game and standing video game were played on the same device, and the postural adjustment to standing changed the activity from sedentary to very light intensity. The effect of standing as opposed to sitting on energy expenditure has been demonstrated in classroom settings (9), and the results of this study suggest that the effect may be observed with screen time as well. Findings from this study also suggest that standing upright may be a major factor in distinguishing sedentary behavior from very light intensity physical activity. This warrants further investigation.

A potential practical application of the very light intensity threshold is its use in breaking up bouts of sedentary time. Breaks in sedentary time and avoiding sedentary bouts of ≥10 minutes are associated with lower BMI and reduced cardiometabolic risk in 8-11-year-old children (10). The potential of using very light intensity activities to break up bouts of sedentary time has been demonstrated in a pair of adult studies. An intensity category of "low intensity" that fell between sedentary and light in adults was identified in the literature (11). A separate study investigated the association of breaks in objectively measured sedentary time with biological markers of metabolic risk in adults with a mean age of 53.4 years (12). Breaks in sedentary time were associated with improved markers of metabolic risk (12). These breaks, which elicited positive cardio-metabolic changes in adults, were in the intensity range of the 'low' category that was identified elsewhere in the literature (11). This low category is similar to the very light category in the present study, in that it falls between sedentary and light intensity activity. Comparison between the two adult studies and the current study is very difficult because of the different ages and epoch lengths used; however, it does demonstrate the potential benefits of using very-light intensity activities to break up sedentary time. Results from the current study provide a starting point for the definition of a very light intensity physical activity category in children. Further refinement of accelerometer count cut-points defining very light intensity physical activity can provide a preliminary definition of the activity intensity necessary to break up bouts of sedentary time. This may prove to be a very feasible method of breaking up bouts of sedentary time in children to implement in a variety of settings, such as the class room and home environment, where there are many opportunities for sedentary pursuits.

Comparison across studies is only beneficial if the studies employ same model of accelerometer at the same site with a similar age group. Comparison of our study with other studies is particularly challenging due to the nature of the present study. Our study was designed specifically to develop cut-points that distinguish a 'very light' intensity activity category from sedentary behavior and light intensity activity. Due to the novelty of this intensity category, activities that we classify as 'very light' in the present study would be classified as either sedentary or light in other calibration studies. For this reason, comparisons between this study and others are particularly difficult; however, it is still useful to compare results to previously generated cut-points using similar age groups.

VM generated cut-points for the hip accelerometer site in the literature are considerably higher for sedentary (0-180 counts/15 seconds) and light intensity activity (181-756 counts/15 seconds) than in the current study (0-10 and 132-563, respectively) (13). A calibration study using the dominant wrist accelerometer site on 8-15-year-old children identified counts defining sedentary behavior (0-100 counts/ 15 seconds) and light intensity activity (101-609 counts/ 15 seconds) that were higher than the results of the current study (0-180 and 306-829, respectively at the non-dominant wrist site) (2). It is possible that the dominant wrist placement as opposed to non-dominant wrist placement of the accelerometer contributed to these differences; however, we observed strong correlation (r=0.96) between dominant and non-dominant wrist counts in the current study, suggesting that accelerometer placement did not make considerable contributions to the observed differences. Finally, the non-dominant wrist accelerometer site was used to identify cut-points in 8-12-year old children, with heart rate as the criterion measure to calibrate the accelerometers (14). Identified cut-points were reported in 5 second intervals (14). The identified cut-points for sedentary (0-305 counts/ 5 seconds) and light intensity activity (306-817 counts/ 5 seconds) were considerably higher than those identified in the current study (0-180 and 306-829, respectively) (14). The use of a different criterion measure and shorter epoch length may have contributed to differences in the generated cut-points. Although the comparisons to other studies are difficult to interpret, we did observe a common theme. The generated cut-points for sedentary behavior in the current study were consistently lower than that of the established literature (2, 13, 14).

A major strength of this study is the advancement of accelerometry derived study of sedentary behavior and light intensity activity. To our knowledge, we were the first to derive non-dominant wrist and hip accelerometer count cut-points to define a very light intensity activity category in 10-12-year old children. The identification of this activity category will allow for further refinement of accelerometry study related to light intensity physical activity in children. This study has some limitations as well. The sample size was relatively small and predominantly comprised of Caucasian children. In addition, the majority of the participants identified themselves as physically active and were of healthy weight status. This may limit generalizability of the findings. Another potential limitation lies in our findings with the hip accelerometer site. The hip has been a traditionally used site for accelerometer based physical activity study; however, little trunk movement is involved in very light intensity activities, which appears to limit the effectiveness of a hip-worn accelerometer in differentiating very light intensity activities from sedentary activities. Results of this study suggest that the non-dominant wrist may be superior to the hip in that regard.

Future studies should include a measurement of resting VO_2. Children have higher resting energy expenditures than adults (15, 16), and having measured resting VO_2

values rather than estimates derived from the literature may improve the identification of intensity thresholds. Additionally, future studies should include more activities in each intensity category. Particularly in the very light intensity category, it would be beneficial to have activities that encompass the entire range of associated VO_2 values. In the current study, all of the very light intensity activities (standing texting, standing video game, and standing drawing), had mean VO_2 values that fell on the lower end of the very light intensity boundaries. Having a better distribution of VO_2 values may help to improve classification accuracy of the identified cut-point. Finally, this is the first time a very light intensity cut-point has been identified in this age group, thus it should be tested in different, more diverse samples of 10-12-year old children to validate our findings.

In conclusion, the major finding of the current study was the wrist accelerometer site is superior to the hip accelerometer site in differentiating between sedentary and very light intensity physical activity. Very light intensity activities are characterized by limb movement that is not detected by the traditionally used hip accelerometer site. Additionally, results of this study suggest that a change in posture from sitting to standing upright may be a major distinguishing factor between sedentary behavior and very light intensity activity. This was the first study to derive accelerometer count cut-points for measurement of very light intensity physical activity in 10-12-year old children. Future investigations should test these cut-points on different samples of children in order to further refine accelerometer-based study of light and very light intensity physical activity.

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CHAPTER 4

PROPOSAL

Introduction

The accurate measurement of free-living physical activity is vital for research studies in which the outcome or exposure of interest is physical activity (1). There is considerable evidence associating physical activity with many dimensions of health (2). Among these health outcomes associated with physical activity are cardiovascular disease, non-insulin-dependent diabetes, and obesity (3). The assessment of energy balance associated with these health conditions relies on precise measurements of energy expenditure (4).

The prevalence of overweight and obesity has been rising in the United States for several years in every segment of the population, including children (5). As a result, increased attention has been given to potential etiologies, treatments, and preventions (6). This led to greater interest in measuring children's physical activity levels (4). Subsequent investigations revealed epidemiological evidence of a decline in physical activity among youth in America in recent decades (6). The 2008 Physical Activity Guidelines for Americans recommend that youth participate in moderate-to-vigorous physical activity (MVPA) for at least 60 minutes every day (7). Physical activity levels that are lower than these recommendations in childhood are associated with an increased risk of childhood obesity (8). The negative effects of low childhood physical activity can follow children into adulthood, with increased risk for chronic disease risk factors such as hypertension, insulin resistance, and dyslipidemia (8). Independent of low levels of physical activity, high levels of childhood sedentary behavior are associated with these acute and chronic adverse health outcomes as well (8). Sedentary behavior is defined as sitting and lying during waking hours when there is very low energy expenditure (9). Pearson et al conducted a meta-analysis of the association between sedentary behavior and physical activity in children and determined that physical activity and sedentary behavior should be considered distinct constructs (9). Physical activity and sedentary behaviors track from childhood into young adulthood, demonstrating the importance of studying both childhood physical activity and inactivity (7).

To properly investigate the relationship between the physical activity, sedentary behaviors, and health outcomes, valid and reliable measures of physical activity are of critical importance (6). Precise measures of physical activity are crucial to determine the strength and direction of the association of interest (1). Historically, physical activity data had been collected via subjective measures, such as national health surveys (5). Subjective measures of physical activity, however, are vulnerable to considerable reporting bias, including social desirability bias and recall bias, which negatively impact the reliability of the measures (5). Social desirability bias refers to the tendency of research subjects to give socially desirable responses instead of choosing responses that are reflective of their true feelings (10). Recall bias can be described as embroidery of personal history by respondents due to memory failure (11). In the pre-adolescent population, physical activity had commonly been assessed via questionnaires or direct observation (6). Questionnaires and surveys are limited by the number and quality of questions that are used to assess behavior, and by their lack of reliability (6). Conversely, direct observation is very intrusive to the participant (6). An additional issue with direct observation is that the participant's behavior may be altered due to the presence of a researcher, a phenomenon known as participant reactivity (12). The need for more precise and convenient physical activity measurement methods led to the exploration of alternatives that did not rely on subjective information and minimized the effect of biases (1).

Technological advances spearheaded the shift to objective measurements of physical activity (13). Motion sensor based objective measures of physical activity, such as pedometers and accelerometers, eliminated many of the problems associated with self-report measures (14). Pedometers detect steps taken with acceptable accuracy, however, they are not designed to capture the intensity of activity (13). Accelerometers provide more information about physical activity than pedometers, and thus, the development of accelerometer technology provided a robust alternative for physical activity measurement in large populations (8). Accelerometers can capture free-living physical activity information, expressed as activity counts, on a minute by minute basis for substantial time periods (13). Activity count cut-points are developed in laboratory settings to translate the physical activity data into specific intensity categories, ranging from sedentary behavior to vigorous intensity activities (13). Coupled with the minute by minute activity counts, this allows researchers to objectively determine how much time a subject spends in each intensity category (14). This is particularly attractive to physical activity epidemiology researchers who are attempting to determine what proportion of the population is meeting activity guidelines or to determine a dose of activity that is sufficient to elicit health benefits, such as reducing the prevalence of obesity (14). To accurately determine the time spent in each activity category, valid and reliable methods of determining accelerometer cut-points are necessary.

Aim 1

To generate an accelerometer count cut-point defining a very light intensity physical activity category, differentiating from light physical activity, in 10-12-year-old children.

Aim 2

To generate an accelerometer count cut-point differentiating very light intensity physical activity from sedentary behavior in 10-12-year-old children.

Significance of the Proposed Study

The concept of physical activity profiling attempts to move beyond single point estimates of time spent in MVPA (13). Objective measurement of physical activity by accelerometers produces a wealth of information that can be assessed to better understand the nature of physical activity and sedentary behaviors (13). The effects of physical activity on health outcomes has been well documented and guidelines for physical activity recommendations have been established for all segments of the population, including children. Less is known about sedentary behavior, as it has only recently emerged as a distinct risk factor for cardio-metabolic diseases in children (15). It was once suggested that physical activity and sedentary behavior were two sides of the same coin, though this is no longer thought to be the case (15). There is accumulating evidence suggesting that the amount of time children spend in sedentary behavior is independent of other risk factors, such as physical activity (15).

Current evidence suggests that North American children spend between 40% and 60% of their waking hours engaging in sedentary behavior (15). Researchers have concluded that breaks in sedentary time are associated with a favorable cardio-metabolic profile in children (15). Reducing time spent in 5-19-minute sedentary bouts via activity breaks may be important, particularly for children who achieve lower levels of daily MVPA (16). In a study examining the effect of breaks in bouts of sedentary time in adults, the accelerometer measured average intensity of the breaks was on the low end of the light intensity category (17). Independent of total sedentary time, total number of breaks in this low intensity range were associated with benefits in waist circumference, body mass index (BMI), triglycerides, and glucose levels (17). Studies examining breaks in sedentary bouts in children have been very varied and therefore complicate the comparison between studies and in turn, the progression in this field of research in the childhood population (18). Research on sedentary behavior epidemiology in the child population is in its infancy, and standardized operational definitions of sedentary bouts and breaks, as well as the ability to differentiate between sedentary, standing, and light intensity activity, are urgently needed (18).

A practical application of defining a very light physical activity category using accelerometer counts in children is that it may better equip researchers in further investigation of the effects of breaking up bouts of sedentary time. Once the proposed aim is achieved, it can be utilized in future studies as a potential definition of the intensity level necessary to provide a break in a bout of sedentary time. Future researchers will be able to identify activities that fall in this very light intensity range in children. They can then investigate the effects of displacing bouts of sedentary time with these very light intensity activities. This may prove to be a very feasible method of breaking up bouts of sedentary time in children to implement in a variety of settings, including a classroom.

Review of Literature

Definitions

The metabolic equivalent (MET) is a widely used physiological concept used for expressing the energy cost of physical activity as a multiple of resting metabolic rate (RMR) (19). 1 MET can be defined as the quantity of oxygen consumed from inspired air under basal conditions, or at rest (19). It was determined through laboratory testing that 1 MET is equal on average to 3.5 milliliters of oxygen consumed per kilogram of bodyweight per minute (ml/kg/min) (19). As previously stated, activities are classified as multiples of 1 MET. Therefore, a 2 MET activity requires two times the metabolic energy expenditure of being at rest, and so on (20). Moreover, the energy cost of an activity is calculated by multiplying the MET level of the activity by the standard RMR value of 1 kilocalorie (kcal) per kg of bodyweight per hour (19). A commonly viewed advantage of the MET is that it provides a common descriptor of energy expenditure across populations (19). Using this information, a Compendium of Physical Activities was developed in 1993 to promote comparability of coding of physical activities across studies (20). The compendium was not developed to determine precise energy costs of physical activities, but rather to serve as a classification system to standardize MET intensities in research (19). The Compendium received widespread acceptance and has been revised multiple times as technology advanced and allowed for the inclusion of more MET values (21, 22). It was noted, however, that the Compendium MET values were intended for able bodied adults aged 18-65 and did not reflect the energy cost of children and youth (21).

The adult Compendium provided the framework for a Compendium of Energy Expenditures for Youth to be established. It is difficult to define levels of intensity in youth and using adult data to assign energy cost to children's activities can be problematic (4). Resting energy expenditure is influenced by physical characteristics, such as weight and maturation, so it can be very variable in children (23). Because of this variability, it is recommended that resting energy expenditure be directly measured or estimated using regression equations based on gender and age (23). While youth typically have a higher RMR than adults resulting in a larger gross energy cost, the ratio of activity energy expenditure and resting energy expenditure appears to be similar in adults and youth (4). Therefore, by using individualized measures of resting energy expenditure, the work rate of a given activity may be standardized across populations (23). There are 244 activities likely to be performed by children included in the Compendium of Energy Expenditure for Youth (4). About 35% of those activities have MET values based on data that was measured in youth (4). The remaining activities were assigned MET values based on values from the adult compendium using child RMR as correction factors, which was determined to be the most accurate technique when youth data is not available (4). The youth compendium is very useful in that it is an organized list that contains the most precise estimates of energy expenditure in youth (4). The youth compendium is an invaluable resource for researchers who are interested in characterizing physical activity in children (23).

Physical activity researchers are primarily concerned with the relationship between time spent in physical activity intensity categories and various health outcomes. To do this, methods for differentiating between intensity categories are necessary (24). Due to their ability to record activity counts in a given time interval, accelerometers are a promising method towards being able to accomplish this goal (24). The accelerometer must be calibrated against a criterion measure of physical activity intensity, such as oxygen consumption (VO_2), in a controlled experiment (24). A calibration curve relating VO_2 to accelerometer counts can then be fit to the data and used to estimate a MET score from accelerometer counts (24). Identifying MET scores from accelerometer counts that correspond to intensity categories is advantageous for larger scale studies where criterion measures of physical activity are not feasible.

Calorimetry can be defined as the measurement of heat lost or gained by a system, corrected for as many extraneous heat losses or gains as possible (25). Indirect calorimetry involves measuring heat production through the amount of oxygen consumed and the amount of carbon dioxide expired during an activity (25). These criterion measures are used to quantify the intensity of the activity (26). Indirect calorimetry is a commonly used method of measuring VO_2 in calibration studies. Technological advances have allowed for portable metabolic systems that measure VO_2 during activity (27). One such portable system is the COSMED K4b2 model, which measures oxygen consumption and carbon dioxide production on a breath-by-breath basis (27). The unit is programmed with the participant's age, gender, height, and weight. This information is used to determine energy expenditure, and in turn the intensity of the activity in METS. The COSMED K4b2 system has been shown to be a valid, reliable, and accurate method of measuring oxygen uptake over a wide range of exercise intensities (27). When measured simultaneously with accelerometer counts, it allows for the determination of prediction equations and accelerometer count cut-points to differentiate between intensity categories. The determination of these cut-points allows for objective physical activity measurement than can be used for large scale epidemiological studies, which demonstrates the importance of calibration studies.

Adult Calibration Studies

One of the earliest calibration studies was performed in 1993 (28). The purpose of the study was to determine the accuracy of the Caltrac personal activity computer during walking and running (28). The Caltrac measured acceleration in the vertical plane (28). The sample consisted of 10 men and 10 women who were moderately to well-trained (28). The subjects wore two Caltrac accelerometers, one on each hip, while expired air and inspired air were measured throughout the protocol (28). VO_2 and energy expenditure were calculated every 30 seconds (28). Each subject walked at speeds of 2-5 miles per hour (mph) and ran at speeds of 4-8 mph for 4 minutes at each speed (28). The average of the last 2 minutes of each bout was used for analysis (28). Analysis of Variance (ANOVA) with repeated measures was used to compare the Caltrac and indirect calorimetry estimates of energy expenditure during walking and running (28). Pearson correlation coefficients and linear regression were determined for the pooled data, walking and running separately, and at each speed (28). They found that the Caltrac did not adequately discriminate between running speeds of 5-8 mph (28).

A few years later in 1998, a similar study was conducted using the Computer Science and Applications (CSA) accelerometer (14). The sample in this study consisted of 25 males and 25 females with a mean age of 23.9 years (14). The CSA model that was used in this study was a uniaxial accelerometer (14). A 60 second epoch was used, and activity counts were expressed as the average counts per minute over 6 minutes of exercise (14). The CSA accelerometer was worn over the right hip and oxygen consumption was measured minute by minute using open circuit spirometry (14). Each participant performed 6 minutes of slow walking, fast walking, and jogging (14). Linear regression was used to establish the relationship between metabolic cost and accelerometer counts (14). It was determined that there was adequate discrimination between count ranges to discern different intensities of exercise (14). Accelerometer count cut points were identified as follows; Light intensity activity was defined as <1952 counts per minute, moderate intensity was defined as 1952-5724 counts per minute, and hard (or vigorous intensity) was defined as 5725-9498 counts per minute (14). This became the most widely used simple linear regression model for the CSA, later renamed ActiGraph, single axis accelerometer worn on the hip (29).

Calibration studies conducted with this early generation of accelerometers began by focusing on dynamic activities such as walking and running to develop prediction equations (30). The accelerometer technology grew very capable of capturing these dynamic activities (30). Since that time, accelerometer technology became more accessible and the application of accelerometers as a measure of physical activity expanded exponentially (31). As interest grew, studies shifted focus to activities that were more generalizable to the full range of activities performed in daily life, such as housework and gardening activities (30). This also included static activities where body acceleration and energy expenditure are not tightly coupled (30). The inclusion of new activity types and intensities produced considerable variation in prediction equations and cut-points, even when using the same accelerometer (30). Moderate intensity cut-points obtained from walking and running equations were much higher than cut-points obtained from life-style oriented activities (30). This created a wide range of measures that became much less comparable, which lessened the ability to interpret the accelerometer data (30). An additional issue with these early studies was that none of the attempted to characterize the low end of the physical activity spectrum by separating inactivity from light activity (30). Researchers concluded that these accelerometers provided useful objective information about dynamic activities such as walking and running, but more studies were needed to identify cut-points that differentiate inactivity and light intensity activities (30). Another finding was that a single hip mounted accelerometer is not sufficient for certain activities with complex movement patterns (30).

The hip has been the conventional attachment site for accelerometers due to its proximity to the center of mass (32). Some evidence suggests, however, that the wrist may be a more ideal attachment site because it can capture the arm motions of non-ambulatory based activities such as desk working (32). In 2000, a prediction model was created relating CSA counts to energy expenditure using a combination of data from two CSA accelerometers, one on the right hip and the other on the dominant wrist (33). They used a combination of lifestyle and dynamic activities, including walking, yardwork, and family care (33). The accelerometers were set to a 60 second epoch time interval (33). The hip and wrist regression equation explained more variability than the regression equation using the hip alone, and it was concluded that an accelerometer worn on the wrist along with one worn on the hip would increase the accuracy of predicting energy expenditure of various activities compared with an accelerometer worn only on the hip (33). The increase in accuracy was small, however, and researchers determined that it was offset by the extra time required to analyze the data (33).

In 2013, the first study was conducted to validate the ActiGraph GT1M, worn on the right hip, against the criterion measure of indirect calorimetry during level and graded walking (34). The GT1M model could sample data at 30 Hz which was an improvement over sampling frequencies of earlier models (34). They had a sample of 20 healthy adults with a mean age of 28.2 years (34). The epoch period was set to 10 seconds and collapsed to 60 second epochs for comparison to other studies (34). Linear regression was used to establish the relationship between energy expenditure and accelerometer determined physical activity (34). The researchers concluded that the ActiGraph GT1M was able to discriminate between speeds in the normal walking range as well as between level and graded walking, indicating that it was a valid tool for assessing walking across a wide range of speeds and gradients (34). This model was better able to observe changes in grade due to the improved sampling frequency of the model (34).

Another model from the new generation of ActiGraph accelerometers was the GT3X/GT3X+ (35). One updated feature of this model was that it had the ability to determine the sum of movement over 3 axes (35). A study was conducted to compare the GT1M and GT3X models, worn on the right hip, during treadmill exercise at 3 different speeds, against the criterion measure of VO_2 obtained through indirect calorimetry (36). Both models were significantly positively correlated with VO_2 (36). It was hypothesized that the GT3X would more effectively quantify physical activity by measuring motion in more planes than the GT1M (36). Results did not support this hypothesis, as the 3-

dimensional GT3X was not more accurate than the uniaxial GT1M in measuring walking and running (36). Several authors have suggested, however, that the tri-axial GT3X may be more sensitive to the torsional, non-vertical movement associated with free living activities (36).

This information appears to illustrate that the advantage of using tri-axial accelerometers lies in the measurement of free living activities. This may be beneficial for distinguishing sedentary and light intensity activity, a gap in the literature (30). Technological advances have allowed for development of newer versions of accelerometers that can capture and store raw acceleration signals with higher sampling frequencies up to 100 Hz (31). With these advances, it is important to harness the advantages of raw acceleration signal data (31). It is recommended that accelerometers be tri-axial and provide raw acceleration data when measuring sedentary behavior (37). Researchers also suggested that thigh worn accelerometers are the gold standard for measuring sedentary behavior but acknowledges the potential of hip and wrist worn accelerometers in this area (37). It was determined that more research is needed to better understand and identify clinically relevant measures to describe sedentary behavior (37).

Of particular interest is breaks and bouts of sedentary behavior. Along these lines, a study was conducted to examine the association of breaks in objectively measured sedentary time with biological markers of metabolic risk in adults with a mean age of 53.4 years (17). Each minute that accelerometer counts were <100 was identified as sedentary time, and a break was identified as a minimum of 1 minute in which accelerometer counts rose to levels above 100 counts per minute (17). The average intensity of breaks was 514 counts per minute and the average duration was less than 5 minutes (17). Breaks of this intensity and length were associated with improved markers of metabolic risk (17). In a separate study, an intensity category called "low intensity" was identified that fell between sedentary and light (38). The cut-points identified for this low intensity category was 100-499 counts per minute, which is in range of the intensity level of the breaks in sedentary time identified previously in the literature (17). Both studies used the early generation of the uniaxial ActiGraph accelerometer (17, 38). As mentioned earlier, that more research is needed to better understand clinically relevant measures to describe sedentary behavior (37). This work provides a platform on which to further investigate the necessary intensity of breaks in sedentary time, and the clinical impact of such breaks. The improvements made in accelerometer technology since the completion of these studies should provide more insight into the area of breaks in sedentary time.

Children Calibration Studies

In 1998, the validity of the CSA accelerometer as a measure of children's physical activity was evaluated using energy expenditure determined by indirect calorimetry as the criterion measure (39). The study consisted of 30 children ranging in age from 10 to 14 years (39). Two accelerometers were worn with one on each hip, and they were set to 60 second epochs (39). Subjects performed two 5-minute bouts of treadmill walking at different speeds and one bout of treadmill jogging, with 3-minute rest periods between each bout (39). A prediction equation for energy expenditure was determined using stepwise multiple linear regression with CSA counts per minute and body mass as predictors (39). There was strong and significant correlation between actual and predicted mean energy expenditure at each treadmill speed (39). It was determined that the uniaxial

CSA accelerometer was a reliable and valid tool for quantifying treadmill walking and running in children aged 10 to 14 years (39).

In a study published in 2004, researchers attempted to generate cut-points defining sedentary, light, moderate, and vigorous activity in middle school girls, aged 13-14 years (24). ActiGraph accelerometers were worn by participants on the right and left hip and activity counts were stored in 30 second time intervals (24). The 30 second epoch was chosen because children tend to complete activities more sporadically than compared to adults (24). 10 activities typical to middle school girls, ranging from sedentary to vigorous, were completed for 7 minutes each, with necessary rest in between (24). Resting VO_2 was obtained for 15 minutes prior to the activities (24). MET values were computed based on the individualized resting values rather than the standard adult MET, because resting VO_2 tends to be higher in children than in adults (24). These individualized MET values were then used for further analysis (24). The method of selecting optimal cut-points was based on sensitivity, the correct identification of the target or higher intensity, and specificity, which is the correct exclusion of lower intensity activities (24). Using moderate activities as an example, an observation was considered a false positive when it did not represent moderate activity but was interpreted as moderate activity (24). A false negative was an observation known to represent moderate activity that was interpreted as less than moderate activity (24). Cut-points were established in this way for each intensity category (24). Optimal thresholds for each intensity were the cut-points that balanced and minimized the number of false positives and false negatives (24). Cut-points were reported in counts per 30 seconds and counts per 60 seconds, as counts per minute is standard in the literature (24). Sedentary behavior was defined as

<100 counts per minute, light activity was 101-2999 counts per minute, moderate activity was 3000-5200 counts per minute, and vigorous activity was >5200 counts per minute (24). It was determined that accelerometers worn at the waist do not work well for certain activities, including upper extremity work, and may be limited in their ability to estimate activity levels or metabolic rates during cycling, stair stepping, or other similar activities (24).

In 2006 the uniaxial ActiGraph accelerometer was calibrated on preschool children aged 3-5 years against the criterion measure of VO_2 collected via indirect calorimetry (40). This was the first calibration study conducted on this population using a 15 second epoch (40). The shorter increment was recommended because children tend to perform physical activity in short bouts (40). Resting VO_2 was obtained for 10 minutes and then the participants performed structured ambulation at 3 different paces for 5 minutes each, with adequate rest time between each bout (40). A regression line was calculated using ActiGraph accelerometer counts as the only independent variable (40). Cut-points were determined for MVPA and vigorous physical activity using the generated equation (40). Researchers concluded that the established cut-points could be used for pre-school age children when accelerometer data was collected in 15-second intervals (40). This continued the trend towards capturing accelerometer data in shorter increments when studying physical activity in children.

In 2008, the uniaxial ActiGraph accelerometer was calibrated against indirect calorimetry in 5-8-year-old children (41). The accelerometer was placed on the right hip and the activity counts were stored in 15 second intervals (41). Resting VO_2 was recorded for 15 minutes and 9 activities ranging from sedentary to vigorous were performed for 7 minutes each (41). Cut-points were identified by the point at which sensitivity and specificity were maximized using receiver operating characteristic (ROC) curve analysis (41). Cut-points for the ActiGraph accelerometer were reported as counts per 15 seconds and were identified as follows: Sedentary behavior was ≤25, light intensity activity was 26-573, moderate intensity activity was 574-1002, and vigorous intensity activity was ≥1003 (41). Results from this study suggested that the identified cut-points provide excellent discrimination across intensities and that age-specific cut-points were not needed in this age group (41).

In 2011, the uniaxial ActiGraph GT1M accelerometer was calibrated against indirect calorimetry on 7-year-old children (8). The accelerometer was worn on the right hip and 15 second epochs were used (8). Participants were required to perform seven activities that were selected to provide a full range of intensities and reflect free living activities typical of 7-year-old children (8). Linear discriminant analysis (LDA) was used to determine optimal bounds of each of the non-sedentary intensity categories (8). ROC curves were used to assess the discriminatory power of the cut-points proposed by LDA via their sensitivity and specificity (8). Identified cut-points were reported as counts per minute and were as follows: sedentary behavior was ≤100, light intensity activity was 101-2240, moderate intensity activity was 2241-3840, and vigorous intensity activity was ≥3841 (8). These defined cut-points were very comparable to the cut-points defined by Evenson et al on a similar age range using 15 second epochs with the uniaxial ActiGraph accelerometer, demonstrating consistent findings with similar methodologies (8). It was concluded that to keep findings consistent, it may be beneficial to include children of narrow age ranges due to considerable variation in height, leg length, and movement economy that may affect count values registered by hip worn accelerometers (8). Researchers also concluded that evaluating cut-points based on the optimal sensitivity and specificity values obtained from ROC analysis reduces the misclassification of physical activity (8).

The effectiveness of the ActiGraph in assessing children's sedentary time was examined because there had been considerable variability in the cut-points used to identify sedentary time using the ActiGraph in child populations (42). A sample of 56 children between the ages of 8-12 were included in the study, and the accelerometers were worn for 2 days (42). ActiGraph counts were measured against activPAL accelerometers worn on the thigh, which had demonstrated reliability and validity for measuring sitting time in adults (42). The ActiGraph sampled data in 15 second epochs (42). ROC analysis was used to determine optimal sensitivity and specificity for sitting time, and they found that was at an accelerometer cut-point of 24 counts per 15 second epochs (42). This cut-point confirmed previously identified cut-points (8, 41). Researchers determined that 100 counts per minute provided a good estimate of free living sitting time in children during school hours (42). However, it was concluded that more research was needed to examine the 100 counts per minute cut-point against health indices in children (42).

In 2015, cut-points were identified for the tri-axial ActiGraph GT3X+, worn on the non-dominant wrist, in children aged 8-12 years (43). Heart rate was used to measure intensity (43). The accelerometers were set to record in 5 second epochs, utilizing the benefits of advances in technology to record the data in even shorter increments (43). Activities were performed in a summer camp setting and were designed to mimic free living activities as well as structured activity (43). All activities, including resting, were performed for 10 minutes, except for the PACER test (43). ROC analysis was used to determine cut-points for each intensity category (43). The findings of this study suggested that meaningful physical activity intensities can be distilled using the ActiGraph GT3X+ among children aged 8-12 in a setting where wrist placement is advantageous (43). A similar study was conducted in youth between the ages of 8-15 using the Actigraph GT3X set to record in 5 second epochs (44). They also used structured and unstructured, free living activities (44). Indirect calorimetry was used as the criterion measure and the accelerometer was placed on the dominant wrist (44). Researchers in this study chose the dominant wrist because they believed it would detect more of the activities performed requiring the dominant hand, which would provide a better overall estimate of energy expenditure (44). They developed dominant wrist cut-points using ROC curve analysis along with wrist regression equations to distinguish sedentary behavior from light physical activity (44). Researchers determined that placing the ActiGraph on the wrist may be a better location than the hip for estimating child-MET's and time spent in each intensity category (44). It remained unclear whether dominant or non-dominant wrist location should be used, but this study showed promising results with the dominant wrist (44).

In a review of the literature on accelerometer calibration in children, it was recommended that, given the sporadic nature of physical activity in children, 5 second epochs may be necessary, and raw acceleration may be appropriate in some instances (1). This trend was observed in the literature as shorter epochs were used as technology improved. Subsequent reviews agreed, recommending that studies determine cut-points using raw counts or very short epoch lengths that provide comparable data to previously used longer epochs (45, 31). It was concluded that the potential advantages of raw acceleration signal data must be harnessed (31). One area of note that needs attention is sedentary behavior. Due to alternative and portable platforms for television viewing and active video games, it may no longer be appropriate to infer sedentariness from reported behavior relating to screen use (9). This creates a more pressing need to assess sedentary behavior objectively to create a better understanding of children's sedentary behavior patterns (9). Numerous cut-points have been established to classify sedentary behavior, and the choice of cut-point can change estimates of sedentary time by more than 4 hours per day (45). In a review of the literature describing bouts and breaks in sedentary time, researchers found inconsistent definitions of bouts and breaks, which made comparison particularly difficult (18). An important issue that was emphasized was the need to distinguish between light, moderate, and vigorous breaks in sedentary time, and to differentiate sedentary time from light intensity physical activity when measured objectively (18). They concluded that standardized operational definitions of sedentary bouts and breaks are urgently needed (18).

To summarize, calibration studies using indirect calorimetry as the criterion measure have demonstrated that accelerometers are very effective in their ability to capture dynamic and laboratory-based activities such as walking or running (30). The technological advances of tri-axial accelerometers provided an effective measure of intensity during free living physical activities (30). The ability of accelerometers to identify time spent in MVPA in many populations has been well established in the literature (1, 5, 14, 30, 31, 41). Independent of MVPA, bouts of sedentary behavior are considered a risk factor for adverse health outcomes in children (15). Breaking up bouts of sedentary time appears to be beneficial, however more research is needed to determine standardized, objective definitions of bouts and breaks in sedentary time (16, 18). There is a gap in the literature regarding the objective measurement of these sedentary behaviors (18). Altenburg and colleagues identified a need to distinguish between sedentary, standing, and light intensity activity (18). Universal accelerometer count cut-points to differentiate between these intensity categories are needed to advance the field of accelerometer measured sedentary behavior (45).

Methods

Purpose

The purpose of this study is to further advance the field of accelerometer study by generating an accelerometer count cut-point distinguishing very light intensity physical activity from light intensity physical activity in 10-12-year-old children. Additionally, the generated cut-point will distinguish very light intensity activity from sedentary behavior in 10-12-year-old children.

Operational Definitions

Sedentary behavior includes passive lying, passive reclining, passive sitting, and passive standing activities (46). Examples of activities that fall in this category are reading, and screen time (television, computer, some video games, telephone) in a lying, reclined, or seated position, in which there is little to no limb movement (46). Sitting in a car, bus, or train and stationary standing or supported standing, such as standing while holding a parent’s hand, without shifting weight or accompanying limb movement also qualifies as sedentary behavior (46). This can also be defined physiologically as any activity that produces ≤1.5 MET intensity levels, or an activity that requires ≤1.5 times the energy expenditure, expressed as METS, as is required at rest for an individual.

The very light physical activity intensity category includes active standing and active sitting activities. Examples of these would be seated or standing activities that require some limb movement or weight shifting, such as washing dishes, preparing food, painting, drawing, playing a video game, or playing an instrument (46). Very light intensity activity can be defined physiologically as any activity that produces 1.6-2 MET intensity levels, or an activity that requires 1.6-2 times the energy expenditure, expressed as METS, required at rest for an individual.

Light intensity activity includes activities that require light effort such as ambulation at slow speeds, ambulation while carrying a light load, or skill practice such as low intensity kicking or throwing. Light intensity activity can be defined physiologically as any activity that produces 2.1-3 MET intensity levels, or any activity that requires 2.1-3 times the energy expenditure, expressed as METS, required at rest for an individual.

MET levels are reported in both absolute terms and relative to resting energy expenditure because resting energy expenditure can be influenced by factors such as weight and maturation for children in the 10-12 age group, however the ratio of activity energy expenditure and resting energy expenditure appears to remain similar to that of adults (23). Activities that fall in this very light intensity range, as identified by the determined accelerometer count cut-points, can then be tested in future studies to determine their effectiveness in breaking up bouts of sedentary time in children. The hope is that this very light intensity category, identified objectively by accelerometer counts, can become an operational definition of the physical activity intensity necessary to break up a bout of sedentary time and improve the cardio-metabolic profile of children in this age group.

Study Design

This is a cross-sectional study using accelerometer counts and indirect calorimetry data collected simultaneously on 10-12-year-old-children from South Carolina.

Participants

We are targeting boys and girls aged 10-12 from all race, ethnicity, and income groups to create a diverse and representative sample of healthy youth in South Carolina. Exclusion criteria include inability to follow instructions (due to language barrier mental impairment, etc.) and any physical impairment affecting the ability to stand in an upright position, and any physical impairment affecting proper use of the limbs. Potential participants will be recruited via word of mouth and by flyers using the snowball sampling technique. The flyer will have information about the study that is pertinent to the participant.

Sample

The sample will consist of 20 children between the ages of 10 and 12. A total sample of 20 children was selected based on the recommendation that studies should include at least 10 subjects per age group because body mass is known to be a significant factor in the relationship between accelerometer signal and energy expenditure (1). Written informed consent will be obtained from parents and assent forms will be obtained from the participants prior to participation in the study.

Measures

Data collection will be completed at the Public Health Research Center at The University of South Carolina. The visit should take between 60 and 90 minutes to complete. Participants will be encouraged to refrain from eating for at least 90 minutes prior to the visit.

During the visit, trained data collectors will measure the participant's standing height, seated height, and weight using a standardized protocol while he/she is wearing loose fitting clothes with shoes and socks off. Next, they will fit the participant with 5 ActiGraph GT3X+ accelerometers. They will be worn around each wrist, over the right hip, and around each ankle. The hip monitor will be attached to an elastic belt and worn over the participant's clothing. The wrist and ankle monitors will be attached using small adjustable straps around the wrist and ankle.

Trained data collectors will also fit the participant with a COSMED K4b2 portable metabolic system to measure energy expenditure via indirect calorimetry. The COSMED K4b2 is a portable device that measures oxygen consumption and carbon dioxide production. It is worn on the back with a harness. It is light weight (less than 5 pounds) and attaches to the participant via straps around the torso and over the shoulders. A flexible rubber facemask will cover the participant's mouth and nose. The mask is secured via straps around the back and top of the head. The participant will be given adequate time to become accustomed to wearing the mask and harness, as well as breathing through the face mask before the activity assessments begin. Nine activities, including resting, will be completed by the participant, each lasting 5 minutes. The Actigraph activity monitors and COSMED system will be worn for the entire duration of the testing session. Recovery time will be given as needed between activities. There will be no coaching for any of the activities aside from ensuring that directions are being followed and tasks are being completed as intended. The activities were chosen to be representative of activities performed by children in this age group, ranging from sedentary to MVPA, consistent with MET values provided by the Compendium of Energy Expenditure for Youth and with the operational definitions discussed earlier. An overview of the activities will be provided before assessments begin. The activities that will be completed are as follows:

Resting watching a DVD: The participant will sit reclined in a chair and watch an age appropriate DVD. He/she will be instructed not to sleep or make any sudden movements during this period. A resting measure of energy expenditure is included due to the variation in resting VO_2 in children. It is recommended that individualized resting energy expenditure be measured for use in child calibration studies (1, 2, 23).

Seated reading: The participant will sit in a chair and read an age appropriate book. This activity is considered a passive sitting activity, and therefore was chosen to represent sedentary behavior.

Standing texting: The participant will stand in an upright position and type text messages on a cell phone. This activity is considered a passive standing activity and was chosen to represent sedentary activity.

Seated videogame: The participant will sit in a chair and play a standardized, age appropriate video game on a tablet. This activity was chosen to represent very light activity as an active sitting activity.

Standing videogame: The participant will stand in an upright position and play a standardized, age appropriate videogame on a tablet. This activity can be classified as an active standing activity, and thus was chosen to represent very light intensity activity.

Drawing on a board: The participant will stand in an upright position and draw a standardized picture on a large white board using markers. This activity is considered active standing and was chosen to represent very light intensity activity.

Slow walk: The participant will walk at 1.5 miles per hour (mph) on a treadmill. This activity was chosen to represent light intensity activity as it involves ambulation at slow speeds.

Kick a ball: The participant will stand in an upright position and kick a ball back and forth with a partner with light effort. This activity is considered low intensity skill practice and was chosen to represent light intensity activity.

Light jog: The participant will jog at a speed of 4mph on a treadmill. This activity was chosen to represent MVPA and anchor the calibration study.

Variables

Descriptive variables will be obtained from all participants, including standing height, seated height, weight, sex, age, and race. Anthropometric measurements will be taken by trained data collectors using standardized protocols. Seated height will be used in equations to estimate age at peak height velocity as a measure of maturity for each participant. Height, weight, sex, and age variables will be entered into the COSMED K4b2 system for each participant to measure energy expenditure during each activity. The dependent variable will be energy expenditure, defined as MET values recorded by the COSMED K4b2 during each activity. MET values will be recorded via indirect calorimetry. This process measures the oxygen inspired and carbon dioxide expired to determine heat produced during each activity, and thus the energy expenditure of the activity in METs. Accelerometers will collect data for the duration of each activity. Accelerometer data will be collected in the raw data format, consistent with recommendations (1, 31, 37). The raw accelerometer data will then be collapsed to 5 second epochs as recommended in the literature (1). The mean counts recorded during minutes 3-5 of each activity will serve as the independent variable.

Analysis

Means and standard deviations will be calculated for hip worn accelerometer counts and VO_2 observed during rest and each activity. Intercepts and slopes will be fitted for each participant, and then an overall regression line will be calculated. Count cut-points for sedentary behavior, very light intensity, and light intensity physical activity will be identified through visual inspection of the distribution of VO_2 values observed during the activities. This is similar to the method of analysis used previously in the literature (40). This method will be used because there is variability in resting energy expenditure in children, so adult metabolic equivalent-based cut-points may not be appropriate (23, 40).

Additionally, receiver operating characteristic (ROC) curve analysis will also be conducted to determine accelerometer count cutoff values. The light jog will be excluded from this analysis, as the protocol is not designed to determine a cut-point involving moderate intensity activity. The remaining activities will be grouped based on their expected intensity categories. Average 5-second accelerometer values from minutes 3-5 of each activity will serve as the independent variable in this analysis. The dependent variable will be an indicator variable, identified as either a 0 or 1, for each activity, depending on the expected intensity category of each activity. The optimal cut-point will be determined based on the points at which sensitivity and specificity are maximized. A similar analysis was performed previously in the literature (41).

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