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Accelerometer Thresholds: Accounting for Body Mass Reduces Discrepancies between Measures of Physical Activity for Individuals with Overweight and Obesity

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Accelerometer Intensity Thresholds and Obesity

Abstract

Objective: To explore whether accelerometer thresholds that are adjusted to account for differences in body mass influence discrepancies between self-report and accelerometer measured physical activity (PA) volume for individuals with overweight and obesity.

Methods: 6164 adults from 2003-2006 NHANES surveys were analyzed. Established accelerometer thresholds were adjusted to account for differences in body mass to produce a similar energy expenditure (EE) rate as individuals with normal weight. Moderate, vigorous, and moderate-to-vigorous (MV) intensity PA durations were measured using established and adjusted accelerometer thresholds and compared to self-report.

Results: Durations of self-report were longer than accelerometer measured MVPA using established thresholds (normal weight: 57.8±2.4 vs 9.0±0.5 min/day, overweight: 56.1±2.7 vs 7.4±0.5 min/day, and obesity: 46.5±2.2 vs 3.7±0.3 min/day). Durations of subjective and objective PA were negatively associated with body mass index (BMI) ($P<0.05$). Using adjusted thresholds increased MVPA durations, and reduced discrepancies between accelerometer and self-report measures for overweight and obese groups by 6.0±0.3 min/day and 17.7±0.8 min/day, respectively ($P<0.05$).

Conclusion: Using accelerometer thresholds that represent equal EE rates across BMI categories reduced the discrepancies between durations of subjective and objective PA for overweight and obese groups. However, accelerometer measured PA generally remained shorter than durations of self-report within all BMI categories. Further research may be necessary to improve analytical approaches when using objective measures of PA for individuals with overweight or obesity.

Keywords: Physical Activity, Accelerometry, Intensity Thresholds, Body Mass Index

Introduction

The assessment of physical activity (PA) volume, which refers to the frequency and duration of PA, is an important component of surveillance programs, interventions and public health initiatives (Warren et al. 2010; Strath et al. 2013). In research and clinical settings, objective and subjective assessments of PA are useful for investigating trends and associations between PA with health and disease (Warren et al. 2010). Self-report PA is widely used in population-based studies (Strath et al. 2013) however, it is not considered as accurate as objectively measured PA (Westerterp 1999; Hallal et al. 2013). Accelerometers, which provide an objective measure of PA (Dishman et al. 2001; Prince et al. 2008), have become increasingly popular in recent decades and are now used for assessing PA in population-based studies (Dishman et al. 2001; Mâsse et al. 2005).

Accelerometers capture changes in velocity over time (accelerations) which are known as activity counts (Gabriel et al. 2010; Tudor-Locke et al. 2012). Thresholds for activity counts per minute (CPM) (Troiano et al. 2008; Tudor-Locke et al. 2012) have been created to correspond to Metabolic Equivalents (MET) for moderate (3-6 MET), and vigorous (>6 MET) intensities of PA (Ainsworth et al. 2000). However, using the same (guideline) CPM intensity threshold values across a heterogeneous population may bias accelerometer measured PA against individuals with greater body mass as they will expend more energy during PA at the same acceleration compared to individuals with a lower body mass (Newton's second law: Force= mass·acceleration) (Yang and Hsu 2010).

The differences between accelerometer measured and self-reported durations of PA are often attributed to biases of self-report, and tend to be greater among children (McMurray et al. 2008) and adults with overweight and obesity compared to normal weight (Tully et al. 2014).

While factors such as body mass, sex, age, ethnicity, sedentary behaviour, and health status may contribute to the discrepancies between accelerometer measured and self-report PA volume, it has been suggested that body mass will likely have the greatest influence on energy expenditure (EE) (Klausen et al. 1997). Whether the discrepancies in between accelerometer measured and self-report PA volume are reduced when using CPM intensity thresholds that account for the difference in EE rates (kcal/hour) among body mass index (BMI) categories is yet to be established. Therefore, the objective of this study is to evaluate how adjustment of established accelerometer CPM intensity thresholds to correspond to similar EE between BMI categories influences measured PA duration. The second objective is to examine how measured PA duration using adjusted thresholds will compare with self-reported PA for individuals with overweight or obesity.

Methods

Data for the current study was obtained from the National Health and Nutrition Examination Survey (NHANES) cycles 2003-2004 and 2005-2006. The NHANES is an ongoing survey which uses a multistage probability design to provide nationally representative data of the United States. Data on demographics, health behaviours, and PA are collected via household interviews (n=20,470) that are followed by health examinations conducted in a mobile examination center (n=19,593). Written informed consent was obtained from participants and study protocol was approved by the National Center for Health Statistics. Complete details of the study design and procedures are reported elsewhere (Zipf et al. 2013).

Participants were excluded from this analysis if they were under 18 years of age (n=8956), classified as underweight (n=3590), were pregnant (n=647), missing self-reported PA (n=4052) or BMI data (n=2834) or had invalid or missing accelerometer data (n=7951). This left 6164 eligible participants.

Data on age (years), sex (male/female), and self-reported PA (minutes/day) were extracted from questionnaires. Body mass and height were measured by trained health technicians using a standardized protocol (CDC 1996; CDC 2005). Calculated BMI was used to stratify individuals according to standard cutoffs (WHO 2004): normal weight (18.5-24.9 kg/m^2), overweight (25.0-29.9 kg/m^2), and obese ($\geq$30 kg/m^2).

Self-reported Physical Activity

NHANES includes a questionnaire to assess the mode, frequency, and duration of PA for the 30 days prior to the interview. Moderate and vigorous intensity PA were evaluated with the questions: 1) “Over the past 30 days, did you do moderate activities for at least 10 minutes that caused? only light sweating or a slight to moderate increase in breathing or heart rate?” and 2) “Over the past 30 days, did you do any vigorous activities for at least 10 minutes that caused heavy sweating, or large increases in breathing or heart rate?" Participants who answered "Yes" to either question were asked to provide the duration and frequency of their activities. To assess active transportation and household/domestic moderate to vigorous physical activity (MVPA), the following two questions were asked: 1) "Over the past 30 days, have you walked or bicycled as part of getting to and from work, or school, or to do errands?" and 2) "Over the past 30 days, did you do any tasks in or around your home or yard for at least 10 minutes that required moderate or greater physical effort?" Participants who answered "Yes" to either question were asked to report the frequency and duration of these activities. Durations of all self-reported PA were summed to derive average minutes of MVPA per day.

Accelerometers

Ambulatory participants were asked to wear a PA monitor on their right hip (Actigraph model 7164, LLC; Ft. Walton Beach, FL) during waking hours for a period of seven days. Only respondents with at least four valid days of wear with ≥10 hours of wear time per day were used in the analysis. Accelerometer output was classified using established PA intensity thresholds: Light <2020 CPM, Moderate ≥2020 CPM and Vigorous ≥5999 CPM (Troiano et al. 2008). Accelerometer measured durations of moderate, vigorous, and MVPA intensities were calculated as the sum of moderate and/or vigorous activity performed in bouts of at least 10 minutes in duration with an allowance of up to 2 minutes below the intensity thresholds (Troiano et al. 2008; Tudor-Locke et al. 2010). To be consistent with self-report, accelerometer measured durations of PA were used to derive average minutes per day. The Statistical Analysis System (SAS) syntax used to calculate PA volume is available at: http://www.cdc.gov/nchs/tutorials/PhysicalActivity/Downloads/downloads.htm (CDC/ National Center for Health Statistics 2013). Additional details of the NHANES accelerometer protocol have been previously described elsewhere (Tudor-Locke et al. 2012).

Energy Expenditure Prediction Equations

At the established moderate (2020 CPM or 3 MET) and vigorous (5999 CPM, or 6 MET) PA intensity thresholds, four validated generalized EE prediction equations (Freedson et al. 1998; Hendelman et al. 2000; Swartz et al. 2000; Yngve et al. 2003) were used to calculate gross MET values and EE rates across the BMI categories. Resting metabolic rate (1 MET) was subtracted from the derived gross MET values, and then multiplied by the mean body mass of each BMI category to obtain activity EE (kcal/hour; assuming 1MET = 1 kcal/kg/hour) at the moderate and vigorous CPM intensity thresholds. The net EE rates of the normal weight group at the established CPM intensity thresholds were then used to derive new CPM intensity thresholds for overweight and obese groups using their respective mean body masses. As such, the calculated BMI-specific CPM intensity thresholds resulted in similar EE rates for all BMI classes. The following prediction equations were used to determine new CPM intensity thresholds for overweight and obese individuals:

1) Freedson et al.: $MET = 1.439008 + (0.000795 \cdot CPM)$

2) Hendelman et al.: $MET = 1.602 + (0.000638 \cdot CPM)$

3) Swartz et al.: $MET = 2.606 + (0.0006863 \cdot CPM)$

4) Yngve et al.: $MET = 0.751 + (0.0008198 \cdot CPM)$

New CPM intensity thresholds for moderate and vigorous intensity were used to calculate durations of moderate, vigorous, and MVPA for overweight and obese groups, which were then compared with self-reported durations of PA.

Data Analysis

Continuous variables are reported as mean ± SE and categorical as frequency and prevalence. Group differences for characteristics by BMI category, and durations of PA at all intensities were assessed using one-way analysis of variance tests for continuous variables, and chi-square tests for the categorical variable. Differences between measured durations of PA calculated by the different equations and between measured and self-reported durations of PA within BMI categories were assessed using repeated measures analysis of variance with least-squared differences post hoc comparisons tests. All statistical analyses were conducted using SAS v9.4 survey procedures and weighted to provide results representative of the U.S population. Statistical significance was considered at $P < 0.05$.

Results

Participant characteristics and physical activity durations by BMI category are presented in **Table 1**. Self-reported durations of PA in all BMI categories were significantly longer than accelerometer measured PA using the established thresholds ($P<0.05$). In general, durations of self-reported and measured PA were shorter with increasing BMI. The absolute difference between durations of accelerometer measured and self-report moderate PA intensity were similar across the BMI categories, and the absolute differences between durations of accelerometer measured and self-report vigorous intensity and MVPA were significantly lower among those with obesity compared to normal and overweight groups.

New calculated intensity thresholds and PA durations

EE rates for each BMI category were calculated using the Freedson, Hendelman, Swartz and Yngve prediction equations using the mean body mass of the respective BMI groups (**Table 2**). EE rates at established moderate and vigorous intensity thresholds were significantly higher with increasing BMI (**Table 2,** $P<0.05$). New CPM intensity thresholds were calculated to represent the CPM required for groups with overweight and obesity to reach similar activity EE rates as the normal weight group (referent), at moderate (3 MET) and vigorous (6 MET) intensity (**Table 3)**. The durations of MVPA using the adjusted thresholds for the overweight and obesity groups were significantly different between all the equations within each BMI class ($P<0.05$) and were significantly longer with new intensity thresholds as compared to established thresholds ($P<0.05$) but generally remained shorter than self-report values (**Figure 1**). Within the overweight and obesity groups, the Swartz adjusted thresholds produced significantly longer durations of MVPA than the other equations and self-report values ($P<0.05$).

Between BMI groups, the new thresholds still generally resulted in shorter MVPA durations for individuals with obesity as compared to normal weight ($P<0.05$). The only exception was when using the Yngve adjusted thresholds that resulted in MVPA durations that were not significantly different between the between the normal weight with the overweight ($P=0.13$), and obesity groups ($P=0.55$).

Discussion

Findings from this study suggest that using a single established accelerometer CPM intensity threshold may bias measures of PA durations for individuals with overweight or obesity as compared to normal weight. When accelerometer CPM intensity thresholds were adjusted for differences in body mass among BMI categories, the discrepancies between accelerometer measured and self-reported PA volume were reduced for individuals with overweight or obesity. Therefore, additional research is needed to clarify whether population-specific accelerometer thresholds are needed to evaluate PA volume.

The current approach of applying guideline CPM intensity thresholds for quantifying moderate (2020 CPM or 3 MET) and vigorous (5999 CPM or 6 MET) PA (Troiano et al. 2008) does not account for differences between individuals that may influence PA intensity and how it relates with CPM. Indeed, individuals with greater body mass require more energy (greater force) to achieve the same acceleration or movement compared to individuals who are normal weight. For example, at an equal walking pace, individuals with obesity will expend more energy than individuals who are normal weight (Bloom and Eidex 1967), yet accelerometers capture similar CPM (Liu et al. 2012). Additionally, as the guideline CPM thresholds correspond to 3 and 6 MET using the standard reference of a healthy 65kg male (Ainsworth et al. 2000) , they do not account for the differences in aerobic and musculoskeletal fitness among individuals (Ferrari et al. 2007; Alhassan and Robinson 2010; Miller et al. 2010; Ozemek et al. 2013; Ramirez-Marrero et al. 2014; Zisko et al. 2015). Thus, at a given absolute intensity of PA (ie. 3 or 6 MET), individuals with a lower aerobic fitness will experience higher relative intensity of PA compared to those who with a higher level of aerobic fitness (Katzmarzyk et al. 2005). As individuals with overweight and obesity are more likely to have a low fitness (Ozemek et al.

2013), in conjunction with their higher body mass, they will need to work at even higher relative intensities at the accelerometer CPM threshold values. As such, PA volume may be underestimated for individuals with overweight or obesity. Indeed, small studies demonstrate that individuals with overweight or obesity (Lopes et al. 2009; Alhassan and Robinson 2010) and the elderly (Zisko et al. 2015) work at a higher relative intensity than described by the commonly used definitions of 3 and 6 MET when asked to engage in PA that would measure the same CPM values as normal weight and younger populations. In the current study, we demonstrate that at the established accelerometer CPM intensity thresholds the calculated EE rates were significantly greater with increasing obesity. When the intensity thresholds were adjusted to result in equal EE rates among all BMI categories, individuals with overweight and obesity required lower CPM values to describe moderate and vigorous intensity PA.

Currently, it is unclear what CPM intensity threshold values should be used to more appropriately assess PA volume in various sub-populations. Studies that examine various populations with different fitness levels based on body mass, age and sex report ranges of CPM values for moderate intensity PA between 669 and 7520 CPM (Ozemek et al. 2013; Zisko et al. 2015). In the current study, the adjusted MVPA intensity threshold values generally fall within the lower range of the previously published thresholds, with only the Swartz equation falling below this range. Nevertheless, this extremely large range suggests that there may not be a single appropriate threshold value to define PA intensity in a heterogeneous population. The choice of CPM intensity threshold values to appropriately represent relative PA of individuals or groups within a population remains a challenge as the validation of CPM threshold values are influenced by population characteristics, the accelerometer used and the ranges of activities performed. Clearly more work is needed to verify the findings here to determine the most optimal balance between the ease of using a single threshold versus the accuracy of multiple population-specific thresholds.

Both accelerometers and self-report are used to assess PA volume. However the PA durations reported by each method are generally very different, and this likely due to the differences in how they capture PA. Accelerometers are considered a valuable tool for the assessment of ambulatory movement, but are unable to capture activity such as those involving the upper extremities (Prince et al. 2008), weight training (Yngve et al. 2003; Mâsse et al. 2005), cycling or swimming (Swartz et al. 2000; Prince et al. 2008; Jerome et al. 2009), which are captured in self-report. Further, activities that involve interval or short bursts of movement interspersed between larger periods of light or sedentary activity such as volleyball or soccer, would likely be captured by accelerometers as a much shorter overall duration as compared to the self-reported values. This may contribute to the shorter durations of PA commonly measured by accelerometers. Indeed, self-reported durations of PA were greater than measured for all BMI groups. Further, there are differences in the types of PA that different BMI groups engage in. For example, a study suggests that individuals with overweight or obesity report that they are more likely to engage in swimming (Spees et al. 2012) which will not be captured by accelerometers. Given the differences that exist between the ways in which PA volume is captured using self-report and accelerometers, the comparison these two measures is challenging, yet it occurs frequently in the literature. While the measurement of PA using accelerometers and self-report both have their own inherent limitations (Orme et al. 2014), the discrepancies between these measurements are often attributed to errors in self-report (Troiano et al. 2008). Individuals with overweight or obesity are reported to be more affected by factors such as social desirability, and weight stigma thereby further contributing to the over-estimation of moderate to vigorous PA

(Dishman et al. 2001; Canning et al. 2014) durations using questionnaires (Dishman et al. 2001). However, the over-estimation of PA durations measured in a questionnaire may be due to individuals underestimating the intensity of PA that are described as MVPA (Canning et al. 2014). Previous literature commonly states that over-reporting is more prevalent among individuals with obesity (Ferrari et al. 2007; McMurray et al. 2008; Prince et al. 2008; Howe et al. 2009; Dyrstad et al. 2014; Ramirez-Marrero et al. 2014; Tully et al. 2014). However, our results suggest that the over-reporting trends could be due to the bias of the accelerometer measurement of PA volume for individuals with obesity. In fact, after accounting for the higher body weight of individuals with obesity, durations of MVPA was increased by 3 to 17 min/day depending on the equation used. This magnitude of difference is likely relevant given that even 10 minutes of MVPA is associated with health effects (Orme et al. 2014). Surprisingly, using the Swartz adjusted thresholds we observed that durations of accelerometer measured MVPA for individuals with obesity were increased by more than 80 min/day as compared to the established CPM thresholds, and were almost 2 times longer than self-report values. This difference may be in part because the Swartz study used fewer ambulatory activities as compared to the other studies, and thus the EE for a given CPM predicted tended to be higher. Thus, more work may be needed to clarify the relationship between EE and CPM, particularly in populations with overweight or obesity.

Several limitations exist in the current study. It is unclear whether the discrepancies observed between MVPA durations as assessed by accelerometer and self-report are due to the ability of self-report to capture a wider scope of activities than accelerometers (ie. swimming, cycling, resistance training, etc.), or due to issues with self-report such as report bias or methodological issues in the way questions were asked resulting in double counting or activities that were missed. The EE prediction equations used in this study are widely used, but were created and validated with predominantly healthy and normal weight participants (Freedson et al. 1998; Hendelman et al. 2000; Swartz et al. 2000; Yngve et al. 2003), and may not be generalizable for individuals with overweight or obesity. However, to our knowledge, valid energy prediction equations derived specifically for individuals with overweight and obesity do not exist. The strength of this study is the use of a nationally representative sample of the civilian adult population in the United States.

In summary, the use of alternate accelerometer CPM intensity thresholds that account for differences in EE due to body mass reduced the discrepancies between accelerometer and self-reported durations of PA for individuals with overweight and obesity. As the guideline intensity thresholds correspond to higher rates of EE for overweight and obese groups, they may inappropriately bias accelerometer measured PA in individuals with overweight or obesity. As such, further research may be required to determine whether the improvements gained in accounting for obesity status or other factors such as age, physical activity patterns or aerobic fitness warrant the creation of population-specific CPM thresholds.

Conflicts of Interest: The authors report no conflicts of interest associated with this manuscript.

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Table 1: Participant characteristics

	Normal Weight	Overweight	Obesity
Sample size (n)	1960	2209	1995
Age (years)	45.2 ± 0.6	50.0 ± 0.6*	48.6 ± 0.5*†
Sex (n, % Male)	937 (47.8)	1314 (59.5)*	917(46.0) *†
BMI (kg/m^2)	22.5 ± 0.0	27.4 ± 0.0*	35.4 ± 0.2*†
Self-Reported PA (min/day)			
Leisure Time Moderate Intensity	20.2 ± 1.3	19.1± 0.8	16.2 ± 0.9*†
Leisure Time Vigorous Intensity	12.9 ± 0.8	9.1 ± 0.6*	5.6 ± 0.4*†
Total MVPA	57.8 ± 2.4	56.1 ± 2.7	46.5 ± 2.2*†
Accelerometer measured PA (min/day)			
Moderate intensity	7.1 ± 0.4‡	6.3± 0.4‡	3.5± 0.2*†‡
Vigorous intensity	0.9 ± 0.1‡	0.6± 0.1*‡	0.1± 0.02*†‡
Total MVPA	9.0 ± 0.5‡	7.4 ± 0.5*‡	3.7 ± 0.3*†‡

Values are presented as mean ± SE.

* = Statistically different from normal weight group (P<0.05)
† = Statistically different from overweight group (P<0.05)
‡ = Statistically different from self-report (P<0.05)

Table 2: Energy expenditure rates calculated using common prediction equations

	Normal Weight	Overweight	Obesity
Body mass, BM (kg)	64.1 ± 0.3	79.5 ± 0.2*	101.0 ± 0.7* †
EE rate at 2020 CPM (kcal/hour)			
Freedson MET = 1.439008 + (0.000795·CPM)	131 ± 1	163 ± 0*	206 ± 1* †
Hendelman MET = 1.602 + (0.000638·CPM)	121 ± 1	150 ± 0*	191 ± 1* †
Swartz MET = 2.606 + (0.0006863·CPM)	192 ± 1	237 ± 1*	302 ± 2* †
Yngve MET = 0.751 + (0.0008198·CPM)	90 ± 0	112 ± 0*	142 ± 1* †
EE rate at 5999 CPM (kcal/hour)			
Freedson MET = 1.439008 + (0.000795·CPM)	334 ± 2	414 ± 1*	526 ± 4* †
Hendelman MET = 1.602 + (0.000638·CPM)	284 ± 1	353 ± 1*	448 ± 3* †
Swartz MET = 2.606 + (0.0006863·CPM)	367 ± 2	455 ± 1*	578 ± 4*†
Yngve MET = 0.751 + (0.0008198·CPM)	299 ± 2	371 ± 1*	471 ± 3* †

Values are presented as mean ± SE.
* = Statistically different from normal weight group (P<0.05)
† = Statistically different from overweight group (P<0.05)

Table 3: New CPM intensity threshold calculations using common prediction equations

	Normal Weight	Overweight	Obesity
Moderate Intensity CPM Thresholds*			
Freedson: CPM= (131/BM – 0.439008) /0.000795	2020	1522	1081
Hendelman: CPM= (121/BM – 0.602) /0.0006389	2020	1446	939
Swartz: CPM= (192/BM – 1.606) /0.0006863	2020	1175	428
Yngve: CPM =(90/BM + 0.249) /0.0008199	2020	1687	1393
Vigorous Intensity CPM Thresholds*			
Freedson: CPM= (334/BM – 0.439008) /0.000795	5999	4729	3607
Hendelman: CPM= (284/BM – 0.602) /0.0006389	5999	4653	3464
Swartz: CPM= (367/BM – 1.606) /0.0006863	5999	4382	2954
Yngve: CPM = (299/BM + 0.249) /0.0008199	5999	4894	3918

*New threshold calculations include adjustment for resting metabolic rate (1MET).

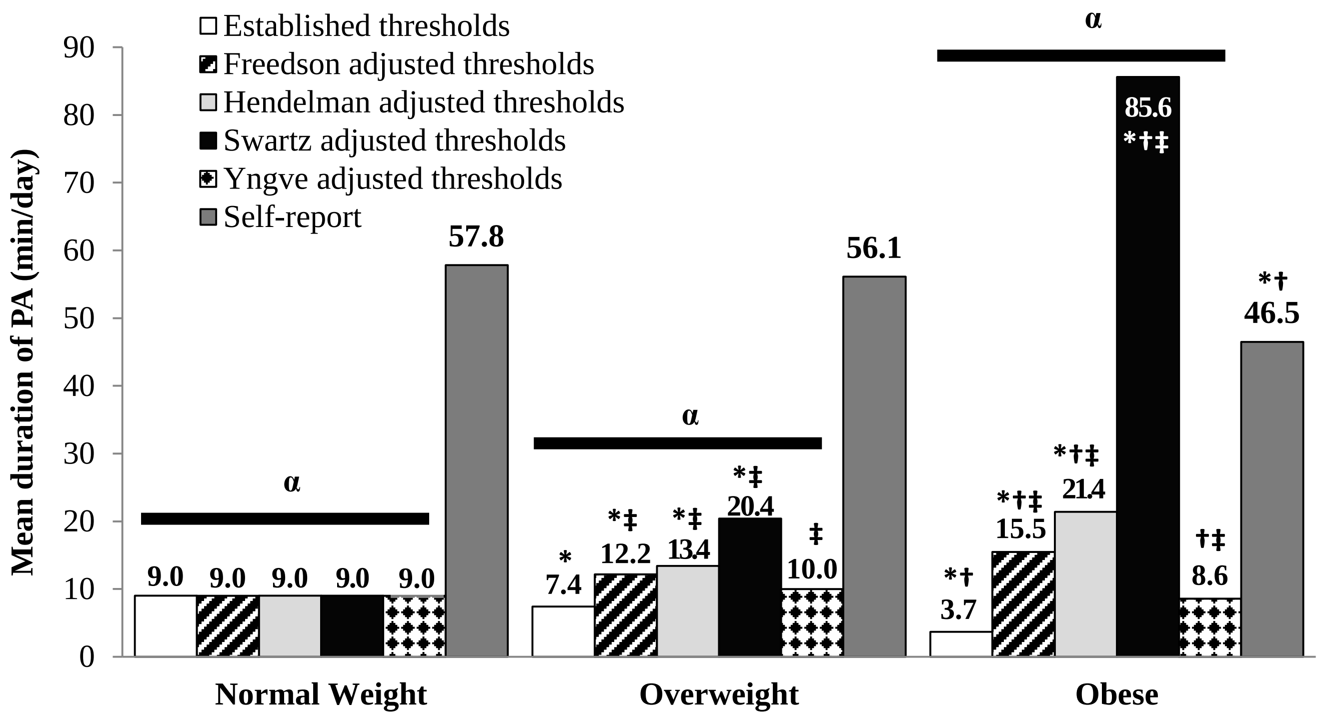
Figure 1: Durations of measured and self-reported moderate to vigorous physical activity by body mass index category.

Caption:

Durations of MVPA between adjusted thresholds are statistically different within overweight and obesity groups.

* = Statistically different from normal weight group (P<0.05)
† = Statistically different from overweight group (P<0.05)
‡ = Statistically different from established thresholds (P<0.05)
α = Statistically different from self-report (P<0.05)

1.


Established thresholds
Freedson adjusted thresholds
Hendelman adjusted thresholds
Swartz adjusted thresholds
Yngve adjusted thresholds
Self-report
Mean duration of PA (min/day)
0
10
20
30
40
50
60
70
80
90
α
9.0
9.0
9.0
9.0
9.0
57.8
α
*
7.4
*‡
12.2
*‡
13.4
*‡
20.4
‡
10.0
56.1
α
*†
3.7
*†‡
15.5
*†‡
21.4
85.6
*†‡
†‡
8.6
*†
46.5
Normal Weight
Overweight
Obese