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Exploring Children’s Physical Activity Levels Through Structure and Measurement

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Exploring Children’s Physical Activity Levels Through Structure and Measurement

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Dedication

This dissertation is dedicated to my dog, Duke. He’s been an exceptional source of stress relief throughout this process. He also gave the best feedback when preparing for my defense as I practiced for him at least 40 times. Thanks bud, you’re the best!
Acknowledgements

I would like to acknowledge several people and organizations that have helped a tremendous amount throughout this process. First, and foremost, I would like to acknowledge Dr. Beets, my mentor. You pushed me to grow as a person, then grow as a researcher. Thank you for never coddling, but always encouraging. I don’t know anyone like you, nor do I think anyone will ever live up to your mentorship. So thank you for being you. Secondly, Glenn Weaver, you have more patience than anyone I’ve ever met. Thank you for being kind and supportive even during some of the more trying, difficult times. I would also like to acknowledge the ever-changing members of the Policy to Practice in Youth Programs research group for making our job more fun than I would have ever imagined. Finally, I would like to acknowledge all of the community partners that have welcomed us into their programs and have shown their commitment to our future generation’s health and well-being.

From a far, I have to thank Monica and Leslie, my best friends for always being supportive, pushing me forward in this process, and cheering me along every single step of this process from 400 miles away. Also, thank you to Sarah for cheering me along the way, helping me with accelerometers, watching Duke when I had long days, and being utterly excited for every bit of progress I made. To Jesse, thank you for your unwavering support during the triumphs and tears. You all have helped more than you will ever know.
Lastly, I would like to acknowledge my amazing family. Thank you all for your support and encouragement in getting me to where I am today. I love you all. Even you, Butterball.
Abstract

The purpose of this dissertation was twofold: 1) to establish best practices for wrist-based accelerometry for 5-11 year old children and 2) to explore the contribution of activity structure to children’s physical activity (PA) levels.

The purpose of study 1 aimed to determine differences in counts/5second epoch produced by the dominant and non-dominant wrist during seated, sedentary activities in 5-11 year old children and ultimately create a cutpoint threshold to distinguish seated sedentary behavior from light physical activity. 167 children, ages 5-11 years, performed up to 8 sedentary activities for 5 minutes while wearing ActiGraph GT3X+ accelerometers on both wrists. Participants walked at a normal pace to elicit light physical activity. The optimal cutpoint threshold for the non-dominant wrist was 203 counts/5s with sensitivity, specificity, and an area under the curve (AUC) of 71.56, 70.83 and 0.72, respectively. A 10-fold cross-validation revealed an average AUC of 0.70.

The purpose of the study 2 was to develop an equating system to translate estimates of moderate-to-vigorous physical activity (MVPA) collected at the wrist to those previously published collected at the hip. 185 children ages 5-11 years wore an ActiGraph GT3X+ on the hip and the non-dominant wrist for up to three hours. Data was distilled into minutes of MVPA using six commonly used hip-based cutpoints (i.e. Evenson, Pate, Puyau, Mattocks, VanCauwenberghe, and Freedson) and one non-dominant wrist-based set of cutpoints (i.e. Chandler). Among the six developed regression equations, the proportion of variance ranged from Freedson 0.29 to Puyau 0.81.
and the absolute error ranged from Pate 20.7% to Puyau 42.9% at the individual level. When cross-validated at the group level, % differences in actual versus predicted values ranged from Puyau -1.8% to Mattocks 56.3%.

The purpose of Study 3 was to determine which structure of PA elicits the most MVPA: 1.) free play (FP), 2.) organized, adult-led activities (ORG) or 3.) a mixed condition in which both FP and ORG were offered during the same opportunity (MIX). Participants included 197 unique children that were 53% male, 55% Caucasian, and averaged 7.7 years. Statistically significant differences were observed in the percent of time boys spent in MVPA during FP and MIX compared to ORG sessions (35.8% and 34.8% vs. 29.4%). No significant difference was observed in the percent of time girls spent in MVPA during FP compared to ORG or MIX (27.2% and 26.1% vs 26.1%). Both boys and girls experienced ~10% less time sedentary during FP compared to ORG and MIX.

This dissertation was the first to assess the contribution of activity structure to children’s PA levels. It was also the first to our knowledge to address the timely matter of the use of wrist-based accelerometry to assess PA levels and how this change impacts accurate measurement and comparisons of PA in youth. In conclusion, this dissertation represents a novel approach in the analysis of children’s physical levels through measurement and activity structure.
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Chapter I

Introduction

Study 1

The National Health and Nutrition Examination Survey (NHANES) has recently changed its physical activity monitoring protocol to incorporate wrist-placed accelerometers in place of the traditionally used waist-placed accelerometer.[1] The device (ActiGraph GT3x+) will remain the same; however the placement of the device has been altered. Calibration studies have created wrist-based cutpoint thresholds for determining what range of “activity counts” corresponds to different activity intensities (i.e., sedentary, light, moderate, vigorous and moderate-to-vigorous intensities).[2, 3] While both the NHANES and ActiGraph’s protocol suggest that the monitor be placed on a person’s non-dominant wrist, some researchers have chosen to use the dominant wrist, regardless.[2]

Placement of the ActiGraph GT3x+ on the dominant wrist may over-estimate the intensity of physical activity, especially light physical activity, since it is the adjacent intensity to sedentary behavior. Sedentary behavior can be defined by energy expenditure (EE) between 1.0 and 1.5 metabolic equivalent units.[4] Sedentary behavior can also be defined by posture: lying down, sitting and screen-based activities. Most sedentary behaviors of youth include large amounts of hand movement, without any movement.
occurring at the hip. Placement of an activity monitor on the dominant wrist, compared to traditional hip placement, is likely to result in increased activity counts, for metabolically insignificant movements, during sedentary behavior.

Sedentary time for children may include a variety of activities such as writing, coloring, playing video games, watching television, reading, arts and crafts, etc. While some of these activities are almost completely motionless (e.g., watching television and reading), most involve some upper extremity movement (video games, coloring, writing). A recent study aiming to determine if waist derived cut-points could be used for wrist-mounted accelerometers by Kim et al.[5], included sedentary activities in which movement occurred in neither hand or both hands (e.g., sitting on a chair, watching television, playing video games, etc.), however this gives no insight into those activities commonly performed by children that solely utilize the dominant hand. In Kim’s study, the accelerometer was only worn on the non-dominant wrist, whereas Crouter and colleagues created cut-point thresholds using counts produced from only examined the dominant hand.[2] The proposed study aims to monitor the wrist activity of both the non-dominant and dominant hand during a large number of commonly performed sedentary activities.

The objective of this study is to establish best practices related to placement of the wrist-mounted ActiGraph GT3x+, exploring differences between counts produced from accelerometers placed on both wrists during commonly performed sedentary activities among 5-12 year old children. A secondary purpose of this study is to determine optimal cutpoint thresholds to distinguish sedentary behavior from light physical activity for both wrist placements. Aim 1 of this study was to determine differences in activity counts
between dominant and non-dominant wrist-placed accelerometers during 8 commonly performed sedentary activities. Specifically, we will examine the difference counts per 5 second epochs produced by the dominant and non-dominant wrist of each participant to ultimately determine if the use of only one placement is warranted in future studies. Further, Aim 2 was to determine an optimal cut-point threshold that distinguishes between wrist movement during sedentary behavior and light physical activity. Specifically, we will evaluate the counts per 5 second epochs of 8 commonly performed sedentary activities in which children partake as compared to light physical activity to determine an optimal cut point value that best distinguishes the two intensity levels. This proposed study is significant because of the nationwide shift of focus from a hip-mounted to a wrist-placed accelerometer. Findings from this study will help determine if there are differences in activity counts between the dominant and non-dominant wrist, filling the literature void of whether placement on the non-dominant wrist is necessary. The proposed study is innovative because, while suggestions have been made to wear the ActiGraph GT3X+ on the non-dominant wrist, no other study has explored if differences exist in the accumulated activity counts during sedentary activities between the dominant and non-dominant placement.

Study 2

Historically, physical activity (PA) assessment has typically been conducted using hip-placed motion sensors.[6-8] Recently, there has been a consumer and researcher-based shift towards placing activity monitors on the wrist to improve compliance and capture upper extremity movement that may not be captured when the device is affixed at
The most recent cycle of the National Health and Nutrition Examination Survey (NHANES) changed its PA monitoring protocol to incorporate wrist-placed accelerometers instead of the traditionally used hip-placed accelerometer. The device (ActiGraph GT3x+) will remain the same; however the location of the device has been changed from the hip to the non-dominant wrist. Calibration studies are necessary with each generation of an existing activity monitor as well as with each new placement of existing monitors. In other words analytical procedures used for a hip-based accelerometer cannot simply be applied to data collected by the same device placed at the wrist. As a result of this, there is no method for comparing PA levels between hip and wrist-based data. While wrist-based accelerometry is relatively new, its use certainly on the rise, both nationally and internationally, as NHANES and several local and overseas research groups are currently utilizing the wrist-worn ActiGraph. As wrist-based PA data continues to accumulate, a method for comparing activity levels to previously published hip-based PA data is a necessity.

As new placements for activity monitors are introduced, analyzing and synthesizing PA data is becoming increasingly more difficult. Wrist-placement of activity monitors is becoming more popular; however this only increases confusion when comparing activity levels across studies that use different placements of the same device for monitoring PA. When considering accelerometer data collected at the hip, there are a multitude of factors that result in incomparability across studies such as various activity monitor manufacturers, updated devices and technology, and differing analytical procedures such as choice of cutpoint threshold or epoch length. With the recent rise in popularity of wrist-based monitoring, placement of device should be added to the list of
considerations. As previously mentioned, data from the wrist cannot simply be compared to data collected at the hip, even if it is collected with identical devices. With national and international focus shifting towards wrist-based PA monitoring, an equating system to compare hip and wrist-based data is warranted to most accurately synthesize estimates of PA across different placements. This will result in the ability to most accurately identify trends in accumulated PA, monitor progress towards PA policies and guidelines, and inform future public health efforts.

The objective of this study is to compare wrist-based versus hip-based accelerometer counts as they relate to activity intensity classification in 5-12 year old children. A secondary purpose of this study is to determine if MVPA estimates distilled from wrist-based data can be appropriately translated and compared to data distilled from hip-based data. Aim 1 of this study was to compare the acceleration counts by epochs between wrist and hip accelerometer placement during free-living activities in 5-12 year old children. Specifically, we will examine the concurrently measured accelerometer counts per 5 second epochs produced by hip and wrist placements and determine if one placement’s counts can be scaled to the other. Additionally, Aim 2 was to compare estimates of MVPA between wrist-based cutpoints and commonly used hip-based cutpoints when applied to data collected during free-living activity measured by accelerometers placed at both the wrist and hip locations. Specifically, we will examine activity levels of 5-12 year old distilled using recently published wrist cutpoints and widely used hip-based cutpoints to determine if the two locations provide comparable estimates of activity.
Through analysis of concurrently measured wrist and hip-based activity counts, the proposed study will provide detailed information regarding movement at two locations during free-living activity in 5-12 year old children. The expected outcome from this study includes insight to the scalability of wrist-based activity counts vs. hip-based counts. Findings from this study will help inform the conversation regarding the comparability among studies utilizing hip-based versus wrist-based accelerometry. This proposed study is significant because of the nationwide shift of focus from hip-mounted to wrist-placed accelerometers. The proposed study is innovative because the novel idea of translating data collected by the same device at two different placements (hip vs. wrist) has yet to be done. The proposed study will result in a better understanding of how data collected at the wrist can relate to data collected at the hip.

Study 3

Over the past decade, numerous state and national physical activity (PA) policies have been adopted that call on afterschool programs (ASPs) to provide children opportunities of engagement in up to 30 minutes of moderate-to-vigorous physical activity (MVPA) and reduce time spent sedentary while in attendance.[13] Although well intended, policies fail to outline how ASP providers can achieve stated policy goals. ASPs schedule 60 minutes per day for PA, averaging 45 minutes of uninterrupted time allotted solely to PA opportunities. Unfortunately, ASP providers fail to use this time to get children “up and moving”. This is clearly reflected from our previous extensive work that indicated children attending ASPs do not achieve recommended levels of MPVA during the program.[14, 15]
Identifying strategies to maximize children’s accumulation of MVPA during pre-existing time scheduled for PA opportunities is a priority; however, there is little scientific evidence on how this is best achieved. Typically, ASPs employ two general strategies – organized games (e.g. adult-led) and unstructured play (e.g. free-play) – as part of children’s PA time. There is no clear answer on which activity structure is most effective in providing MVPA opportunities for children.[16] Recent research has shown that free play elicits higher levels of MVPA compared to traditionally played, adult-led games during a 20-minute session[17], however it has also been shown that children participating in free play experience an immediate “spike” in MVPA, followed by a steady decline in intensity over a 20-minute period.[18] An approach to combat the steady decline in activity levels experienced during free play may be to offer organized, adult-led activities. While each activity structure has various strengths, it is unclear as to which structure can provide the greatest amount of MVPA for children during a 45-minute session. There is no prior research to inform ASPs on the most effective scheduling approach (e.g. organized play only, free play only, a combination of both) to elicit the highest amount of MVPA during the amount of time commonly allocated for activity opportunities in ASPs.

The objective for this study is to identify how to best maximize accumulation of MVPA during time allocated for physical activity in ASPs. To accomplish this objective, we will conduct an experiment on children’s PA levels during different activity structures - free play only, organized play only, or combination of both. This proposed study will utilize two ASPs, with each serving approximately 150 children daily. A counter-balanced, experimental design with four conditions will accomplish the
following two specific aims. Specific Aim 1 for study 3 was to determine the structure of physical activities that elicits the most MVPA while reducing time spent in sedentary behavior of children attending an afterschool program. Specifically, the experimental design of the proposed study will allow the identification of activity structure (i.e., all free play or all organized play) and sequencing of the two structures that produces the most MVPA. Specific Aim 2 was to identify gender and age differences of activity levels by activity structure. Specifically, we will determine if differences exist in activity levels between gender and age groups, providing the most effective activity structure in maximizing MVPA levels in varying groups of children.

Through this experiment, we will determine which activity structure elicits the highest amounts of MVPA at a group level. Further, we will identify any gender and age differences in activity levels attained through all variations of activity structures. We hypothesize that a combination of free play and organized activities, with free play occurring first, will produce the highest amount of time spent in MVPA. The expected outcome from this study is that a combination of adult-led and free play activity sessions elicits the greatest amount of time spent in MVPA. Additionally, it is expected that gender and age differences exist, with younger children (≤9 years) accumulating more activity in free play than their older counterparts (9-12 years). We also anticipate for girls to accrue lower levels of MVPA than boys across all variations of activity structure and sequencing. Finally, we expect that a significant age by gender interaction is a strong possibility in that younger girls and boys will have similar activity levels and as age increases, the gap between boys and girls activity levels will widen.
The proposed research is innovative because no study to date has examined differences in activity levels among free play, adult-led activity, and a combination of both activity structures. Additionally, the proposed research is significant because the results will help inform practitioners of potential best practices in scheduling physical activity for children.
Chapter II: Manuscript 1

Analysis of Accelerometer Counts during Sedentary Activities on Dominant and Non-Dominant Wrists in 5-11 year old Children

1 Chandler, J.L., Drenowatz, C., Moore, J.B., Sui, X., and M.W. Beets. To be submitted to Medicine & Science in Sports & Exercise
Abstract

Purpose: A calibration study was conducted to empirically derive a wrist-placed cut-point threshold for distinguishing seated sedentary behaviors involving upper extremity movement from light intensity walking using the ActiGraph GT3X+ in children. Methods: 167 children, ages 5-11 years, performed up to 8 seated sedentary activities for 5 minutes each while wearing accelerometers on both wrists. Activities represented seated sedentary behaviors normally performed by children of this age range and included: reading books, sorting cards, cutting & pasting, playing board games, eating snack, playing with tablets, watching TV, and writing. Participants walked at a normal pace to elicit light physical activity. Direct observation was used to verify seated sedentary behavior versus light activity. Participants were stratified by gender and age, then randomly assigned to a calibration group (n=100) or a validation group (n=67). A ten-fold Receiver Operator Characteristic (ROC) analysis was used to determine optimal cut-point thresholds. Quantile regression models estimated differences in counts/5s produced between dominant and non-dominant placement.

Results: The optimal cutpoint threshold for the non-dominant wrist was 203 counts/5s with sensitivity, specificity, and an area under the curve (AUC) of 71.56, 70.83 and 0.72, respectively. A 10-fold cross-validation revealed an average AUC of 0.70. Significant differences were found in counts/5seconds produced by dominant and non-dominant placement in five of the eight sedentary activities, with the dominant wrist eliciting higher counts/5s.

Conclusion: Classification of seated sedentary behaviors using the wrist-mounted ActiGraph GT3X+ can be performed with similar confidence as results from previously
published hip and wrist-based cut-point thresholds. Results from this study support the recommendation that accelerometers be placed on the non-dominant wrist to minimize “noise” experienced during seated sedentary behaviors.

**Introduction**

Measurement of physical activity and sedentary behavior is evolving. Recently the National Health and Nutrition Examination Survey (NHANES) discontinued the use of the previously validated hip-mounted ActiGraph GT3x+ to measure physical activity and time spent sedentary, replacing it with the wrist-mounted ActiGraph GT3x+.\[19\] Improved user compliance, an improved ability to measure sleep patterns, as well as the capability of capturing more upper extremity movements that may not have been captured using a device mounted at the hip were all considerations for moving the device to the wrist. [9, 10, 20]

Because of this change, the device’s commonly used activity “count” output must be calibrated and validity of data reduction approaches should be established using the new placement location (i.e. wrist).\[12, 21\] While both the NHANES and ActiGraph’s protocol suggest that the monitor be placed on a person’s non-dominant wrist, researchers have begun collecting data without evidence informing which wrist placement yields more accurate assessments of physical activity or time spent sedentary.\[2, 22-24\] The non-dominant wrist has been proposed to ensure that activity counts collected during sedentary behaviors that involve upper extremity movement isn’t misclassified as physical activity (e.g., coloring, writing, playing with mobile electronic devices). Placement of the ActiGraph GT3x+ on the dominant wrist may misclassify time spent sedentary as time spent physically active. This issue is especially relevant to
distinguishing light physical activity from time sedentary as it is the activity intensity adjacent to sedentary.

Sedentary behavior in children is defined by energy expenditure (EE) of 2.0 metabolic equivalent units (METS) or below [25] or by posture: in the lying down or sitting position. [4] Many sedentary activities in youth include large amounts of hand movement with little to no movement occurring at the hip. Examples of this include writing/coloring, videogames, board games, and most school work. Placement of an activity monitor on the dominant wrist, therefore, is likely to result in increased activity counts for metabolically insignificant movements such as writing, coloring, playing video games, watching television, reading, arts and crafts, etc. Recent calibration studies have created wrist-based cutpoint thresholds for determining what range of “activity counts” correspond to different activity intensities (i.e., sedentary, light, moderate, vigorous and moderate-to-vigorous intensities). [2, 26] Yet both calibration studies and other recent research included limited sedentary activities that require very little upper extremity movement. [2, 25, 26] Restricting activities to include such limited movement of the upper extremities is likely to have resulted in an underrepresentation of the range of counts/5s for seated sedentary behaviors of elementary-aged children.

Empirical evidence for best practices related to placement of the wrist-worn ActiGraph GT3X+ and for defining sedentary behavior needs to be collected to better inform recommendations related to monitor usage and placement and data reduction. Thus, the purpose of this study was to examine differences between counts produced from accelerometers placed on dominant and non-dominant wrists during commonly performed seated sedentary activities that require upper extremity movement among 5-11
year old children and determine optimal cutpoint thresholds to distinguish sedentary behavior from light physical activity for both wrist placements.

Methods

Children between the ages of 5 and 11 years were recruited from one YMCA summer camp in Columbia, SC to take part in this study. Children were eligible to participate in the study if they had no physical limitations that restricted their upper or lower body movements, and could walk without an assistive device. Participants self-reported their age and dominant hand. Each child’s parent provided consent and each child gave verbal assent prior to each day of data collection. All methods were approved by the University of South Carolina Institutional Review Board.

Protocol

Data collection took place at a YMCA summer camp location over a four-week period. The testing protocol lasted between 45-60 minutes per data collection session, and on average, three sessions were conducted each day. Seated sedentary activities included: reading books, playing/sorting cards, cutting and pasting from magazines, playing board games, eating a snack, playing games on a tablet, watching TV, and writing with a pencil. Walking served as the light intensity activity from which all sedentary activities were distinguished. A description of all activities is listed in Table 1. Prior to data collection, all accelerometers were initialized to begin and end recording data at the same time from the same computer using Eastern Standard Time. At the beginning of each data collection session, participants were fitted with two ActiGraph GT3X+ accelerometers, one on each wrist. In order to match accelerometer data with the correct participant and corresponding wrist (i.e., dominant vs. non-dominant), each
accelerometer had a unique numeric identifier that was recorded alongside the
candidate’s name and demographic information. Consistent with previous protocols[12, 25], each activity was performed for five minutes with 1-minute breaks between activities
for research assistants to set up the next activity (e.g., remove scissors and glue from the
cutting/pasting portion and place pencil and paper for writing). During the 1-minute rest
breaks, children were instructed to stay seated and refrain from touching any materials
being set up for the next activity until the research assistant said to begin. All participants
in a data collection session completed the same set of activities at the same time. For
instance if a session of 15 participants included snack, board games, watching TV, and
walking, all 15 participants in that session started and completed each individual activity
together prior to moving on to the next activity. Trained research assistants were present
during all sessions to indicate those participants that did not finish an activity session.
Reasons for incomplete activities include bathroom breaks, dismissals, behavioral
problems, and/or tampering with the accelerometers.

Direct observation was used to verify seated sedentary behaviors and
walking.[27] Verification of sedentary behavior was defined as participants remaining in
a seated position in a chair for the entirety of the activity. Data from children who stood
up and took steps during the sedentary portion of a session were excluded from analysis
for that seated sedentary behavior. However, if the child completed four of five seated
sedentary behaviors, those four behaviors were included; only the activity during which
the child was not seated was excluded from data analysis. Light activity intensity was
verified when a child was walking at the researcher-set pace during the walking portion
of the session.[27]
Data Analysis

The ActiGraph GT3X+ data was downloaded using ActiLife Software (Version 6.11.8) in five-second epochs. All data was then transferred and processed using Stata/SE 13.1 software (StataCorp LP, College Station, Texas, USA). Quantile regression models were used to compare the distribution of counts produced at each wrist at the 25th, 50th and 75th percentiles of the distribution of counts/5seconds for each seated sedentary behavior and walking, separately. The 95% confidence intervals were estimated using 100 bootstrap samples, clustered based on each child to account for observations nested within children. Receiver operator curve (ROC) analyses were conducted to derive the optimal cutpoint thresholds for the dominant and non-dominant wrist to distinguish activity counts produced during seated sedentary behavior from light physical activity. The ROC analyses were conducted using data from the seated sedentary activity that produced the highest counts/5s and data from walking, under the assumption that creating cutpoint from the highest seated sedentary values would undoubtedly classify the activities producing lower values as sedentary. The ROC curves were calculated by dichotomizing intensities, then determining the cutoff value that maximized both sensitivity and specificity. This procedure was performed 10 times for both the dominant and non-dominant wrist. The cutpoint threshold, sensitivity, specificity, and area under the curve (AUC) values produced for each of the 10 ROC iterations were averaged to derive the final values for each wrist-placement.

Results

The sample of participants were 58% male, 70% Caucasian, mean age 8.0±1.8 yrs. During analysis, four participants were excluded for incomplete data resulting in a
final sample size of 167 participants aged 5-11 years. Descriptive statistics of axis 1 counts per 5-second epoch (counts/5s) during each activity on both wrists are presented in Table 2. Watching television consistently produced the lowest counts/5s while playing board games was the seated sedentary activity that produced the highest counts/5s. Results from the quantile regression models are also presented in Table 2. There were significant differences in the median counts/5s between the non-dominant and dominant wrist placement during board games, cards, and cutting and pasting. Further, when analyzing the 75th percentile, differences in counts/5s during writing were observed. The largest difference was observed for board games with the median counts/5s from the dominant wrist 46 counts/5s higher than the non-dominant. The smallest difference was 1 count/5s during books. Across all activities, counts/5s on the dominant wrist were higher than those on the non-dominant.

The distribution of counts/5s for each seated sedentary activity compared to walking for dominant and non-dominant placements are presented in Figure 1. There was a rightward shift, indicating a higher distribution of higher counts/5s of the dominant wrists’ distribution during cards, cut/paste, games and tablets compared to the non-dominant wrist. This is consistent with the quartile regression results that indicate the dominant wrist produces higher counts/5s during all seated, sedentary activities.

Cutpoint thresholds with corresponding sensitivity, specificity and area under the curve (AUC) data are listed in Table 3. The optimal cutpoint thresholds for the dominant wrist are all higher compared to those derived for the non-dominant wrist. The AUC values, however, were higher for the non-dominant wrist (0.66-0.72) compared to the
dominant wrist (0.60-0.68) placement, with Axis 1 producing the highest and Axis 3 producing the lowest AUC for each wrist.

**Discussion**

The findings from this study indicated that differences in counts/5s exist between the non-dominant and dominant wrist placements during seated sedentary behaviors. Seated sedentary activities requiring upper extremity movement produced higher counts than those that require very little to no movement (e.g., playing board games vs. watching tv). During activities requiring movement, the dominant wrist produced higher counts/5s compared to the non-dominant wrist, resulting in a higher cutpoint threshold for distinguishing light physical activity from sedentary behavior. ROC analyses resulted in higher sensitivity, specificity and AUC values for the non-dominant wrist, indicating that the dominant wrist more often misclassifies seated, sedentary activities as light physical activity.

Playing with tablets, writing, board games, sorting cards and cutting and pasting resulted in significantly higher counts/5s from the dominant compared to the non-dominant wrist placement. The remaining activities (i.e., reading books, watching t.v., and eating snack) resulted in no differences. The lack of difference in counts was due to the fact that neither arm was moving, recording counts/5s close to zero from both dominant and non-dominant wrist placements. For writing and playing games on tablets, results varied by percentile of counts/5s. At the lowest quartile, no differences existed, while the middle and upper quartile revealed significant differences in counts/5s between wrist placements. These results indicate the distribution of counts/5s is not uniform, but when differences exist, the dominant wrist always produces higher activity counts. These
findings have important implications for accelerometer wrist-placement, as it is clear that the dominant wrist produces higher counts during seated, sedentary activities that will more often be misclassified as LPA.

A recent study reported no differences in total daily activity counts between the dominant and non-dominant wrist in young adults[28]. These results, however, are not comparable to the current study for two reasons. The present study focused solely on difference in counts collected during time spent sedentary. During physical activity, both wrists are likely moving identically as there are no differences in count/5s distribution during walking as illustrated in Figure 1. Therefore, wrist placement may not be important during physical activity, however for seated, sedentary behaviors, differences exist. Though counts/day may have been similar in the previous study, the data was not distilled into activity intensities, so it remains unclear if each wrist placement’s estimate of time spent in discrete activity intensities would have been equivalent. Second, the previous study included young adults aged 18-35 and results may not be generalizable for children; as their movement patterns differ greatly from adults.[28, 29]

ROC analyses derived optimal cutpoint thresholds of 202 and 221 counts/5s for the non-dominant and dominant wrist placement, respectively. Both cutpoint thresholds are higher, and AUC values lower, than previously reported.[2, 26] This was not unexpected, as higher cutpoint thresholds were anticipated since the protocol intentionally included a battery of activities that required upper extremity movement while seated. The present study found AUC values of 0.72 and 0.67 for the non-dominant and dominant wrist placement, respectively which is substantially lower than AUC values reported in recent wrist-placed calibration of 0.89, 0.94 and 0.95. [2, 26, 30] While the
current study found lower AUC values than other wrist-based calibration studies, they are comparable to many widely cited hip-based cutpoints.[31] Lower AUC values in the present study can be explained by the wider variety of seated sedentary activities requiring upper extremity movement that created a distribution of activity counts that overlapped with the distribution of activity counts from walking. Even so, the newly derived cutpoint thresholds can be used with confidence in capturing more accurate estimates of time spent sedentary in 5-11 year old children compared to previously published wrist-based cutpoints that may misclassify time spent sedentary as meaningful light physical activity.[2, 26, 30]

There are several strengths of this study. First, a sample of 167 unique children is similar to or exceeds many of the widely cited calibration studies of hip-placed accelerometer in children.[32-34] Secondly, rather than including a majority of largely motionless seated sedentary behaviors, this study included a wide variety of seated sedentary activities involving the use both arms.[2, 26] This was important because previously published wrist-based cutpoints were derived using activities that were motionless or only utilized the one hand, thus resulting in cutpoint thresholds that overestimate LPA and underestimate time spent sedentary. Lastly, the ROC analysis is a common approach in determining optimal cutpoint thresholds and the use of a 10-fold calibration and cross-validation strengthens the statistical methods used.[30, 31] The study also has limitations. First, the protocol lacked a free-living component and was designed so that each activity started and ended at a certain time for an entire group of children. Free-living conditions in which children are free to choose which activities in which to partake may yield different data, and therefore should be tested. Secondly, not
all children completed the full battery of nine activities because of time, location, and attendance restraints of the summer day camp. Even so, the range of child observations per sedentary activity ranged from 90 – 120, exceeding other hip-based calibration studies.[32-34] Lastly, the use of direct observation as a criterion measure for sedentary behavior may be criticized, however with the current debate over metabolic equivalents indicating sedentary behavior,[25] classification of sedentary activity by posture (i.e., seated) was deemed appropriate for the current study.[4] The use of direct observation allowed for verification that every participant included in data analysis was seated for all activities, regardless of MET values that might have otherwise classified seated sedentary activities as light PA.

**Conclusion**

The developed cutpoint thresholds for each wrist-placement can be used with confidence when distinguishing seated sedentary behavior from light intensity walking. The results from the current study suggest for the continued use of the non-dominant wrist-placement for children in order to be consistent with already published suggestions and protocols for the ActiGraph GT3X+ and to minimize the misclassification of upper extremity movement during seated, sedentary activities as light physical activity.
<table>
<thead>
<tr>
<th>Activity</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Books</td>
<td>Age appropriate books were provided for the children to choose from and read to themselves.</td>
</tr>
<tr>
<td>Cards</td>
<td>Children were given a portion of a deck of cards and asked to do several sorting tasks such as highest to lowest, sort by suite, and sort by color.</td>
</tr>
<tr>
<td>Cut/Paste</td>
<td>Children were given magazines, scissors, glue sticks, and construction paper to create a collage.</td>
</tr>
<tr>
<td>Games</td>
<td>Board games and building blocks were given to the children to play with on tables.</td>
</tr>
<tr>
<td>Snack</td>
<td>Children were given the choice of a granola bar or applesauce with a spoon and asked to eat their snack and let the research assistant know when they were finished. Start time was the same for every child, but stop time was individual to when the child told the research assistant they were finished eating their snack.</td>
</tr>
<tr>
<td>Tablets</td>
<td>Tablets were provided for children to explore through activities such as online games, typing facts about themselves, and searching the internet.</td>
</tr>
<tr>
<td>TV</td>
<td>Children were provided with an age-appropriate movie to watch as a group.</td>
</tr>
<tr>
<td>Walking</td>
<td>All children walked alongside a research assistant at a pace to elicit light physical activity. The pace was led by the research assistant to ensure children did not move quicker than a light intensity walk.</td>
</tr>
<tr>
<td>Writing</td>
<td>Children were given writing worksheets to trace letters and write complete sentences using a pencil.</td>
</tr>
</tbody>
</table>
Table 2.2 Descriptive Statistics and Quantile Regression Results Testing Differences in Counts Produced by Dominant and Non-Dominant Wrist Placement

<table>
<thead>
<tr>
<th>Counts/5second epoch</th>
<th>Dominant Median (IQR)</th>
<th>Non-Dominant Median (IQR)</th>
<th>Quantile Regression</th>
<th>25th Percentile Difference</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TV</td>
<td>98</td>
<td>0 (0-2)</td>
<td>0 (0-0)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tablets</td>
<td>96</td>
<td>14 (0-66)</td>
<td>0 (0-40)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Writing</td>
<td>98</td>
<td>7 (0-65)</td>
<td>0 (0-42)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Snack</td>
<td>100</td>
<td>20 (0-93)</td>
<td>12 (0-80)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Books</td>
<td>97</td>
<td>36 (0-142)</td>
<td>35 (0-137)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Board Games</td>
<td>120</td>
<td>129 (29-246)</td>
<td>83 (0-210)</td>
<td>29</td>
<td>(16.3, 41.7)</td>
</tr>
<tr>
<td>Cards</td>
<td>110</td>
<td>106 (22-219)</td>
<td>74 (8-176)</td>
<td>14</td>
<td>(5.7, 22.3)</td>
</tr>
<tr>
<td>Cut/paste</td>
<td>90</td>
<td>85 (21-171)</td>
<td>68 (8-158)</td>
<td>13</td>
<td>(3.6, 22.4)</td>
</tr>
<tr>
<td>Walking</td>
<td>128</td>
<td>357 (193-607)</td>
<td>357 (195-602)</td>
<td>-2</td>
<td>(-19.0, 15.0)</td>
</tr>
</tbody>
</table>

Bold text indicates significant difference between counts produced by dominant and non-dominant wrists, ‘—’ indicates lack of convergence during the quantile regression, IQR: Interquartile Range, CI: Confidence Interval
Table 2.3 Descriptive Statistics and Quantile Regression Results Testing Differences in Counts Produced by Dominant and Non-Dominant Wrist Placement

<table>
<thead>
<tr>
<th>Activity</th>
<th>Counts/5second epoch</th>
<th>Quantile Regression</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>Median (IQR)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dominant</td>
</tr>
<tr>
<td>TV</td>
<td>98</td>
<td>0 (0-2)</td>
</tr>
<tr>
<td>Tablets</td>
<td>96</td>
<td>14 (0-66)</td>
</tr>
<tr>
<td>Writing</td>
<td>98</td>
<td>7 (0-65)</td>
</tr>
<tr>
<td>Snack</td>
<td>100</td>
<td>20 (0-93)</td>
</tr>
<tr>
<td>Books</td>
<td>97</td>
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<tr>
<td>Board Games</td>
<td>120</td>
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<td>110</td>
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</tr>
<tr>
<td>Cut/paste</td>
<td>90</td>
<td>85 (21-171)</td>
</tr>
<tr>
<td>Walking</td>
<td>128</td>
<td>357 (193-607)</td>
</tr>
</tbody>
</table>

Bold text indicates significant difference between counts produced by dominant and non-dominant wrists, ‘—’ indicates lack of convergence during the quantile regression. IQR: Interquartile Range, CI: Confidence Interval
Table 2.4 Optimal Cutpoint Thresholds, sensitivity, specificity and AUC based on ROC analyses

<table>
<thead>
<tr>
<th>Non-Dominant Hand</th>
<th>Calibration (n=100)</th>
<th>Cross-Validation (n=67)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Counts/5sec</td>
<td>Sensitivity (%)</td>
</tr>
<tr>
<td><strong>Axis 1</strong></td>
<td>203</td>
<td>71.6</td>
</tr>
<tr>
<td><strong>Axis 2</strong></td>
<td>200</td>
<td>66.6</td>
</tr>
<tr>
<td><strong>Axis 3</strong></td>
<td>201</td>
<td>65.1</td>
</tr>
<tr>
<td><strong>VM</strong></td>
<td>397</td>
<td>68.2</td>
</tr>
</tbody>
</table>

AUC: area under the curve, ROC: receiver operator characteristics, CI: confidence interval, VM: vector magnitude
Table 2.5  Optimal Cutpoint Thresholds, sensitivity, specificity and AUC based on ROC analyses

### Dominant Hand

<table>
<thead>
<tr>
<th>Count/5sec</th>
<th>Sensitivity (%)</th>
<th>Specificity (%)</th>
<th>AUC (95% CI)</th>
<th>AUC (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>229</td>
<td>67.1</td>
<td>66.8</td>
<td>0.67 (0.66-0.68)</td>
<td>0.68 (0.67-0.69)</td>
</tr>
<tr>
<td>220</td>
<td>64.0</td>
<td>62.0</td>
<td>0.64 (0.64-0.65)</td>
<td>0.65 (0.64-0.66)</td>
</tr>
<tr>
<td>219</td>
<td>60.8</td>
<td>58.8</td>
<td>0.60 (0.59-0.61)</td>
<td>0.60 (0.58-0.61)</td>
</tr>
<tr>
<td>428</td>
<td>63.9</td>
<td>62.9</td>
<td>0.65 (0.64-0.65)</td>
<td>0.64 (0.63-0.66)</td>
</tr>
</tbody>
</table>
Figure 2.1 Distribution of counts/5second epoch for each sedentary activity versus walking
Figure 2.2 Distribution of counts/5-second epoch for each sedentary activity versus walking
The Rosetta Stone for equating hip and wrist-based accelerometer derived estimates of physical activity among elementary aged youth\(^2\)

\(^2\) Chandler, J.L., Drenowatz, C., Moore, J.B., Sui, X., and M.W. Beets. To be submitted to Journal of Science and Medicine in Sport
Abstract

Purpose: The recent shift from hip to wrist-based accelerometry has increased the inability to accurately compare estimates of moderate-to-vigorous physical activity (MVPA) across studies. This study builds on two previously published studies that have addressed the incomparability of hip-based estimates of MVPA across studies employing different sets of cutpoints by addressing the incomparability of hip to wrist-based estimates. The objective of this study is to develop an equating system to standardize estimates of MVPA collected at the wrist to match those collected at the hip.

Methods: 185 children aged 5-11 wore an ActiGraph GT3X+ on the hip and the non-dominant wrist for up to three hours. Data was downloaded in 5-second epochs and distilled into minutes of MVPA using six commonly used hip-based cutpoints and one non-dominant wrist-based set of cutpoints. Linear regressions, with non-linear terms where appropriate, were used on a development sample of 100 participants to equate wrist-based estimates of MVPA to the six hip-based estimates. Group level cross-validation analyses were performed on the remaining 85 participants who were randomly assigned to groups of 22.

Results: Across the seven cutpoints, mean MVPA estimates ranged from Puyau (PU) cutpoints 15.5 (± 9.0) to Freedson (FR) cutpoints 32.3 (± 17.1) minutes. Among the regression equations, the proportion of variance ranged from FR 0.29 to PA 0.81 and the absolute error ranged from Pate (PA) 20.7% to PU 42.9% at the individual level. When cross-validated at the group level, % differences in actual versus predicted values ranged from PU -1.8 to Mattocks 56.3%.
Conclusions: The equating system developed in the current study provides a timely solution to the most recent issues related to comparison of MVPA estimates across studies employing different accelerometer placements through the development of an equating system to translate published group-level estimates of MVPA collected at the hip to estimates collected from the non-dominant wrist.

Introduction

Objective physical activity (PA) assessment has typically been conducted using hip-placed motion sensors.[6-8] Recently, there has been a consumer and research shift towards placing activity monitors on the wrist to improve compliance with wearing and capture upper extremity movement that may not be captured when the device is affixed at the hip.[1, 9, 10] For example, the most recent cycle of the National Health and Nutrition Examination Survey (NHANES) changed its PA monitoring protocol to incorporate wrist-placed accelerometers instead of the traditionally used hip-placed accelerometer.[1] The device (ActiGraph GT3X+) will remain the same; however the location of the device has been changed from the hip to the non-dominant wrist.[1]

As new placements for activity monitors are introduced, analyzing and synthesizing PA data is becoming increasingly more difficult. When considering accelerometer data collected at the hip, there are already a multitude of factors that result in an inability to compare estimates of PA across studies. These include different activity monitor manufacturers/devices, updates to devices and technology, and differing analytical procedures such as choice of cutpoint thresholds or epoch length or processing raw signals.[11] The location of the device on the body, namely wrist-placement rather
than hip-placement, only adds to the complexity of comparing estimates of PA across studies.

As wrist-based accelerometry becomes more prominent, there is a clear need to develop a way to directly compare the estimates derived from wrist-placement to those from hip-placed ActiGraph. Previous studies have developed an equating system to directly compare studies that utilized different cutpoints with hip-placed ActiGraphs.[35, 36] This system is referred to as the Rosetta Stone. Currently, there is no Rosetta Stone for comparing PA levels between hip and wrist-based ActiGraph data. Such an equating system would be valuable to those who are using wrist-placement, but want to be able to compare the estimates of PA to previously published studies using hip-placement. The purpose of this study, therefore, was to develop and validate an equating system to translate MVPA estimates distilled from wrist-based data to MVPA estimates collected at the hip.

Methods

Participants and Setting

Children between the ages of 5 and 11 were recruited from two after-school programs (ASPs) in Columbia, SC to take part in this study. Participants in the study had no limitation to be physically active (e.g., asthma, cardiovascular issues, or inability to ambulate without assistance). Participants self-reported their age and dominant hand. Upon arrival at the ASP, children were affixed with two ActiGraph GT3X+ accelerometers; one on the non-dominant wrist and the other on the hip. Specifically, the wrist-mounted accelerometer was affixed using a Velcro wrist strap and the hip-mounted accelerometer was placed around the participant’s waist with an elastic belt. All
accelerometers were initialized to start and stop recording data at the exact same time from the same computer so data matched exactly when paired on the back end. Each accelerometer had a numeric identifier that was recorded alongside participant’s demographic information. The participants wore both accelerometers concurrently for the duration of their time at the ASPs between the hours of 3:00pm and 6:00pm. Participants wore both accelerometers during all activities at the ASP including homework, snack, enrichment and physical activity opportunities. If a child removed or tampered with any device, data from that child for that day were excluded from data analysis. Each child’s parent had the opportunity to opt their child out of data collection and each child gave verbal assent before activity monitor placement or data collection. The methods described were reviewed and approved by The University of South Carolina Institutional Review Board.

Data Analysis

All data were downloaded in 5-second epochs and distilled into time spent in MVPA from six commonly used hip-based cutpoints and the Chandler wrist-based cutpoints (CH). The hip-based cutpoints used to estimate minutes of MVPA were Evenson (EV), Pate (PA), Puyau (PY), Freedson 4-MET (FR), VanCauwenburgh (VC), and Mattocks (MA).[26, 32-34, 37-39] The MVPA threshold (counts/5s) for each set of cutpoints are: EV (≥191), PA (≥140), Pu (≥266), FR (≥XX), VC (≥195), MA (≥299) and CH (≥530). Two other wrist-based cutpoints have been developed for youth[40], however they were not included in the present analysis due to their placement on the dominant wrist while the participant’s in this study wore the accelerometer on the non-dominant wrist. Linear regression models, with non-linear terms where appropriate, were used to
develop prediction equations in a development group of 100 participants. Each covariate (i.e. age, gender, and non-linear terms) was introduced and incorporated in the final model if the proportion of variance ($R^2$) increased and the absolute error decreased.

Finally, the remaining 85 participants were used as a holdout group for cross-validation of the prediction equations. The 85 participants were stratified by gender and age, then randomly assigned to four groups of ~22 for cross-validation purposes. Average estimates of group-level MVPA were calculated and then cross-validated using the new equations. Differences were calculated as the predicted value minus the actual value. Group-level validations were made, instead of individual-level validations, since the equations are designed to convert published group-level estimates rather than converting individual-level data points.

Bland Altman plots were created to illustrate the agreement between true and predicted MVPA estimates.[41] Limits of agreement were calculate as mean of the difference $[\bar{m} \pm (2 \times s)]$ where $\bar{m}$ the mean difference between the actual and predicted estimates of MVPA and $s$ is the mean standard deviation).[41] In absence of an empirically derived range of acceptable error, ±10% was chosen and plotted in Figures 1 and 2 to depict what could be considered reasonable differences between actual and predicted MVPA values.

Results

Data collection occurred over three weeks on 13 week days, resulting in 185 unique participants with paired wrist and hip-based data. Average wear time was 115 ($\pm 36.8$) minutes. Across the six hip-based cutpoints, MVPA estimates were: from PY 15.5 ($\pm 9.0$), MA 13.1 ($\pm 7.9$), VC 22.7 ($\pm 11.9$), EV 23.2 ($\pm 12.1$), PA 30.3 ($\pm 14.8$), and FR
32.3 (± 17.1) minutes. The CH wrist-based cutpoint resulted in a mean MVPA estimate of 31.6 (± 15.6) minutes. Prediction equations with corresponding proportion of variance explained, absolute errors in minutes, and absolute percent error are shown in Table 1. A total of 6 prediction equations were created with gender contributing significantly to all, while age did not, and therefore was not included in the final models. Two of the equations (CH to PA and CH to VC) required a squared term to account for the curvilinear trend in the data. The lowest absolute percent error at the individual level was found in the PA to CH equation (20.0%) and the highest absolute percent error was found in the CH to FR equation (48.8%). The proportion of variance explained ranged from 29.3% (CH to FR) to 81.1% (CH to PA). Table 2 displays the cross-validation results from applying the regression equation to group level estimates of MVPA in the hold out sample. The six regression equations resulted in differences in actual group-level MVPA values and predicted group-level MVPA values ranged from -1.8 to 56.3% difference. Figure 2 illustrates the practical utility of the newly developed regression equations at a group level.

Discussion

Now that wrist-based accelerometry is being employed both nationally and internationally, the incomparability of MVPA estimates across different accelerometer placements must be addressed.[1, 26, 42, 43] Even though studies are reporting minutes of MVPA, results cannot be directly compared as different cutpoints and placements are used across studies which result in differing estimates of PA. The findings from this study offer a practical solution to comparing wrist to hip-based estimates of MVPA in elementary aged children.
Two recent studies addressed the issue of CNE by creating equating systems to translate group-level MVPA estimates from one set of hip-based cutpoints to another.[35, 36] The current study is a follow up to the previous two studies and provides a solution for synthesizing the growing body of literature that reports estimates of MVPA collected at either the hip or wrist.

These conversion systems provide a practical solution to pooling the growing body of literature reporting estimates of MVPA in youth via ActiGraph accelerometry. Table 2 shows the usefulness of these equations when applied to group-level means of MVPA. After employing the developed regression equations, group-level differences between actual and predicted MVPA estimates ranged from -1.8 to 56.3%. A difference of 56.3% might seem large, but it should be kept in perspective that before applying the CH to MA regression equation, the difference was an alarming 111.3%.

While this study is timely and advances the field of physical activity measurement, future efforts should be made to include activity estimates from other methods of PA assessment. These can include the consideration of future wrist-based cutpoints, hip-based cutpoints not included in the current study [44-46], and creating conversion systems for adult populations. It should be noted that there are two other sets of wrist-based cutpoints[40], derived from the dominant-wrist, and therefore could not be included in the present analysis due to participants in this study wearing the wrist-based accelerometer on the non-dominant wrist. Even though the current study has made it possible to compare MVPA estimates from the non-dominant wrist to hip-based ActiGraph in youth, there is still progress to be made toward a universal methodology for PA assessment.
A major strength of this study is the timeliness of the subject matter addressed. As wrist-based accelerometry becomes more prominent, this translating system will serve to compare wrist estimates of PA with previously published hip estimates of PA. Secondly, a large sample size was used in the development and cross-validation of the regression equations. Additionally, a wide age range of children encompassing all of elementary aged children (5-11 years) was included in the current study. Finally, this study utilized the most commonly used hip-based cutpoints [32-34, 37-39]. Although this study did not include all published hip-based cutpoints, the six chosen are the most commonly used within the physical activity literature[47].

Despite the multiple strengths of this study, there are limitations to be considered. The six hip-based cutpoints addressed in this study do not represent all cutpoint thresholds developed for physical activity assessment in youth, limiting applicability of the equating system. Additionally, only one set of wrist-based cutpoints exist for the non-dominant hand, and there will undoubtedly be more wrist-based cutpoints developed in the future. As new cutpoints are introduced and employed, expanding this equating system to include as many wrist-based cutpoints as possible is warranted. Further, the present study resulted in an equating system with the ability to translate from wrist-based estimates of MVPA to hip-based, but not vice-versa. Currently it seems appropriate to translate the limited number of wrist-based estimates to hip-based, but as published wrist-based data increases, it may be necessary to create equations to translate both ways. As previously mentioned in past studies, the primary limitation of the presented analytical procedure is compounding error. There is error introduced during the calibration process of each set of cutpoints as well as with the development of the regression equations,
therefore error is being compounded with error. Even so, translating estimates of MVPA derived from one placement to the other allows for a more reasonable comparison across studies using different accelerometer placements.

**Conclusion**

In conclusion, this study provides a solution to the most recent issues related to CNE through the development of an equating system to translate estimates of MVPA collected at the hip to estimates collected from the non-dominant wrist. This study builds upon work by Brazendale and Bornstein, however does not represent the finality of PA assessment evolution. As new methods for PA assessment are introduced, the synthetization of PA data becomes increasingly more difficult. The prediction equations presented herein offer a timely solution as the popularity of wrist-based accelerometry increases.
Table 3.1 Prediction equations to transform estimates of MVPA from wrist-based cutpoints into MVPA estimated from various hip-based cutpoints

<table>
<thead>
<tr>
<th>Outcome Variable</th>
<th>Regression Equations</th>
<th>Absolute Error (minutes)</th>
<th>Absolute Error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Intercept</td>
<td>MVPA (min d⁻¹)</td>
<td>MVPA²</td>
</tr>
<tr>
<td>Evenson</td>
<td>3.408482</td>
<td>0.6672636</td>
<td>-3.22267</td>
</tr>
<tr>
<td>Pate</td>
<td>5.279632</td>
<td>0.8547377</td>
<td>-3.947811</td>
</tr>
<tr>
<td>Puyau</td>
<td>1.813784</td>
<td>0.4559372</td>
<td>-2.307157</td>
</tr>
<tr>
<td>Van C</td>
<td>3.274847</td>
<td>0.6541901</td>
<td>-3.154424</td>
</tr>
<tr>
<td>Mattocks</td>
<td>1.546766</td>
<td>0.3821528</td>
<td>-2.060369</td>
</tr>
<tr>
<td>FR4</td>
<td>4.067339</td>
<td>1.402522</td>
<td>-0.0108023</td>
</tr>
</tbody>
</table>

Prediction equations developed using a development sample of 100 participants; MVPA: moderate-to-vigorous physical activity; Mean MVPA CH: 30.2 minutes; 52% female
| Group | n  | Mean | Chandler Actual | Chandler Pred | Chandler Diff | Chandler % Diff | Everson Actual | Everson Pred | Everson Diff | Everson % Diff | Pate Actual | Pate Pred | Pate Diff | Pate % Diff | Puyau Actual | Puyau Pred | Puyau Diff | Puyau % Diff |
|-------|----|------|----------------|--------------|--------------|----------------|----------------|--------------|--------------|----------------|-------------|-------------|-----------|-------------|-------------|-------------|-------------|-----------|-------------|-------------|
| 1     | 22 | 32.6 | 25.0           | 23.5         | 1.5          | 6.0            | 31.9           | 31.1        | 0.7          | 2.5            | 17.1        | 15.5       | 1.6        | 9.4         |              |             |             |             |
| 2     | 22 | 33.3 | 24.0           | 24.0         | 0.0          | 0.0            | 31.3           | 31.7        | -0.4         | -1.3           | 16.3        | 15.8       | 0.5        | 3.1         |              |             |             |             |
| 3     | 22 | 35.7 | 25.4           | 25.6         | -0.3         | -1.0           | 33.0           | 33.8        | -0.9         | -2.4           | 17.1        | 16.9       | 0.1        | 1.4         |              |             |             |             |
| 4     | 22 | 29.5 | 21.5           | 21.4         | -0.1         | 0.6            | 27.8           | 28.5        | -0.7         | -2.5           | 14.9        | 14.1       | 0.8        | 5.5         |              |             |             |             |
| Total | 84 | 32.8 | 24.0           | 23.6         | 0.3          | 1.4            | 31.0           | 31.3        | -0.4         | -0.9           | 16.4        | 15.6       | 0.8        | 4.8         |              |             |             |             |

Pred: predicted values derived from regression equations; Diff: difference in the regression predicted mean values and the actual group level mean; % Diff was calculated as the difference divided by the actual estimate. Total values were calculated by averaging the four groups’ values; % female for groups: 1) 0.52, 2) 0.51, 3) 0.49, 4) .53, and Total Holdout Sample) 0.52
Table 3.3 Comparisons of group-level conversions of minutes of MVPA distilled by various cutpoints versus predicted minutes of MVPA

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</tbody>
</table>

Pred: predicted values derived from regression equations; Diff: difference in the regression predicted mean value was calculated as the difference divided by the mean value; % female for groups: 1) 0.52, 2) 0.51, 3) 0.49, 4) 0.53, and Total Holdout Sample) 0.52
Figure 3.1 Bland Altman plot of percent difference between true and predicted values of MVPA versus the true value of MVPA for all cutpoints at a group estimate level.
Chapter IV: Manuscript 3

Structure of Physical Activity Opportunity’s Contribution to Children’s Physical Activity³

³ Chandler, J.L., Drenowatz, C., Moore, J.B., Sui, X., and M.W. Beets. To be submitted to Journal of Physical Activity and Health
Abstract

Purpose: Settings that care for youth are the primary target of physical activity (PA) interventions. PA opportunities in these settings are commonly structured in two ways – organized games and unstructured free play. Intervention efforts have largely focused on incorporating adult-led games to increase children’s PA; however an alternative approach may be to promote free play. The purpose of this study was to determine which structure of PA opportunities elicits the most moderate to vigorous physical activity (MVPA).

Methods: The present study used a three group cross-over design in which participants were exposed to three variations of activity structures; free play (FP), organized (ORG), or a mixture of FP and ORG (MIX). Data collection occurred over eight consecutive weeks (Monday-Thursday). Activity was measured using ActiGraph GT3X+ accelerometers. All data were transformed into percent of time spent sedentary or in MVPA for each activity session. Repeated measures mixed effects models, accounting for multiple measures per child, were used to examine differences in percent of time children spent in MVPA and sedentary among the three activity sessions.

Results: Participants included 197 unique children that were 53% male, 55% Caucasian, and averaged 7.7 years. The average activity session lasted 39.9±6.5 minutes with 166, 196 and 138 child observations for FP, ORG, and MIX, respectively. Statistically significant differences were observed in the percent of time boys spent in MVPA during FP and MIX compared to ORG sessions (35.8% and 34.8% vs. 29.4%). No significant difference was observed in the percent of time girls spent in MVPA during FP compared to ORG or MIX (27.2% and 26.1% vs 26.1%). Both boys and girls experienced ~10% less time sedentary during FP compared to ORG and MIX.
Conclusion: Offering some amount of FP elicits more MVPA for boys and reduces sedentary time for boys and girls compared to offering solely organized PA opportunities.

Introduction

Nationally, 95% of school-aged youth (5-17 years) are enrolled in public/private schools[48] and nearly 60% of children attend some variation of childcare outside of school, with over 10 million children attending afterschool programs and more than 14 million attending summer day camps, annually.[49-51] Because of their extensive reach and allocation of time for physical activity (PA) opportunities (e.g., recess, physical education, outdoor free-time), these settings have been the primary settings where interventions to increase PA are delivered. One of the primary approaches for increasing PA within these settings has been to integrate strategies to maximize children’s accumulation of moderate-to-vigorous physical activity (MVPA) during pre-existing scheduled PA opportunities.

Within scheduled PA opportunities there are two common structures of the PA experience – organized games (i.e., adult-led) and unstructured play (i.e., free play). [52, 53] Interventions have largely focused on incorporating adult-led games to increase children’s PA by either increasing the skills of adults to remove inactive elements from traditionally played games and/or the adoption of PA curricula and equipment.[14, 54-58] Results from intervention studies that have utilized these approaches, however, indicate minimal improvements in MVPA and time spent sedentary.[54-56, 58] An alternative approach may be to promote unstructured, free play. Observational studies have shown that children accumulate more MVPA during free play than organized activities in recess and afterschool programs. [17, 52, 59, 60] Children may be more inclined to be active
during free play because it includes limited adult interference and the ability to regulate elements of games such as teams, rules, and time spent in games.[61, 62] Further, during free play children are free choose when and how to be active to their own liking.

While each activity structure has various strengths, it remains unclear as to which structure can provide the greatest amount of MVPA for children during a PA opportunity.[63] There is no prior experimental research to inform these settings on the most effective approach (e.g., organized play only, free play only, a combination of both) to elicit the highest levels of MVPA. Thus, the purpose of this study was to compare the amount of MVPA and time spent sedentary in children exposed to free play, adult-led, and a combination of the two activity structures.

**Methods**

*Participants and Setting*

Participants (K-5th) were recruited from two local afterschool programs (ASPs) with similar enrollment size, number of staff, time allocated for PA (~45 minutes) and facilities. Each ASP enrolled between 100-130 children, employed 13-16 staff, and had unrestricted access to a gymnasium, two outdoor fields, various sports equipment (e.g., basketballs, soccer balls, hula hoops, jump ropes, etc.) and a fixed playground structure. Participants in the study had no limitation to be physically active (e.g., asthma, cardiovascular issues, or inability to ambulate without assistance). Informed consent was obtained from all participants’ parent/guardian, and each participant gave verbal assent.

*Study Design*

The present study used a three group cross-over design in which all participants were exposed to three variations of activity sessions over the data collection period. Data
collection occurred over eight consecutive weeks (Monday-Thursday) at each ASP location. On each data collection day, two age groups, usually defined by individual grade levels (K, 1st, 2nd, 3rd, 4th, and 5th) per ASP were scheduled to participate in one of three variations of activity session types: free play only (FP), organized activities only (ORG), or a combination of the two (MIX).

Activity Sessions

All activity sessions were performed according to each ASPs’ routine practice. Research assistants provided a schedule to the ASP staff one week ahead of data collection days. This schedule detailed the sessions to deliver to each age group for each day of the week. All sessions ‘start’ times were when the majority of children entered the designated area for PA and ‘stop’ times were when the majority of the children exited the area. No training or feedback was provided to staff regarding PA sessions. All activity sessions were schedule to last the same duration and occur at the same time each day.

Free Play Sessions

During FP sessions, children were not instructed to do any specific activity and were supervised by staff in the area designated for PA. Loose, portable equipment was provided according to the ASPs routine practice, which were similar across ASP sites. These items included basketballs, soccer balls, footballs, and jump ropes. Additionally, each ASP site had a fixed playground structure for children to use during free play sessions. There were no staff-led games provided to the children, however if a child approached a staff member to play, he/she could choose to engage with the child. Children initiated and followed self-declared rules of games with other children of their
choosing. Further, if desired, children could choose to take part in sedentary behavior such as sitting and talking with friends.

*Organized Sessions*

Afterschool program facilitated ORG sessions included games commonly played at their respective programs. ORG sessions started when the group entered the PA area and included all instruction, discipline, and organizational tasks. Staff were allowed to choose the game or activity to play and their level of involvement in the game. The only instruction ASP staff were provided was to include at least one organized game that lasted the entirety of the session. For example, ASP staff could choose to play kickball for the total time allotted for PA or the ASP staff could choose to split their session time in half to play both kickball and tag games, as long as organized/adult led games were offered to all children for the entirety of the session.

*Mixed Sessions*

MIX sessions included time for both free play and organized games during the same session. Whether the free play came first or last was left up to the ASP staff’s discretion. ASP staff were advised to equally distribute free play and organized games throughout the activity session. A research assistant was present to indicate the halfway point of the scheduled session when necessary. The free play and adult-led portion of the mixed sessions followed the FP and ORG protocols.

*Physical Activity Assessment*

Participants wore ActiGraph GT3X+ accelerometers for the duration of the ASP day. Upon arrival at the ASP, children were affixed with an accelerometer attached to an elastic belt with a corresponding numeric identifier. The time of placement and numeric
identifier was recorded alongside the participant’s name. All accelerometers were initialized to start and stop recording from the same computer so that all internal clocks were the exact same. Additionally, the research assistant’s watches were synchronized to the computer used. All data was downloaded in 5-second epochs and distilled using valid cutpoints for MVPA and time spent sedentary.[33, 64] A valid session was defined as the child wearing the activity monitor and being present for the entire PA session. During the PA session, children might have been absent from portions of the time for reasons such as bathroom breaks, water breaks, or refusal to play the game. Data from these children were included in activity estimates to capture authentic group level estimates of MVPA and time spent sedentary. Data from children dismissed to go home before the physical activity session or experiencing severe behavioral problems and dismissed from the PA session were not included in data analysis.

Data Collection Protocol

A minimum of two trained research assistants were present at all days of data collection to ensure fidelity. Both research assistants were responsible for placement of the accelerometer, recording all demographics of participants; daily activity session information such as if an activity session was FP, ORG, or MIX, organized, or a combination, and retrieval of accelerometers at the end of the ASP day. Upon parental pickup, participants removed and returned the monitor to a research assistant positioned at the location of departure. The other research assistant was responsible for indicating the exact start and stop time of PA sessions. The PA session start time was defined as the minute the children entered the designated area. For example, if all children and staff entered the playground area at 2:00 but listened to instructions and rules for games until
2:10, the start time was marked as 2:00 to include the procedural difficulties associated with providing organized physical activities.[65] Research assistants also recorded additional information such as number of staff present, type of games played, type of equipment used, and the space used during each session (i.e., grassy fields, structured playground equipment, blacktop etc.).

*Data Analysis*

All data were transformed into the percent of time spent sedentary or in MVPA for each activity session. Repeated measures mixed effects models, accounting for multiple measures per child, were used to estimate differences in percent of time children spent in MVPA and sedentary among the three types of activity sessions. Models were run separately for girls and boys and controlled for age. All statistical analyses were performed using Stata (v.13.1, College Station, TX), with an alpha level of p<0.05. Because attendance at the ASPs was voluntary, an unequal number of children were exposed to and participated in each session type. Therefore, three analyses were initially conducted that included 1) all children (n=197), 2) only children that took part in at least one FP and one ORG session (n=99), and 3) only children that experienced all three types of PA sessions (n=55) (FP, ORG, and a MIX session). Analyses comparing activity and sedentary levels among FP, ORG, and MIX were conducted on these groups of participants. No differences existed in MVPA or sedentary time estimates, therefore data for all children is presented. A secondary purpose of this paper was to investigate age and gender differences in activity levels during each structure. Age groups were created by splitting grade levels resulting in three groups: 1. Kindergarten and 1st grade, 2.) 2nd and
3rd grades, and 3.) 4th and 5th grades. Differences in activity levels within each gender’s age groups were analyzed using repeated measures ANOVA.

**Results**

Over eight data collection weeks, 197 unique children participated in PA sessions in their respective afterschool program totaling 500 child observations. Participants were 53% male, 55% Caucasian, and aged $7.7 \pm 1.7$ years. Of the 197 children, 55 took part in at least one of each type of activity session and 99 took part in at least one FP and one ORG session. The average session lasted $39.9 \pm 6.5$ minutes and the number of activity sessions per session type ranged from 12-14 each with 12 FP and MIX sessions and 14 ORG sessions. This resulted in 166, 196 and 138 child observations for FP, ORG, and MIX sessions, respectively.

Comparisons of the percentage of time spent in MVPA and sedentary, by activity session, are presented in Table 1. Boys spent 35.8% of time in MVPA during FP compared to 29.4% during ORG (adjusted model difference of 6.4%; 95% CI 2.4 to 10.4). Boys also experienced a higher percentage of MVPA and less time sedentary during MIX sessions compared to ORG. Girls spent 27.2% of activity session time in MVPA during FP with no significant differences across session types (26.1% for both ORG and MIX conditions). Similar to the boys, there was an increase (+10%) in time girls spent sedentary during ORG compared to FP.

Figure 1 illustrates MVPA and sedentary time estimates by age groups during FP and ORG sessions. A significant difference in MVPA between FP and ORG sessions was seen in the 2nd/3rd grade boys and girls and the 4th/5th grade boys with FP eliciting more MVPA and less sedentary time. The biggest difference in MVPA was observed in the
4th/5th and 2nd/3rd grade boys with those participating in FP attaining approximately 13% more MVPA compared to ORG. Significant differences were also seen in the amount of time spent sedentary between FP and ORG sessions for K/1st grade boys and girls and 2nd/3rd grade boy and girls. The biggest difference in time spent sedentary was seen in the 2nd/3rd grade girls with FP resulting in 22.3% sedentary time compared to 43.5% during ORG.

Discussion

This study is one of the first to explore how activity structure contributes to children’s PA levels. The findings from the present study indicate that during opportunities that included FP children accumulated more MVPA and spend less time sedentary compared to ORG sessions. Additionally, children spent significantly less time sedentary during FP compared to ORG adult-led games. Further, offering MIX sessions in which children had the opportunity for free play and organized adult-led games resulted in greater levels of MPVA compared to ORG sessions for boys. Based on these results, it appears that offering some amount of free play is better than offering solely organized adult-led games. Findings from the current study have broad implications for public health efforts for increasing children’s activity, in that offering free play is a simple, potentially effective strategy to maximize time allocated for PA.

The results from this study align with previously reported non-experimental observational studies showing FP sessions elicit more MVPA compared to organized adult-led activity sessions.[52, 59, 66] Two studies reported accelerometer derived activity levels of children attending afterschool programs and the contribution of both free play and organized activities to time spent in MVPA.[52, 59] First, Rosenkranz et
al., found that children engage in MVPA for 35.4 and 42.6% of organized and free play activity sessions, respectively. Although this is in agreement with the findings from the current study, Rosenkranz and colleagues did not separate activity levels by gender. Trost et al. reported both boys and girls spent more time in MVPA during free play than organized activity. On average, boys spent 59.4 and 23.8% of FP and ORG sessions in MVPA, respectively, while girls spent 46.4 and 16.7% of FP and ORG engaged in MVPA, respectively.[66] The current study also analyzed activity levels by age groups and found that trends are constant across age groups, in that FP resulted in more time spent in MVPA and/or less time sedentary for all age groups except the 4th and 5th grade girls. There were no differences in MVPA estimates or time spent sedentary between FP and ORG for 4th and 5th grade girls suggesting that activity levels of this age group may be influenced more by other factors such as motivation and game selection than how the PA opportunity is structured.[67]

An important consideration regarding differences in MVPA levels across studies is the duration of the activity opportunity and how it may influence the percentage of time children are spending in MVPA. One study averaged 26 minutes per activity session[52] whilst the current study averaged nearly 40 minutes per session. Although reporting percentage of time allows comparisons across unequal lengths of time to be made, there is evidence to suggest that children experience a “spike” in activity levels at the beginning of an activity session, followed by a steady decline throughout the remainder of the activity session as children become tired, bored, or disengaged with physical activity.[68, 69] Thus, the results of this study should be interpreted with caution as they may not be generalizable to PA opportunities of different durations.
A unique feature of the current study was the inclusion of a mixed activity session, where both free play and organized physical activity opportunities were provided during the same activity session. To the best of our knowledge, there are no other studies reporting activity levels of children during an activity session of this type. In this study, the staff delivering these mixed activity sessions reported greater logistical and management difficulties during these sessions. For example, older grade levels were not allowed to participate in free play indoors due to behavior and safety issues, and the younger grade levels were unable to focus and listen outdoors to rules and instructions for organized games. Nonetheless, providing the mixed sessions had a beneficial effect for boys in that they experienced more MVPA and less time sedentary during mixed sessions compared with organized. It appears that offering some time for free play in conjunction with organized PA is better than providing only an organized activity.

The present study differs from previous results in that girls experienced no difference in MVPA during FP and ORG sessions. Perhaps the most notable finding for girls was significantly less time was spent sedentary during FP than ORG. While FP may not provide any more or less MVPA for girls than ORG activity sessions, it seems to have a beneficial effect on the amount of time spent sedentary. More specifically, organized adult-led games tend to include inactive elements such as waiting in lines to take turns (e.g., kickball, jump rope), elimination from the activity opportunity (e.g., tag games, dodgeball), and standing and waiting during activity opportunities (e.g., team games like soccer).[17, 70] On the other hand, free play allows children to move when and how they choose rather than following inactive rules of organized games.
The primary findings of the present study have important implications for practitioners responsible for scheduling and structuring children’s activity opportunities. The results suggest that by providing free play during PA opportunities is a simple and effective approach for eliciting MVPA in elementary aged children. Further, the training required to provide free play opportunities to children is likely minimal in comparison to developing the management and organizational skills needed to facilitate quality adult-led games. Best efforts have shown that a physical educator has the ability to provide more MVPA during modified adult-led games compared to free play.[17] Although in this instance modified adult-led games provided higher levels of MVPA compared to free play, providing widespread training to build staffs skills with the purpose of implementing high quality PA opportunities for children in these settings is potentially resource intensive and, therefore, may not be a strategy that can be widely used.[71]

Strengths of this study include the three group cross-over design, the large sample size, the use of accelerometry for PA assessment, the use of direct observation to assess contextual information about games played during organized activity sessions, and the use of current staff members in their typical setting resulting in a realistic estimate of children’s activity as possible. Despite the multitude of strengths, limitations of this study should be acknowledged. First, the study was conducted in one setting, ASPs, which makes it difficult to generalize the findings to other settings that provide different structured (time allocated, number of children per session, and more or less equipment, etc.) opportunities for physical activity. The time allocated for PA opportunities may impact the percentage of time children spend active, therefore current results may not hold true over various lengths of PA opportunities.
**Conclusion**

In conclusion, offering free play during physical activity opportunities can help children attain as much if not more MVPA compared to only offering organized, adult-led games. Additionally, when free play is offered, time spent sedentary is minimized for both boys and girls. Across settings that care for youth, quality PA training for front line staff is costly and widely unavailable,[55, 72] therefore promoting free play during PA opportunities may be a more effective approach to getting children active. To maximize elementary aged children’s time spent in MVPA and minimize time spent sedentary, practitioners should offer free play and if resources and time allow, supplement with organized, adult led games.
Table 4.1 Means of MVPA and Time spent Sedentary by Activity Session Context

|           | Free Play |          | | Organized |          | | Mixed |          |
|-----------|-----------|----------|----------|-----------|----------|----------|----------|
| n         | Mean      | SD       | CV       | n         | Mean      | SD       | CV       | n         | Mean      | SD       | CV       |
| Boys      |           |          |          |           |          |          |          |           |          |          |          |
| MVPA      | 85        | 35.8     | 15.3     | 0.4       | Combined  | 99        | 29.4     | 13.2     | 0.4       | 81        | 34.8     | 16.1     | 0.5       |
|           | Striking & Fielding | 28 | 20.3 | 11.1 | 0.5 | |               | | | |               | | | |
|           | Invasion  | 21        | 30.7     | 11.4     | 0.4       | | | | | | | |
|           | Chasing & Fleeing | 31 | 34.9 | 12.8 | 0.4 | | | | | | | |
|           | Mixed Organized* | 19 | 33.2 | 12.3 | 0.4 | | | | | | | |
| Sedentary | 85        | 22.7     | 12.1     | 0.6       | Combined  | 99        | 31.9     | 15.6     | 0.5       | 81        | 28.2     | 19.6     | 0.7       |
|           | Striking & Fielding | 28 | 42.2 | 15.3 | 0.4 | | | | | | | |
|           | Invasion  | 21        | 28.2     | 15.3     | 0.5       | | | | | | | |
|           | Chasing & Fleeing | 31 | 27.0 | 10.5 | 0.4 | | | | | | | |
|           | Mixed Organized* | 19 | 29.2 | 17.5 | 0.6 | | | | | | | |
| Girls     | 81        | 27.2     | 14       | 0.5       | Combined  | 97        | 26.0     | 11.7     | 0.5       | 57        | 26.1     | 12.8     | 0.5       |
|           | Striking & Fielding | 26 | 18.2 | 8.9 | 0.5 | | | | | | | |
|           | Invasion  | 26        | 25.0     | 9.3      | 0.4       | | | | | | | |
|           | Chasing & Fleeing | 26 | 30.4 | 11.6 | 0.4 | | | | | | | |
|           | Mixed Organized* | 19 | 31.9 | 12.7 | 0.4 | | | | | | | |
| Sedentary | 81        | 28.1     | 13.8     | 0.5       | Combined  | 97        | 38.3     | 16.3     | 0.4       | 57        | 35.0     | 17.9     | 0.5       |
|           | Striking & Fielding | 26 | 49.3 | 15.9 | 0.3 | | | | | | | |
|           | Invasion  | 26        | 36.9     | 14.6     | 0.4       | | | | | | | |
|           | Chasing & Fleeing | 26 | 34.7 | 13.6 | 0.4 | | | | | | | |
|           | Mixed Organized* | 19 | 30.4 | 15.5 | 0.5 | | | | | | | |

MVPA: moderate-to-vigorous physical activity, SD: Standard Deviation, CV: Coefficient of Variation, CI: Confidence Interval, Average session lengths- FP: 39.2 ± 6.5, ORG: 37.6 ± 6.0, and MIX: 41.0 ± 7.0 minutes
Table 4.2. Regression Derived Differences (95% Confidence Interval)

<table>
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<td>3.7</td>
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<tr>
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<td>(-11.9, -1.9)</td>
<td>(-1.6, 7.9)</td>
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</tbody>
</table>

MVPA: moderate-to-vigorous physical activity, SD: Standard Deviation, CV: Coefficient of Variation, CI: Confidence Interval, Average session lengths- FP: 39.2 ± 6.5, ORG: 37.6 ± 6.0, and MIX: 41.0 ± 7.0 minutes
Overall Discussion
**Discussion**

More than 50% of US children do not meet the nationally recommended guidelines of 60 minutes of MVPA daily. [73] Current efforts are failing to get children sufficiently active [55, 56, 58, 74]; therefore novel approaches to PA promotion are needed. Opportunities for PA for youth are typically offered as free, unstructured play or organized, adult-led games. Both structures of PA opportunity have been researched independently and have their own strengths and weaknesses; however there is no current research regarding the structure that maximizes children’s physical activity levels. Additionally, in order to identify trends in children’s’ PA and inform policies and guidelines, accurate methods for PA measurement are imperative. As technology evolves, issues related to the measurement of PA in children continue to compound onto those that already exist, such as activity monitor manufacturer, choice of cutpoint thresholds, and most recently, placement of activity monitor. Both researcher and consumer focus has shifted from hip-based to wrist-based PA monitors. [19] This change of monitor placement raises concern not only surrounding accurate measurement of PA, but also the comparability of estimates collected at the wrist to those previously collected at the hip.

This dissertation addresses two important aspects of children’s physical activity: how to maximize children’s accumulation of MVPA during differently structured PA opportunities and measurement challenges related to the recent shift from hip-based to wrist-based activity monitor placement.

**Purpose**

The objectives of the research conducted in this dissertation were to: 1) establish best practices for wrist-based accelerometry by exploring differences between counts
produced from accelerometers placed on both wrists during commonly performed
sedentary activities, 2) compare wrist-based versus hip-based estimates of MVPA and
develop an equating system to accurately compare estimates between the two
accelerometer placements and 3) to identify how to maximize accumulation of MVPA
during time allocated for PA through either free play, organized activities, or a mixture of
the two. All studies focused on elementary aged children, aged 5-11 years.

Major Findings

Study 1 was designed to establish best practices related to accelerometer
placement when used on the wrist. The purposes of this study was two-fold: 1) to
determine differences in counts per 5-second epoch between the dominant and non-
dominant wrist and 2) to derive an optimal cutpoint threshold to distinguish sedentary
behavior from light physical activity for both wrist placements. Findings from this study
suggest that placement of accelerometer does, in fact, matter during seated sedentary
behaviors in 5-11 year old children. Sedentary behavior that requires upper extremity
movement resulted in higher counts per 5-second epoch on the dominant wrist compared
to the non-dominant wrist. During activities in which there was little to no movement at
the upper extremities, no differences per 5-second epoch were observed due to the fact
that neither wrists move during these types of activities, resulting in 0 counts per 5-sec
epoch for both wrists. For example, playing board games and cutting and pasting (i.e. arts
and crafts) require children to use both wrists resulting in ~40 more counts per 5-second
epoch on the dominant wrist compared to the non-dominant. Alternatively, when children
watch television or read books, their upper extremities are largely motionless, resulting in
median values of 0 counts per 5-second epoch for both wrists. As a result of higher
counts/5sec on the dominant wrist, the optimal cutpoint thresholds between the two wrist placements were different, with the dominant wrist cutpoint higher than the non-dominant wrist. The optimal cutpoint thresholds were 203 counts/5sec and 229 counts/5sec for the non-dominant and dominant wrist, respectively. Receiver Operator Characteristic analyses revealed that the dominant wrist placement leads to an increased misclassification of sedentary activity as light physical activity.

Study 2 aimed to address the newest issue related to comparing youth MVPA estimates across studies using the ActiGraph GT3X+. The objective of this study was to develop an equating system to compare estimates of MVPA from the hip and non-dominant wrist. Children wore two accelerometers, one at the hip and one on the non-dominant wrist for up to three hours during free-living activities. Comparing mean MVPA estimates across all cutpoints, both hip and wrist, values ranged from 15.5 to 32.3 minutes of MVPA. The newly developed regression equations resulted in proportion of variance explained ranging from 29.3% to 81.1%. When the regression equations were applied to a four-group hold out sample, differences in mean MVPA between the actual hip-based estimates and the predicted values ranged from -1.8 to 56.3%. Findings from this study offer a practical solution to comparing wrist to hip-based estimates of MVPA in elementary aged children.

Study 3 aimed to determine which structure of PA opportunity maximizes time spent in MVPA. Children were exposed to three variations of activity opportunities: 1) free play only, 2) organized activity only and 3) a mixed condition in which both free play and organized activity were offered within the same activity session. Results indicated that, for boys, free play elicited more MVPA and less time spent sedentary
during free play compared to organized activity. Further, the mixed sessions elicited more MVPA and less time sedentary compared to organized activity sessions. It seems that for boys, offering some amount of free play is better than none. Girls experienced no differences in MVPA levels across all conditions. However, girls spent less time sedentary during free play compared to organized sessions. There were no differences in time spent sedentary between the mixed and organized only sessions. Overall it seems that offering free play to boys and girls maximizes time by eliciting more MVPA in boys and limiting the amount of time spent sedentary for both boys and girls.

Limitations to Dissertation

Study 1 has several limitations to be noted. The study design lacked a free-living portion of the protocol in which children are free to choose what activities in which they take part. The activities assessed were designed to begin and end at the same time for up to 20 children at a time, therefore it was structured in nature. A free living portion of testing may have yielded different results and should be tested in the future. Additionally, the use of direct observation to verify that children were seated, therefore sedentary, was employed and may be criticized by researchers who prefer that a metabolic equivalent (MET) value be the criterion for indication of time spent sedentary. The purpose of the study was to determine activity counts that occur even when seated, therefore direct observation was deemed the necessary and appropriate criterion measure.

Study 2 also has limitations to be discussed. The major limitation of this study is that creating regression equations to equate MVPA estimates derived from different sets of cutpoints compounds error on error. During calibration studies (i.e. the process of creating cutpoints), a certain degree of error is introduced. Additionally, all regression
equations developed in the present study had associated error, therefore adding another
degree of error to the equating system. Compounding error is not ideal, but it must be
kept in perspective that in some cases, differences of MVPA estimates were alleviated by
almost half; a difference of nearly 15 minutes was reduced to only 8 minutes. Also, the
exclusion of some published wrist and hip-based cutpoints may be criticized[40, 44, 46];
however the six most cited hip-based cutpoints and the only non-dominant wrist-based
cutpoints were utilized. The two sets of cutpoints based on the dominant wrist were
excluded due to participants study wearing the accelerometers on the non-dominant
wrist.[40]

Limitations of study 3 include the assessment of only one setting that offer PA
opportunities for children and the constant duration of activity sessions. Children have
the opportunity to be active in many settings, however afterschool programs was the only
settings evaluated, therefore generalizability may be limited. Additionally, the time
allocated for PA opportunities may impact the percentage of time children spend active;
therefore results may vary when assessed over various PA opportunity durations.

Considerations for Future Research

Papers 1 and 2 resulted in significant advancements towards accurate
measurement and comparisons of PA in youth; however there is far more progress to be
made. Future research should assess free-living activities to validate the newly developed
cutpoint thresholds. Additionally, expanding the analyses to include other activity
intensities (i.e. moderate and vigorous) to verify differences or similarities in counts
produced by each wrist-placement is warranted as researchers are currently using both
placements. The equation system developed in Study 2 will undoubtedly need to be
updated as more wrist-based cutpoints are introduced. Additionally, an equating system should be created for adult populations, as currently the three already developed can be applied only to youth PA levels.

Future research should investigate activity structure’s contribute to the accumulation of MVPA across different settings that provide PA opportunities as well as across various durations of activity sessions. Lastly, future studies should also examine the effects of offering a choice of free play or organized activity as children may be most active when they have a choice of activity structure.

Conclusion

This dissertation was the first to assess the contribution of activity structure to children’s PA levels. It was also the first to our knowledge to address the timely matter of the use of wrist-based accelerometry to assess PA levels and how this change impacts accurate measurement and comparisons of PA in youth. Results from this dissertation provide empirical evidence to support recommendations regarding wrist-based accelerometry. Further results from Study 3 provide practical knowledge for PA providers that offering free play to children during PA opportunities will maximize time spent in MVPA and minimize time spent sedentary. In conclusion, this dissertation represents a novel approach in the analysis of children’s physical levels through measurement and activity structure
References


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