**Do Moderate to Vigorous Intensity Accelerometer Count
Thresholds Correspond to Relative Moderate to Vigorous
Intensity Physical Activity?**

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**Do Moderate to Vigorous Intensity Accelerometer Count Thresholds Correspond to
Relative Moderate to Vigorous Intensity Physical Activity?**

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ABSTRACT

OBJECTIVES: We aim to predict %VO₂max at absolute accelerometer thresholds, and estimate and compare durations of objective physical activity (PA) among body mass index (BMI) categories using thresholds that account for cardiorespiratory fitness.

METHODS: 828 adults (53.5% male, age= 33.9±0.3 years) from NHANES 2003-2004 were analyzed. MET values at absolute thresholds were converted to %VO₂max, and accelerometer counts corresponding to 40 or 60% VO₂max were determined using 4 energy expenditure prediction equations.

RESULTS: Absolute thresholds under-estimated PA intensity for all adults; however, individuals with overweight and obesity work at significantly higher %VO₂max at the absolute thresholds, and require significantly lower accelerometer counts to reach relative moderate and vigorous PA intensities compared to normal weight due to lower fitness (P<0.05). However, Moderate-to-Vigorous PA (MVPA) durations were shorter using relative thresholds compared to absolute thresholds (within all BMI groups, P<0.05), and remained shorter among individuals with obesity compared to normal weight when using relative thresholds (P<0.05). Regardless of the thresholds used, a greater proportion of individuals with normal weight met PA guidelines of 150 min/week of MVPA compared to individuals with obesity (absolute: 21.3 vs 6.7%, Yngve: 4.0 vs 0.2, Swartz: 10.7 vs 3.9, Hendelman: 4.7 vs 0.2, Freedson: 6.4 vs 0.5, P<0.05).

CONCLUSIONS: Current absolute thresholds of accelerometry-derived PA may over-estimate MVPA for all BMI categories compared with relative thresholds that account for cardiorespiratory fitness. Given the large variability in our results, more work may be needed to better understand how to use accelerometers for evaluating PA at the population level.

Keywords: Physical Activity, Accelerometry, Relative Intensity, Intensity Thresholds, BMI, Fitness

65 BACKGROUND

66 In research and clinical settings, the assessment of physical activity (PA) volume is
67 important for monitoring the frequency, duration and intensity of PA on health and disease
68 management outcomes (Warren et al., 2010). The volume, which commonly refers to the
69 duration and frequency of PA required to positively influence health and disease outcomes
70 acutely and chronically, may be achieved through any combination of intensity, duration, and
71 frequency of PA that considers the unique needs and the physical and physiological attributes of
72 the individual (Strath et al., 2013).

73 Accelerometers are commonly used for objectively measuring PA volume in research
74 studies (Dishman et al., 2001; Masse et al., 2005). Accelerometers capture changes in velocity
75 over time (accelerations) or activity counts per minute (CPM) (Gabriel et al., 2010; C Tudor-
76 Locke et al., 2012). An absolute threshold of 2020 CPM is typically used to differentiate MVPA,
77 however, this approach may bias PA assessment in certain populations. Previously, we
78 demonstrate that discrepancies between objective and subjective measures of PA is reduced for
79 individuals with overweight and obesity after accounting for differences body weight (Raiber et
80 al., 2017). Using a single absolute CPM threshold value to denote moderate or vigorous PA
81 intensities also does not account for the individual differences in cardiorespiratory fitness or
82 maximal oxygen consumption ($\text{VO}_{2\text{max}}$) on the perceived or relative intensity ($\%\text{VO}_{2\text{max}}$) of
83 PA. Thus, we hypothesize that using a single absolute CPM threshold will under-estimate the
84 relative intensity of PA and durations of PA engagement in populations with lower levels of
85 cardiorespiratory fitness, such as those with obesity. This may contribute to the larger magnitude
86 of discrepancies between measures of subjective and objective PA that are commonly observed
87 among individuals with overweight and obesity (McMurray et al., 2008). As such, the purpose of

88 this study is two-fold: 1) to predict the relative intensity of PA that corresponds to absolute CPM
89 intensity thresholds across body mass index (BMI) categories; and 2) to estimate and compare
90 durations of accelerometer measured PA using absolute and relative CPM intensity thresholds
91 based on cardiorespiratory fitness.

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92 **METHODS**

93 Data for the current study was obtained from the publicly available National Health and
94 Nutrition Examination Survey (NHANES) 2003-2004 study cycle as this was the only survey
95 year in which accelerometer measured PA and fitness testing data were collected. The NHANES
96 is an ongoing survey which uses a multistage probability design to provide nationally
97 representative data of the United States. Data on demographics, health behaviours, and PA are
98 collected via household interviews and followed by health examinations conducted in a mobile
99 examination center. Written informed consent was obtained from participants and the study
100 protocol was approved by the National Center for Health Statistics. Complete details of the study
101 design and procedures are reported elsewhere (Zipf et al., 2013).

102 Of the total of 10,122 participants in this study cycle, 7313 participants were excluded
103 because of missing estimated VO_2max . Of the remaining participants, individuals were also
104 excluded if they were missing self-reported PA ($n=44$), invalid or missing accelerometer data
105 ($n=1176$), and BMI ($n=6$). Participants were also excluded if they were under 18 years of age
106 ($n=718$), pregnant ($n=10$), and classified as underweight ($\text{BMI} < 18.5 \text{ kg}\cdot\text{m}^2$, $n=27$). The
107 resultant analyses were conducted on 828 individuals.

108 Age, sex, and self-reported PA durations over 30 days were extracted from
109 questionnaires. Body mass and height were measured by trained health technicians using a
110 standardized protocol (CDC/ National Center for Health Statistics, 2005; Centers for Disease
111 Control and Prevention, 1996). Calculated BMI was stratified according to standard categories
112 (Health Topics, n.d.): normal weight ($18.5\text{-}24.9 \text{ kg}\cdot\text{m}^2$), overweight ($25.0\text{-}29.9 \text{ kg}\cdot\text{m}^2$), and
113 obesity ($\geq 30 \text{ kg}\cdot\text{m}^2$).

114

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 (Centers for Disease Control and Prevention, 2017). 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 self-report PA were converted to average minutes per day (min/day). Additional details of the NHANES PA questionnaire have been previously described elsewhere (Centers for Disease Control and Prevention, 2017).

Accelerometry

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 consecutive days. Participants were asked to remove the accelerometer for sleep. Only respondents with at least four valid days of wear with ≥ 10 hours of waking wear time per day were used in the analysis. Accelerometers record the frequency of acceleration in units called counts over a specified time

interval. For this study, the counts were summed over a minute (i.e. counts per minute, or CPM). Accelerometer output was classified using absolute PA intensity thresholds: Moderate ≥ 2020 CPM and Vigorous ≥ 5999 CPM (Troiano et al., 2008). To be consistent with the self-reported PA questionnaire data, accelerometer measured durations of moderate, vigorous, and MVPA intensities were calculated as the sum of moderate and/or vigorous activity bouts of at least 10 minutes in duration with an allowance of up to 2 minutes below the intensity thresholds to be consistent with previous accelerometer literature (Troiano et al., 2008; Catrine Tudor-Locke et al., 2010). To be consistent with the self-report volume of PA data, accelerometer durations of PA were used to derive average min/day. In order to compare adherence to PA guidelines and self-reported PA, objectively measured durations of MVPA/day were multiplied by 7 to provide an estimate of duration per week. The Statistical Analysis Software (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 (C Tudor-Locke et al., 2012).

Maximal Oxygen Consumption

The American College of Sports Medicine's submaximal treadmill validated protocol was used for predicting VO_2max (ACSM, 2013) and the tests were conducted by trained health technicians. They were assigned one of eight treadmill protocols based on their sex, age, BMI, and self-reported PA (Jackson et al., 1990). All protocols included a 2-minute warm up, two 3-minute exercise stages, and a 2-minute cool down. Estimated VO_2max values at age-predicted maximal heart rate were extrapolated assuming a linear relationship between heart rate and oxygen consumption during exercise (ACSM, 2013). A more detailed description of the 2003-

2004 NHANES fitness test procedures and protocols can be found elsewhere (CDC/ National Center for Health Statistics, 2013).

Absolute and Relative Calculated Intensity Thresholds

Four (Freedson et al., 1998; Hendelman et al., 2000; Swartz et al., 2000; Yngve et al., 2003) EE prediction equations were used to calculate MET values at the absolute intensity thresholds for moderate (2020 CPM) and vigorous (5999 CPM) intensity PA by sex and BMI categories:

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

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

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

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

MET values were converted to absolute oxygen uptake (VO_2 ; assuming 1 MET = 3.5 $\text{mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$) and then expressed relative to the estimated $\text{VO}_{2\text{max}}$ (% $\text{VO}_{2\text{max}}$). Next, the reverse process was undertaken to determine the mean CPM values which corresponded to the commonly used % VO_2 max thresholds for moderate (40% $\text{VO}_{2\text{max}}$) and vigorous (60% $\text{VO}_{2\text{max}}$) intensity (Pollock et al., 1998). Relative and absolute CPM intensity thresholds were then used to estimate durations of accelerometer measured PA.

Data Analysis

Continuous variables were reported as mean $\pm$ standard error and categorical variables were reported as prevalence $\pm$ percent standard error. Differences in demographics and PA variables by BMI category and sex were assessed using one-way analysis of variance tests for continuous variables, and chi-square tests for the categorical variables. Differences between absolute and relative % $\text{VO}_{2\text{max}}$ and accelerometer CPM values, objective and subjective

184 durations of PA, and proportion of individuals meeting PA guidelines between and within BMI
185 categories and sex were assessed using repeated measures analysis of covariance (ANCOVA)
186 with least-squared differences *post hoc* comparisons tests with adjustment for age, and
187 McNemar's test where appropriate. All statistical analyses were conducted using SAS v9.4
188 survey procedures and weighted to provide results representative of the U.S population using the
189 NHANES examination sample weights (Code & Used, 2010). Effect size analysis was
190 undertaken using G*Power. Even for the smallest cell size, we are sufficiently powered (0.80)
191 for small effect sizes for an ANCOVA analysis with 3 covariates (cohen's $f = 0.12$) (Faul et al.,
192 2009; White & White, 2001). Statistical significance was considered at $P < 0.05$.

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RESULTS

Participant characteristics and durations of objective and subjective PA by BMI category and sex are presented in **Tables 1** and **2**, respectively. Cardiorespiratory fitness (estimated VO_2max) was lower among individuals with overweight and obesity compared to those with normal weight ($P<0.05$), and in women compared to men ($P<0.05$). Cardiorespiratory fitness did not differ between men or women with overweight and obesity. Durations of accelerometer measured MVPA using the absolute and relative CPM thresholds were shorter than self-report MVPA for all BMI categories and both sexes ($P<0.05$). Further, self-report and accelerometer measured MVPA tended to be shorter among individuals with obesity compared to normal weight using the absolute accelerometer CPM thresholds (**Table 2**). Thus, a greater proportion of men and women with normal weight met the PA guidelines of 150 min/week of MVPA compared to individuals with obesity using self-report and accelerometer measured PA using the absolute threshold (**Table 2**).

Relative intensity of PA at absolute accelerometer thresholds

The % VO_2max (relative intensity) corresponding to the absolute 2020 (moderate intensity) and 5999 (vigorous intensity) CPM were calculated using the four prediction equations (**Table 3**). Regardless of the equation used, individuals with overweight and obesity had a significantly higher predicted % VO_2max at 2020 and 5999 CPM compared with those with normal weight ($P<0.05$).

New calculated relative intensity thresholds

CPM that correspond to 40% (moderate intensity) and 60% (vigorous intensity) of VO_2max by sex and BMI category were calculated (**Figure 1**). Depending on the prediction

equation used, the relative CPM intensity thresholds were generally greater than the absolute intensity thresholds within all BMI categories and both sexes. Further, the relative CPM intensity thresholds were significantly lower for individuals with overweight or obesity compared to normal weight for both sexes ($P < 0.05$), and were lower for women compared to men ($P < 0.05$).

Mean durations of MVPA for all BMI categories estimated with relative intensity thresholds were significantly shorter than durations of PA estimated using absolute thresholds (Absolute: 9.4 ± 1.0 min/day vs Yngve: 2.2 ± 0.4 , Swartz: 5.7 ± 0.7 , Hendelman: 2.3 ± 0.4 , Freedson: 3.3 ± 0.6 min/day). In fact, on average, less than half of this sample achieved even one minute of MVPA using the relative thresholds (Normal weight: 42.4%, Overweight: 38.0%, Obesity: 23.7%), whereas the proportion achieving at least one minute of MVPA were substantively higher using the absolute thresholds (69.4% normal weight, 65.0% Overweight, and 47.2% Obesity). Using the relative CPM intensity thresholds, 0.0-15.0% of individuals met the guidelines of 150 min/week of PA as compared to 60-78% when using self-report, and 4-25% when using the absolute thresholds (**Table 2**). The BMI differences in the proportion of individuals meeting the PA guidelines were less consistent with the relative thresholds as compared to the absolute.

DISCUSSION

This study suggests that the absolute moderate and vigorous intensity CPM thresholds may be associated with lower than expected relative intensity values in the U.S population. When CPM intensity thresholds were adjusted to correspond to 40 and 60% of predicted VO_2max for moderate and vigorous intensity, durations of accelerometer measured PA were even shorter than using the absolute intensity thresholds for all BMI categories and sexes. This may suggest that there are issues with applying the current accelerometer EE-CPM algorithms to estimate PA at a population level. Nevertheless, the absolute CPM thresholds currently used are associated with the highest relative intensity for individuals with obesity. Thus, the greater discrepancies between subjective and objective PA in individuals with obesity compared to normal weight may be in part due to methodological issues associated with using an absolute CPM intensity threshold that bias against those with lower fitness. However, more research is still needed to clarify the best approach for assessing PA volume on a population level using accelerometers.

Previous validation studies demonstrate that the EE is accurately predicted by accelerometers (Freedson et al., 1998; Hendelman et al., 2000; Swartz et al., 2000; Yngve et al., 2003), however some studies report that these equations may substantially misclassify PA intensity in free-living settings (Lyden et al., 2011; Rothney et al., 2008). A review by Lyden et al. (Lyden et al., 2011) concludes that the Actigraph MET prediction equations under-estimate EE 72% of the time. Similarly, they report a prediction bias of -1.4 MET for the Freedson equation, and -0.6 MET for the Swartz equation across various activities. Conversely, Hendelman (Albinali et al., 2010) and Yngve (Yngve et al., 2003) equations are reported to over-estimate EE at moderate intensity PA. We also demonstrate substantial variations in the

predicted %VO₂ associated with the absolute CPM thresholds between the equations. These equations are often conducted in laboratory settings, using specific activities and small samples which consist of predominately young, healthy and normal weight populations which may limit their generalizability (Crouter et al., 2006; Valenti et al., 2013; Westerterp, 1999). However, in our study, even the relative intensity estimated for individuals with normal weight at the absolute CPM threshold (12-19% of VO₂max) was substantially lower than the common definition of 40% of VO₂max for moderate intensity. Further, the discrepancies between the absolute and relative CPM values associated with moderate and vigorous relative intensity were even greater for individuals with normal weight than for individuals with overweight or obesity. Thus, future research is needed to better understand how to best translate CPM values into PA intensity.

For a given absolute intensity of PA, individuals with a lower cardiorespiratory fitness will experience higher relative intensity of PA compared to those with a higher level of fitness (Katzmarzyk et al., 2005). This means that individuals with overweight and obesity, who tend to have lower levels of cardiorespiratory fitness are more likely to work at higher intensities of PA than individuals with normal body weight at the same CPM value (Ozemek et al., 2013). Thus, much of the literature that use the single absolute CPM values (i.e 2020 and 5999 CPM) to describe moderate and vigorous PA (Alhassan & Robinson, 2010; Ferrari et al., 2007; Miller et al., 2010; Ozemek et al., 2013; Ramirez-Marrero et al., 2014; Zisko et al., 2015) have not accounted for the inter-individual differences in cardiorespiratory fitness levels and have biased PA assessment against populations with lower cardiorespiratory fitness levels, such as those with obesity. In the current study, accounting for differences in VO₂max led to substantially lower relative intensity CPM thresholds for individuals with overweight and obesity than individuals with normal weight. However, all of the relative CPM thresholds were higher than the absolute

thresholds. In the literature, there is a large range in CPM thresholds for moderate intensity PA ranging between 669 and 7520 CPM (Ozemek et al., 2013; Zisko et al., 2015), in populations with different ages (Miller et al., 2010), body masses (Alhassan & Robinson, 2010; Lopes et al., 2009), and cardiorespiratory fitness levels (Ozemek et al., 2013; Zisko et al., 2015). This may reflect the need for more research in more representative populations to develop better EE-CPM equations, particularly for older and heavier populations. Despite being used widely in the literature, the absolute thresholds were created from predominately younger and normal weight populations which should theoretically be associated with higher absolute thresholds (Crouter et al., 2006; Valenti et al., 2013; Westerterp, 1999). However, applying equations to populations different from the cohort used to develop the equation may have reduced accuracy and may have contributed to our unexpected results. However, the advantages gained in prediction accuracy for surveillance and examination of the association between PA and health need to be balanced with the clinical feasibility of using and developing multiple population-specific CPM intensity thresholds.

Durations of PA achieved will depend on the intensity CPM threshold value used (Alhassan & Robinson, 2010; Jefferis et al., 2016). Lower moderate intensity CPM threshold values will result in longer durations of measured PA. Conversely, using a higher moderate intensity CPM threshold values will mean that more PA would not qualify as moderate intensity PA, resulting in shorter durations of PA. It is suggested that adults with overweight and obesity tend to over-report PA and engage in less MVPA compared to normal weight (Ferrari et al., 2007; Howe et al., 2009; McMurray et al., 2008; Prince et al., 2008; Ramirez-Marrero et al., 2014; Tully et al., 2014). However, as the methods for objectively assessing MVPA in populations often use a one-size-fits-all approach, they may be biased against individuals with

lower levels of cardiorespiratory fitness, such as those with overweight or obesity. Accounting for cardiorespiratory fitness reduced the magnitude of difference in objective PA duration between the BMI categories. Nonetheless, durations of objective PA remained shorter for individual with obesity than normal weight across all PA intensities. Thus, while accounting for cardiorespiratory fitness may improve the measurement errors associated with assessing PA with accelerometers, large discrepancies remained between durations of objective and subjective PA for both sexes across all BMI categories. Given the large discrepancies between the methods of PA assessment, it is clear that more research is needed in order to assess population PA engagement and to determine the proportion of individuals that meet the PA guidelines by objective measures. However, given that PA recommendations are largely based on self-reported PA, our results suggest that the 150-minute target may not be similarly applied for subjective and objective measures of PA. Nevertheless, it is likely that there is a large proportion of individuals who could receive additional health benefits from performing more PA. Thus, it is important to ensure that public health messaging continues to focus on promoting PA across all BMI classes. With current PA guidelines being largely based on self-report levels of PA, and emphasis and growing interest for assessing objective MVPA in interventions and public health initiatives, more research is needed to improve the comparability of objective and subjective measures of PA.

Several strengths and limitations exist in the current study. The NHANES provides direct measures on a nationally representative sample of the civilian adult population in the United States. Additionally, the use of four different EE equations resulted in considerable variability in EE estimates, suggesting that further work may be needed to confirm or improve EE-CPM prediction equations. These differences may be partially attributed to demographic differences

between the cohorts in the studies used to derive the absolute CPM intensity thresholds and the current study sample. Further, due to the limitations of the EE-CPM equations, we were unable to examine light intensity PA. Additionally, the chosen threshold of 60%VO₂max is a more conservative approach, and other commonly used higher thresholds would only reduce the already low estimates of vigorous activity duration. Sub-maximal tests are a valid method for predicting VO₂max (Marsh, 2012), but may result in the over or under-estimation of VO₂max, which would bias our results to the null unless there are any systematic biases by obesity status. We are not aware of any studies that have shown a systematic bias in the estimation of VO₂max with obesity. Additionally, data was not captured for individuals who did not complete the NHANES fitness test due to factors such as older age, mobility issues or previous cardiorespiratory disease, which means that the sample examined in this study is likely younger, healthier and more fit compared to the individuals who did not complete the fitness test. With higher VO₂max values, the discrepancies between the expected and calculated relative intensities at the absolute CPM intensity thresholds and the differences between the absolute and relative CPM intensity threshold values may have been more pronounced. It may also be important to note that while accelerometers and the PA questionnaire are commonly used measures of PA, there are disadvantages associated with both measures. Accelerometers do not capture all forms of PA, and the questionnaire may be impacted by factors such as recall error and self-report bias (American College of Sports Medicine., 2003; Troiano et al., 2008). Lastly, objective and subjective measurements of PA did not occur over the same time period. Nevertheless, our measures are sufficiently long as to be valid measures of regular habitual PA (Jaeschke et al., 2018; Matthews et al., 2002), and as the point of the study is to examine the influence of fitness on objectively measured PA by BMI category, any bias or discrepancies between the PA

measures would likely be similar across the BMI groups. Thus, the patterns we observe between BMI categories are likely valid despite the limitations in our PA measure.

CONCLUSIONS

PA intensity may be under-estimated for all adults at the absolute CPM intensity thresholds, and even more so for normal weight individuals. Additionally, adults with overweight and obesity may require lower CPM values to reach moderate and vigorous intensities of PA as they tend to have lower levels of cardiorespiratory fitness than normal weight. However, when cardiorespiratory fitness levels were accounted for, estimated durations of objectively measured MVPA were even shorter for individuals across all BMI categories. Thus, more research may be necessary to validate prediction equations and improve the use of accelerometers for assessing the impact of volume of PA participation in a population.

LIST OF ABBREVIATIONS

PA: Physical activity **CPM:** Counts per minute **EE:** Energy expenditure **MET:** Metabolic equivalents **BMI:** Body mass index **NHANES:** National Health and Nutritional Examination Survey **MVPA:** Moderate-to-vigorous physical activity **VO₂max** Maximal Oxygen Consumption

DECLARATIONS

Ethics: NHANES was granted ethics approval by the National Centre for Health Statistic Ethics Review Board. All individuals provided written informed consent prior to study participation. This study is a secondary analysis of anonymized data that did not require ethics approval from the institutional review board.

Consent for publication: Not applicable.

Availability of Data and Materials: Data from this study is made publicly available by the Centers for Disease Control and Prevention, <
<https://wwwn.cdc.gov/nchs/nhanes/continuousnhanes/default.aspx?BeginYear=2003>>

Competing Interests: None

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Authors' Contributions: LR and JLK conceived and designed the study. LR analyzed the data, and wrote the manuscript. All authors provided feedback of analysis and manuscript. JLK and VKJ had final approval of the manuscript.

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Table 1: Participant characteristics by body mass index category and sex

BMI Category Sex	Normal Weight		Overweight		Obesity	
	Men	Women	Men	Women	Men	Women
Sample size (n)	167	178	160	102	118	103
Age (years)	30.2 ± 0.9	32.3 ± 0.8	35.2 ± 0.9 [‡]	37.0 ± 1.3 [‡]	35.6 ± 0.6 [‡]	34.6 ± 0.9
BMI (kg/m ²)	22.8 ± 0.2	22.0 ± 0.1 [†]	27.5 ± 0.1 [‡]	27.3 ± 0.1 [‡]	33.8 ± 0.3 ^{‡*}	35.4 ± 0.6 ^{†‡*}
VO ₂ max (mL·kg ⁻¹ ·min ⁻¹)***	45.3 ± 0.9	37.3 ± 0.8 [†]	41.1 ± 0.7 [‡]	33.8 ± 0.7 ^{†‡}	39.6 ± 0.7 [‡]	34.6 ± 0.9 ^{†‡}

Values are presented as Mean ± SE.
[†] Different from men within BMI group (P<0.05)
[‡] Different from Normal weight group (P<0.05)
^{*} Different from Overweight group (P<0.05)
^{***} Estimated VO₂max

Table 2: Age adjusted durations of bouts MVPA, and proportions of individuals meeting recommended PA guidelines of 150 min/week of MVPA using self report, absolute, and relative CPM intensity thresholds by body mass index category and sex.

BMI Category	Normal Weight		Overweight		Obesity	
	Men	Women	Men	Women	Men	Women
Sex	(n=167)	(n=178)	(n=160)	(n=102)	(n=118)	(n=103)
Durations of MVPA (min/day)						
Self-Report	65.9 ± 5.9*	59.4 ± 4.6*	72.0 ± 10.9*	52.4 ± 10.9*	58.9 ± 9.9*	43.0 ± 4.9 ^{‡*}
Absolute CPM thresholds	14.0 ± 1.6	10.4 ± 1.8	11.7 ± 1.7	8.2 ± 1.0	6.0 ± 1.3 ^{†‡}	3.0 ± 0.8 ^{†‡}
Yngve- Relative CPM thresholds	1.6 ± 0.5 ^a	3.9 ± 0.8 ^a	2.4 ± 1.1 ^a	2.8 ± 0.7 ^a	0.4 ± 0.3 ^a	0.3 ± 0.3 ^{†‡ a}
Swartz- Relative CPM thresholds	4.6 ± 0.8 ^a	8.7 ± 1.5 ^a	5.6 ± 1.5 ^a	8.3 ± 1.1 ^a	2.8 ± 0.9 ^a	2.9 ± 0.8 ^{†‡}
Hendelman- Relative CPM thresholds	1.5 ± 0.5 ^a	4.1 ± 0.8 ^a	2.2 ± 1.0 ^a	3.4 ± 0.9 ^a	0.4 ± 0.3 ^a	0.4 ± 0.3 ^{†‡ a}
Freedson- Relative CPM thresholds	2.5 ± 0.6 ^a	5.3 ± 1.0 ^a	3.6 ± 1.4 ^a	4.7 ± 0.9 ^a	0.7 ± 0.5 ^a	0.9 ± 0.5 ^{†‡ a}
Proportion of Individuals Meeting PA Guidelines (%)						
Self-Report	69.5 ± 3.3*	77.7 ± 3.4*	64.4 ± 5.9*	63.8 ± 7.1*	61.4 ± 7.9*	60.4 ± 5.4 ^{†*}
Absolute CPM thresholds	23.5 ± 5.4	19.7 ± 4.1	13.2 ± 2.6 [†]	11.7 ± 3.0	8.4 ± 0.9 [†]	4.1 ± 2.0 [†]
Yngve- Relative CPM thresholds	0.9 ± 0.8 ^a	6.3 ± 2.6 ^a	3.8 ± 2.2 ^a	4.0 ± 2.7 ^a	0.4 ± 0.4 ^a	0.0 ^{†‡}
Swartz- Relative CPM thresholds	5.0 ± 2.2 ^a	15.0 ± 2.4 ^a	7.8 ± 2.8 ^a	11.8 ± 3.0	3.8 ± 2.2 ^{†a}	4.1 ± 1.2 ^{† a}
Hendelman- Relative CPM thresholds	0.9 ± 0.8 ^a	7.4 ± 2.7 ^a	3.8 ± 2.2 ^a	4.0 ± 2.7 ^a	0.4 ± 0.4 ^a	0.0 ^{†‡}
Freedson- Relative CPM thresholds	2.7 ± 1.7 ^a	9.1 ± 2.6 ^a	4.9 ± 2.3 ^a	5.5 ± 3.1 ^a	0.4 ± 0.4 ^{‡a}	0.8 ± 0.8 ^{† a}

Values are presented as Mean, and % Prevalence ± % SE.

[†]Different from Normal weight group (P<0.05)

[‡]Different from Overweight group (P<0.05)

*Different from objectively measured PA

^a Different from absolute thresholds

Table 3: Percent VO₂max corresponding to the absolute accelerometer intensity thresholds of 2020 and 5999 CPM by body mass index category and sex adjusted for age.

BMI Category	Normal Weight		Overweight		Obesity	
	Men	Women	Men	Women	Men	Women
Sex	(n=167)	(n=178)	(n=160)	(n=102)	(n=118)	(n=103)
%VO ₂ at 2020 CPM						
Yngve equation	14.0 ± 0.2	17.0 ± 0.3	15.0 ± 0.2 [†]	18.4 ± 0.4 [†]	15.6 ± 0.2 ^{†‡}	18.1 ± 0.4 [†]
Swartz equation	13.7 ± 0.2	16.2 ± 0.2	14.6 ± 0.2 [†]	17.3 ± 0.3 [†]	15.1 ± 0.2 ^{†‡}	17.2 ± 0.4 [†]
Hendelman equation	11.9 ± 0.2	14.3 ± 0.2	12.7 ± 0.1 [†]	15.3 ± 0.3 [†]	13.2 ± 0.2 ^{†‡}	15.2 ± 0.3 [†]
Freedson equation	14.3 ± 0.2	17.2 ± 0.2	15.3 ± 0.2 [†]	18.8 ± 0.4 [†]	15.9 ± 0.2 ^{†‡}	18.3 ± 0.4 [†]
%VO ₂ at 5999 CPM						
Yngve equation	40.2 ± 0.7	49.0 ± 0.8	43.1 ± 0.6 [†]	53.0 ± 1.2 [†]	45.0 ± 0.7 ^{†‡}	52.4 ± 1.3 [†]
Swartz equation	35.6 ± 0.6	43.0 ± 0.6	38.1 ± 0.5 [†]	46.4 ± 1.0 [†]	39.6 ± 0.6 ^{†‡}	45.8 ± 1.1 [†]
Hendelman equation	32.3 ± 0.6	39.2 ± 0.6	34.6 ± 0.4 [†]	42.4 ± 0.9 [†]	36.1 ± 0.6 ^{†‡}	41.8 ± 1.0 [†]
Freedson equation	39.7 ± 0.7	48.2 ± 0.7	42.5 ± 0.5 [†]	52.2 ± 1.2 [†]	44.3 ± 0.7 ^{†‡}	51.5 ± 1.3 [†]

Values are presented as Mean ± SE.
[†]Different from normal weight group (P<0.05)
[‡]Different from overweight group (P<0.05)

Figure 1. Accelerometer CPM values corresponding to 40 and 60% VO_2max by sex and body mass index category adjusted for age.

† Different from men within BMI group ($P < 0.05$)

‡ Different from normal weight group ($P < 0.05$)

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Men

Women