Original Research

Actical Accelerometry Cut-Points for Quantifying Levels of Exertion: Comparing Normal and Overweight Adults

JAMIE GIFFUNI[†1], ROBERT G. MCMURRAY[‡1], TODD SCHWARTZ[‡2,3], and DIANE BERRY[‡3]

[1]Department of Exercise and Sport Science, [2]Department of Biostatistics, and [3]School of Nursing, University of North Carolina, NC, USA

‡Denotes professional author, †Denotes graduate student author

ABSTRACT

Int J Exerc Sci 5(2) : 170-182, 2012. Weight, body fatness and ambulatory pattern all have the potential to affect accelerometer output and cause differences in output between overweight and normal-weight adults. The purpose of this study was to determine if Actical (Philips Respironics, Bend, OR) activity count cut-points for moderate and vigorous intensity exercise are different for overweight adults compared to normal-weight adults. Overweight adults with BMI >25 kg/m² (n=29) and Normal-Weight adults (n=25) walked at 3.2 and 4.8 km·h⁻¹ and ran at 6.4 km·h⁻¹ on a treadmill while simultaneously wearing an Actical accelerometer and obtaining measurements of oxygen uptake. Counts per minute (counts·min⁻¹) were determined at 3 METS (moderate) and 6 METS (vigorous) using ROC curves. The counts·min⁻¹ at 3 METs was 1726 and 1923 counts·min⁻¹ for Overweight and Normal-Weight groups, respectively. The cut-points at 6 METs were 4117 and 4032 counts·min⁻¹ for Overweight and Normal-Weight groups, respectively. The differences between groups were not statistically significant (p>0.73 for both). Correlations between BMI and counts·min⁻¹ were not significant (p>0.05) at any speed for the Normal-Weight group but were significant at 3.2 and 4.8 km·h⁻¹ for the Overweight group. Although there appears to be some relationship between activity counts·min⁻¹ and BMI, the results suggest that similar cut-points may be used for normal weight and overweight adults. However, the greater variability in counts at each speed and lower ROC curve areas for overweight adults suggest that it is harder to classify the activity intensity of overweight subjects compared to normal weight subjects.

KEY WORDS: ROC curves, moderate physical activity, vigorous physical activity, oxygen uptake

INTRODUCTION

Approximately 67% of adults in the United States are overweight and 34% are obese as indicated by a body mass index (BMI) greater than 25 kg·m² and 30 kg·m², respectively (10). Physical activity is important for overweight and obese individuals because it is a major component of energy expenditure and weight control (7, 13, 15, 24). As a result, the American College of Sports Medicine (ACSM) recommends that physical activity result in an energy expenditure of greater than 2,000 kcal per week to promote and maintain weight loss (7).

Moderate intensity exercise is considered by many to be the minimal threshold of intensity for improving health (13, 14, 24). Further, 30 min of moderate-to-vigorous intensity physical activity (MVPA) per day, five days per week (total 150 min/week) has been shown to improve previously sedentary individuals' health (14, 24). However, 45 to 60 minutes per day of MVPA on five days per week (total 300 min/week) may be most effective for improving weight loss and preventing weight regain after weight loss in overweight and obese adults (7, 14, 15). Thus, it is important to be able to quantify MVPA in overweight and obese adults to determine if an individual is meeting the recommended intensity and dose of physical activity.

There are many different ways to assess an individual's physical activity: self-report, pedometers, heart rate monitoring, indirect calorimetry, and accelerometry. Accelerometry is an objective measurement of physical activity that allows researchers to track the amount and intensity of physical activity of their subjects (5, 30). There are many different manufacturers of accelerometers, and while this increases availability, devices are not inter-changeable due to variations in sensitivity and calibration equations (30). Thus, studies of adults and children have developed cut-points, or thresholds, separating different intensities (light, moderate, and vigorous) for various accelerometer devices (4, 5, 8, 16, 22, 25, 26, 29), including the Actical® device (Phillips Respironics, Bend, OR) (4, 5, 25). These cut-points allow researchers to objectively determine if a person has met the recommendations for moderate-to-vigorous

intensity exercise. However, it is known that height, size, body fatness, and economy of movement patterns have the potential to affect accelerometer output (16, 20, 30). Furthermore, obesity modifies movement patterns (20, 30) and there is a tight coupling of stature, weight, gait mechanics, and metabolic energy expenditure of ambulation (20, 31). Thus, research on cut-points in the overweight and obese population is needed.

The Actical® accelerometer is becoming widely used in physical activity research (4, 5, 6, 9, 12, 18, 32). Regression equations to estimate energy expenditure from activity counts were originally developed in adults and provided reasonable predictions of MET levels (4, 19). However, based on the subjects' characteristics they seem to be normal weight. To our knowledge, only one study has focused on cut-points for obese adults and that study used the Actigraph accelerometer (22). Therefore, research is needed in the overweight and obese population to determine cut-points for moderate and vigorous exercise intensities for the Actical accelerometer and to determine if these cut-points differ between normal and overweight adults. Thus, the primary aim of this study was to determine cut-points for delineating moderate and vigorous intensity exercise for normal and overweight adults and clarify any differences between normal and overweight adults.

METHODS

Participants
The subjects were 29 overweight or obese (BMI >25 kg·m²) and 25 normal weight male and female adults aged 18 to 63 years.

Overweight participants were recruited from rural eastern and central North Carolina through the ongoing Family Partners for Health study (Principal Investigator: Diane Berry). Normal-weight subjects were recruited from the university community. Subjects were required to have the ability to walk and jog on a motorized treadmill and be of health low-risk to be included in this study. Before participation, each potential subject was informed of the possible risks of the exercise protocol and signed an informed consent, previously approved by the Institutional Review Board of the University of North Carolina. All subjects received medical clearance to participate in physical activity from a Family Partners for Health nurse or their personal physician.

Instrumentation
Height was measured using a portable stadiometer (Seca, Hamburg, Germany) and weight was determined using an electronic scale (Tanita, Arlington Heights, IL). Body mass index (kg·m²) was calculated from measured height (m) and mass (kg). Heart rate was measured using a Polar heart rate monitor (Polar Electro, Inc., Lake Success, NY) and rating of perceived exertion (RPE) was measured using Borg's original 6-20 RPE scale (1).

The accelerometer used in this study was the Actical® (Philips Respironics Inc., Bend, OR), an omni-directional, small (28 x 27 x 10 cm), lightweight (17 g) accelerometer which measures accelerations in multiple planes. Two Acticals were used for the entire study and they were factory calibrated. In addition, we put the two accelerometers on a oscilating chemistry shaker (Lab Line, Model 3506, Melrose, IL,

USA) at slow moderate and fast speeds and then compared the counts against each other to insure they provided the same output (Δ <3%). Activity counts were obtained in one-minute epochs. The metabolic systems to obtain oxygen uptake ($\dot{V}O_2$) were different between the overweight and normal weight subjects. The overweight subjects used the portable COSMED® metabolic system (Rome, IT). This was the systemic choice, since the data were obtained on the remote site of the Family Partners for Health study and not in the laboratory. The metabolic data for normal weight subjects was obtained using a PARVO Medics TrueMax 2400® system (Parvo Medics, Salt Lake City, UT). The two systems were tested against each other using a one-liter syringe to obtain tidal volume and standard gases. The one-liter syringe was pumped at three different speeds, representing low, moderate, and high minute ventilations, for both systems (set by a metronome) to obtain minute volumes for both systems. The standard gases were sampled simultaneously to obtain fractions of expired oxygen (F_EO_2) and carbon dioxide (F_ECO_2). The differences in F_EO_2, F_ECO_2 and minute ventilation were less than 2%, resulting in mean $\dot{V}O_2$ differences of 0.2-0.5 mL·kg^{-1}·min^{-1} between the two systems. Calibrated motorized treadmills were used for ambulation: Marquette Model T2100® (General Electric Healthcare Products, Palatine, IL) at the Family Partners for Health site and a Quinton Q55® (Quinton Instruments Seattle, WA) in the Laboratory.

Protocol
Subjects were asked to complete only one exercise session which lasted approximately 45 minutes. Informed

consent was obtained from all subjects before testing began. Testing took place either on a treadmill at the Partner's Study site or in the Applied Physiology Laboratory on the campus of UNC-Chapel Hill. All study exercise sessions took place at the same time of day (during the late afternoon to evening), regardless of field or laboratory location. Before subjects arrived to the exercise session, the Actical accelerometer was initialized using one-minute epochs and metabolic systems were calibrated. Upon arrival, height and body mass of subjects were measured. Subjects were fitted with the heart rate monitor and asked to rest seated for five minutes in order to obtain an estimate resting heart rate value. Once heart rate was obtained, the Robergs and Landwher equation [208.754 – (0.734 * age)] was used to predict maximal heart rate of the participant (26). Eighty-five percent of heart rate reserve was then calculated using the Karvonen formula and used as the termination point of the exercise session (17). Subjects then had the opportunity to familiarize themselves with the motorized treadmill and ask any questions they had of the researchers. They were then trained in the use of the ratings of perceived exertion (RPE), the Borg 6-20 scale. At the remote site, the subjects were then fitted with the Actical accelerometer on the right hip aligned with the midline of the right thigh. The portable COSMED system was fixed on the subject's back or the subject was then fitted with the mouthpiece, depending on the location of testing.

The subject moved to the treadmill and was asked to stand still for a two-minute recording of resting $\dot{V}O_2$. The exercise protocol involved walking, and possibly jogging, for four minute stages on a level treadmill, at a speed starting at 3.2 km·h^{-1} (2 mph) and increasing 1.6 km·h^{-1} (1.0 mph) at the end of every four minute stage. The test terminated when 85% of heart rate reserve was reached or the subject requested termination. Heart rate and RPE were monitored throughout the test, with recordings of each taken during the last 10 seconds of each stage, and again during the final minute of exercise. If the subject reached this heart rate value during the first minute of the stage, the test was terminated. If the subject reached this heart rate value in the second or third minute, the researchers encouraged the subject to continue and complete the end of the stage, producing four minutes of data. Subjects engaged in an active walking cool down at 3.2 km·h^{-1} (2.0 mph) until their heart rate slowed to 120 beats per minute. They were assisted off the treadmill, encouraged to drink water, and sat in a chair until their heart rate returned to near resting values.

Data Management
Oxygen uptake ($\dot{V}O_2$) data from minutes one and two of each stage were eliminated in order to obtain a more accurate representation of steady state exercise at that speed. The average of the $\dot{V}O_2$ for minutes three and four were used to represent steady state metabolic demands of that stage. For subjects who did not complete the fourth minute of the stage, the last minute of data were used. All $\dot{V}O_2$ used in calculations were verified for the attainment of steady state responses. To reduce activity count data, minutes one and four of each stage were eliminated in order to remove any changes in acceleration due to changes in treadmill speed between stages and the measurement of oxygen

uptake. The average of minutes two and three were used to represent the counts for the stage. Most subjects completed all four minutes at the 6.4 km·h⁻¹ (n=51/54), but for subjects who did not complete four minutes of the final stage, the average of the last two minutes (minutes 2 and 3) were used.

The metabolic equivalent (MET) is one of the most common methods used to estimate the energy cost of activities (1, 2, 4, 8). The MET is the ratio of work metabolic rate to the standard resting metabolic rate: 1 MET = 3.5 mL O_2·kg⁻¹·min⁻¹ (1, 2, 11, 13). Although the exact value for the MET is controversial (3), the 3.5 mL·kg⁻¹·min⁻¹ is commonly used by the American College of Sports Medicine (1, 28). Light activities are defined as those <3 METs, moderate as 3-5.99 METs, and vigorous as ≥6 METs. These MET levels have been used by previous research studies when attempting to quantify the exercise intensity of subjects (5, 13, 15, 21), and this approach was used for the present study.

Regression equations were computed for each subject to determine activity counts for the estimated oxygen uptake ($\dot{V}O_2$; mL·kg⁻¹·min⁻¹) of moderate activity at a cut-point of 3 METs (or $\dot{V}O_2$ = 10.5 mL·kg⁻¹·min⁻¹) and for vigorous activity at a cut-point of 6 METs (or $\dot{V}O_2$ = 21 mL·kg⁻¹·min⁻¹), based on previous work (13, 28). Next, a linear regression model with $\dot{V}O_2$ as the independent variable and activity counts as the dependent variable was developed for each subject and used for the activity count extrapolation at 3 and 6 METs. In addition, maximum aerobic power ($\dot{V}O_2$max) was predicted for each subject using the method described by Margaria et al. (23). This procedure has been validated in various populations with an error of ±7%. The predicted $\dot{V}O_2$max was used to estimate the proportion of maximal capacity for the subject at each speed of ambulation.

Statistical Analysis
Means and standard deviations were calculated for the subjects' physical characteristics, and the heart rates, $\dot{V}O_2$, and RPEs at each speed. Receiver Operation Characteristic curves (ROC curves) were used to determine the optimal counts·min⁻¹ threshold at moderate (3 METs) and vigorous (6 METs) intensity for the normal and overweight groups. ROC curves graphically depict the inverse relationship between sensitivity and specificity as a function of the threshold selected to determine the intensity of activity. Sensitivity represents the proportion of true "cases" which are correctly identified by exceeding a specific threshold for the accelerometry measurements. Specificity, on the other hand, indicates the proportion of true "non-cases" which are correctly identified by the $\dot{V}O_2$, but remained below a specific threshold in the accelerometry measurements. Acceptable values for sensitivity and specificity vary according to the context. For the analyses, the cut-points for the two intensities had the optimal sensitivity and low specificity, as defined by the largest area under the curve; as recommended by Treuth et al. (29). High sensitivity in our study reflects our priority of identifying moderate (or vigorous) intensity via accelerometry when it exists as measured by $\dot{V}O_2$. A standardized approach was utilized in choosing the lower threshold for activity counts corresponding to moderate intensity physical activity (29). True and false positive classifications were also computed

on the same sample to estimate the percent of subjects who were misclassified at each intensity, for both groups (as an estimate of cross-validation). In addition, variation in counts·min^{-1} at 3 and 6 METs was also computed.

Three mixed model ANOVAs were run to compare differences between the two groups in heart rate, $\dot{V}O_2$, and accelerometer counts·min^{-1} at speeds of 3.2, 4.8, and 6.4 km·h^{-1}. Since this information was used for descriptive purposes, only the main effects for group and speed were examined. If the ANOVA was significant ($p < 0.05$), T-test was run for post hoc pairwise comparisons to determine where the statistically significant difference(s) occurred. Since the gender distribution of the subjects was unequal, analysis by gender were not completed. In addition, the overweight group was comprised of subjects with BMIs ranging from >25 to 58 kg·m²; thus, an effect of weight status on the accelerometry counts was also evaluated by correlating BMI and counts·min^{-1} at each of the three common speeds for ambulation, for all subjects combined and separately for each group (normal and overweight). All data analysis used SPSS version 17.0 (Chicago, IL) with an accepted two-sided significance level (set *a priori*) of 0.05.

RESULTS

The Overweight group consisted of 17 females and 12 males, while the Normal-Weight group had 12 females and 13 males. The mean (±SD) physical characteristics and predicted $\dot{V}O_2$max are presented for the normal and overweight groups in table 1. The Overweight subjects were significantly older, heavier, and had a lower predicted $\dot{V}O_2$max (mL·kg^{-1}·min^{-1}). Height and predicted absolute $\dot{V}O_2$max (L·min^{-1}) were similar between groups (both $p > 0.05$). The majority of Overweight subjects completed only three speeds, 3.2, 4.8, and 6.4 km·h^{-1}; while the Normal-Weight subjects were able complete higher speeds. Thus, for comparative purposes, these three speeds were chosen for presentation to allow between-group analysis.

Table 1. Mean (±SD) physical characteristics of the normal and overweight subjects.

Variable	Normal Weight (n=25)	Overweight/Obese (n=29)
Age (years)*	26.1±9.4	31.9±9.0
Height (cm)	174.3±8.7	169.1±8.3
Body mass (kg)*	70.0±10.0	100.8±23.3
BMI (kg·m²)*	23. 0±2.2	35.2±7.6
Predicted VO$_{2max}$ (mL·kg^{-1}·min^{-1})*	40.8±10.2	29.1±11.5

* $p < 0.03$: between groups

The exercise responses of the Normal and Overweight groups at the three speeds of ambulation are shown in table 2. Mean heart rate of the Overweight group was significantly greater at every speed compared to the Normal-Weight group (all $p < 0.05$). The oxygen uptakes of the Normal and Overweight groups were similar at all three speeds ($p > 0.05$), although the mean $\dot{V}O_2$s were slightly higher for the Overweight group. As anticipated, the Overweight group was exercising at a higher proportion of their maximal capacity at all three speeds ($p < 0.05$). Actical activity counts (counts·min^{-1}) were not significantly different between groups at any speed of ambulation ($p = 0.142$ for all speeds).

Table 2. Mean (±SD) physiological responses of the normal-weight and overweight groups at the three speeds of ambulation.

		Speed (km·h⁻¹)		
	Group	3.2	4.8	6.4
Heart Rate (bpm)†	Normal	87±11	97±12	114±14
	Overweight	103±14	118±15	146±25
$\dot{V}O_2$ (ml·kg⁻¹·min⁻¹)	Normal	9.2±1.3	11.8±1.4	16.8±2.2
	Overweight	9.8±2.0	12.7±2.1	18.5±2.8
% Predicted $\dot{V}O_2$ max	Normal	16±5	24±7	39±14
	Overweight*	28±13	42±17	67±27
Activity counts (count·min⁻¹) **	Normal	1182±296	2428±454	4262±887
	Overweight	1352±516	2655±832	4744±1559

† p < 0.0005: Heart rate by speed interaction.
* p < 0.05: Main effect Overweight vs. Normal Weight
** p < 0.05: Main effect of speeds.

The thresholds for moderate (3 METs) and vigorous (6 METs) were determined for each individual. For the Overweight group the mean speed for the 3 and 6 MET thresholds were 3.7±0.8 and 7.4±1.0 km·h-1, respectively; at 43±18 and 85±35% of predicted $\dot{V}O_2$ max. For the Normal-Weight individuals the speeds were quite similar to the overweight group (4.2±0.7 and 7.0±0.3 km·h-1, respectively; p > 0.05), but the percentages of $\dot{V}O_2$ max were significantly lower; 27±7 and 55±15% (p = 0.0002).

ROC curves were used to determine the thresholds for moderate and vigorous intensity exercise (see table 3). At both the 3 and 6 MET thresholds the areas under the curves (sensitivity) were approximately 6% higher for the Normal-Weight than the Overweight, while the specificities were similar. The moderate cut-points (3 MET) obtained from the ROC curves for the Normal- Weight group was about 200 counts·min-1 lower than for the Overweight group, whereas the 6 MET thresholds were within 80 counts·min-1 of each other. These differences between the groups were not significant at either level of intensity (both p > 0.05). Follow-up analyses exploring the results for misclassification found that three Normal-Weight subject (11%) were false

Table 3. Optimal activity counts per minute (count·min⁻¹) cut-points for the Normal-Weight and Overweight groups presented with the Sensitivity and Specificity values derived from the ROC coordinates.

	Normal Weight		Overweight/Obese	
	3 METs	6 METs	3 METs	6 METs
Optimal Cut-point (count·min⁻¹)	1726	4117	1923	4032
Sensitivity	0.957	1.000	0.895	0.944
Specificity	0.192	0.184	0.160	0.181

Table 4. Correlations between body mass index (BMI) and Actical counts per minute for both groups combined (Overall) and within each weight group at the three speeds of ambulation.

Speed (km·h⁻¹)	Overall	Normal Weight	Overweight
3.2	0.549*	0.033	0.704*
4.8	0.541*	0.189	0.697*
6.4	0.318**	0.198	0.290

* p = 0.0001; ** p = 0.018

negative for moderate activity (< 1726 counts·min⁻¹, and between 3-6 METs) and there were no false positives (>4117 counts·min⁻¹, but > 6 METs). None of Normal-Weight subjects were misclassified for the vigorous intensity category (<4117 counts·min⁻¹ and < 6 METs). More misclassifications were evident for the Overweight group at low threshold for moderate intensity (3 METs), with six subjects (21%) being false negatives, while at vigorous intensity (6 METs), three subjects (10%) were false positives. Two Overweight subjects (7%) were misclassified as exercising at moderate intensity when their counts·min⁻¹ actually placed them in the vigorous intensity category. In addition, two Overweight subjects (7%) were misclassified for the vigorous intensity category (<4023 counts·min⁻¹ and > 6 METs).

The correlation between BMI and counts·min⁻¹ at each of the three speeds of ambulation are presented in table 4. With both groups combined (Overall), the correlations between BMI and counts·min⁻¹ at all speeds were moderate, but statistically significant (p < 0.02). Analyses within each weight group resulted in significant correlations for the overweight (p = 0.0001) at the two lower speeds, but no

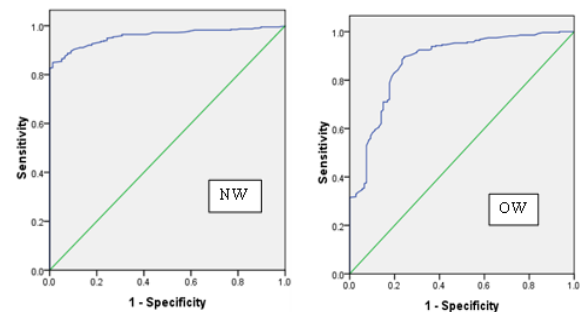significant correlations for the normal weight group.

Figure 1. ROC curves of the counts per minute for moderate intensity (3 METs) exercise for the normal (NW) and overweight (OW) groups.
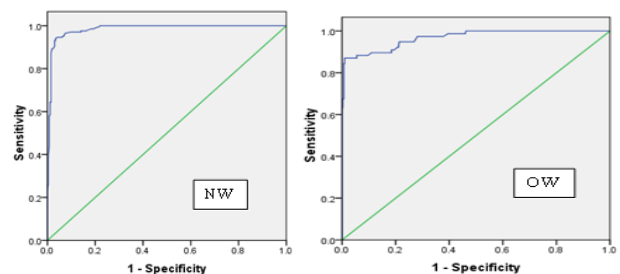

Figure 2. ROC curves of the counts per minute for vigorous intensity (6 METs) exercise for the normal (NW) and overweight (OW) groups.

Analyses within each weight group resulted in a significant correlation for the overweight (p = 0.0001), but not the normal weight group at 3.2 km·h⁻¹. The correlations at 4.8 km·h⁻¹ were somewhat higher for the overweight group than the normal weight

group, but both were statistically significant (p ≤ 0.025). At 6.4 km·h-1, the correlation between BMI and counts·min^{-1} was not significant for the overweight group but was significant (p = 0.025) for the normal weight group.

DISCUSSION

The results of this study revealed large variation in moderate and vigorous cut-points within and between normal and overweight adults, suggesting that determining a single value that is appropriate for all is somewhat difficult. Although, the mean moderate and vigorous intensity cut-points were different between the Normal-Weight group and the Overweight group (11% and 2%, respectively) and there were relationships between BMI and accelerometry counts·min^{-1} in the Overweight group, the differences were not statistically significant. The lack of statistical difference could be due to the large variances (29-30%) in individual responses (see table 2). Thus, our data suggests that similar counts·min^{-1} cut-points for moderate and vigorous intensities can be used for both normal and overweight adults.

There are several possible reasons that no differences in activity counts were observed between groups. Previous literature has suggested a relationship between energy expenditure and stature (31) and that stride frequency was related to stature (Brage 2003). In our sample the mean height of the Normal-Weight group was ~4 cm taller than the Overweight group. Thus, we would have anticipated that at the same speed there would be slightly fewer counts for our Normal Weight group, simply

based on stature. Although the mean height of our subjects differed by group, the variation in heights of both groups were similar (Normal: 31 cm, Overweight: 34 cm); thus the variations in height may have negated any group differences. Also, the 3 and 6 MET speeds were not significantly different between the Normal Weight group than the Overweight group and the energy expenditure per kilogram body weight were comparable; similar to previous research (Browning 2006). Thus, differences in counts would not be expected. Previous research has shown that positioning the accelerometer on the hip could significantly influence activity counts by as much as 30% (9, 16). While the positioning was standardized to the midline of the right thigh for both Normal and Overweight subjects, it is possible that for the Overweight group a shift in position on the hip occurred during exercise at the higher speeds, resulting in less movement and fewer counts. In addition, the significantly greater torso size and central fat mass of the overweight subjects could have possibly altered the motion of the accelerometer device, and subsequently, activity counts, while still positioned on the hip. This has been shown to occur when using the Actical accelerometer in obese adults (9). These last two statements bring uncertainty to the findings.

Colley and Tremblay recently published cut-points for moderate and vigorous intensities using the Actical (4). Their cut-points, obtained on 26 normal weight adults, were lower than ours at the 3 MET level (1535 vs. 1726-1923 counts·min^{-1}), and slightly lower at the 6 MET level (3960 vs. 4117-4023 counts·min^{-1}). Adding to the controversy, Hooker et al. (12) has

suggested that the 3 MET cut-point for obese middle-aged adults is 1635 counts·min^{-1} and only 1107 for normal weight adults. The authors did not provide any cut-points for higher intensities. The differences could be related to 1) sample size, 2) differing populations/samples, 3) different accelerometers can provide differing output by as much as ±5%; about 90 counts·min^{-1} at 3 METs or 200 counts·min^{-1} at 6 METs, or 4) the use of differing statistical techniques to determine the cut points. Although, using the same sample to determine misclassifications is not optimal, the low number of misclassifications with our cut-points in our normal weight group suggests that our cut-points may be appropriate. The greater number of misclassifications in our overweight group suggests that it is more difficult to classify activity when the weights of the subject are above normal and have a wider range of variability (table 1). This inference is consistent with the overall correlation data from table 4.

Our overall correlation data suggest that there may be a relationship between BMI and accelerometer counts·min^{-1} that was not evident in the group comparison statistics. The Normal-Weight group had no significant correlations at any speed; whereas the Overweight group had significant correlations at the lower two speeds. The differing responses may be related to the fact that at the slow speed (3.2 kph or 2 mph) the Normal-Weight individuals may have altered their typical stride to compensate for a movement pattern that was slower than habitual ambulation pattern; whereas the Overweight group felt more comfortable at that slow speed. The reverse may be true at the fastest speed. This makes sense when comparing normal and overweight individuals because of the differing patterns of ambulation (27).

The sample size could be considered a limitation of the study. In our defense, because of the high variability, a sample size of over 320 per group would be required to statistically detect a 10% difference at α = 0.05 with 0.80 power. Another limitation of this study was the use of standard 3 and 6 MET values to represent moderate and vigorous intensities, and the standard resting value of one MET (3.5 mL/kg/min). We were unable to obtain accurate resting metabolic rates because of the afternoon-evening testing schedule and this approach could have provided a better estimate of true values for 3 and 6 MET cut-points. In defense, the use of the standard 3 and 6 MET values for moderate and vigorous intensities is widespread in the literature (4, 11, 13, 14, 24).

One may also question the use of 3 and 6 MET as representing moderate and vigorous activity levels for all participants. The vigorous threshold of 6 METs may be perceived as "light" for one individual but as "hard" for another. Another approach would have been to use 40 and 65% of maximal aerobic capacity as the physiological moderate and vigorous activity thresholds as suggested by the textbooks (13). Using this approach, larger differences in the cut-points would have been obtained. For example, 40 % of $\dot{V}O_2$max for the Normal-Weight group would have occurred at approximately 6.4 km·h-1 (or ~17 mL·kg^{-1}·min^{-1}), resulting in essentially 5240 counts·min^{-1}. For the

Overweight group 40% would be between 3.2 - 4.8 km·h-1 (or ~ 10 mL·kg^{-1}·min^{-1}), an average of 3159 counts·min^{-1}. The counts at 65% $\dot{V}O_2$max would have averaged 9532 counts·min^{-1} for the Normal-Weight and only 5522 counts·min^{-1} for the Overweight group.

There is a well-known trade-off between sensitivity and specificity. The desired balance depends on the context and on whether a false positive is deemed as a more serious error than a false negative, or vice versa. The high sensitivity found in our study reflects our priority of identifying moderate (or vigorous) intensity cut points when they existed as measured by $\dot{V}O_2$. The low specificity indicates the potential for increased false positives. False positive in that the measured $\dot{V}O_2$ of an individual fell below the 3 or 6 METs, but the accelerometry output incorrectly identified the individual as achieving that level of intensity (*i.e.*, an increasing number of false positives). Following previous research by Treuth et al. (29), we were willing to accept the lower specificity.

In many cases, accelerometry output is used to predict energy cost (5, 8, 12, 15, 19, 25, 29). A complete discussion on this topic is beyond the scope of this manuscript. Nevertheless, our data suggests that during walking the same formula could be used for normal and overweight adults to predict energy cost, with respect to body mass; e.g. kJ/kg or Kcal/kg. The greater variability in energy cost of running in the overweight group suggests less accuracy, but if the clinician/ researcher is willing to accept the error, then the same formula could be used for the higher intensity exercise. As a caveat, the reader should keep in mind that

although the energy cost per kilogram may be similar, the absolute energy cost of the activity for the overweight will be greater.

The relationship of accelerometry output and energy expenditure also depends on the type of activity being performed (5, 11, 16, 29). Therefore, the suitability of applying cut-points developed with laboratory exercises to field based (or free living) activities is questionable, because the activity count patterns during activity will be different. The exercise protocol of the present calibration study was a laboratory calibration study, as subjects only completed treadmill exercise. The stride frequency was constant because of the use of the treadmill, which may lead to a different activity count pattern than free living, over-ground walking (11). In support, the cut-points developed in the present study were based on the measurement of oxygen uptake, not treadmill speed. However, caution should be employed when applying these cut-points to studies utilizing free living walking and jogging activities.

The results suggest that for normal-weight, overweight or obese individuals who wear the Actical accelerometer, the cut-point for moderate (3 MET) activities is in the range of 1726-1923 counts·min^{-1}, while the cut-point for vigorous activity (6 METs) ranges from 4032-4117 counts·min^{-1}. These thresholds resulted in a relatively low number of misclassifications for our study population. The greater variability in counts at each speed of ambulation and lower ROC curve areas for overweight adults suggest that it is harder to classify the activity intensity of overweight subjects compared to normal weight subjects.

Because of the greater variability, perhaps other researchers working with obese adults should develop and validate cut-points specific to their sample and take into consideration the shape (android vs. gynoid) of the obese individual which could affect placement of the accelerometer.

ACKNOWLEDGMENTS

REFERENCES

1. American College of Sports Medicine. ACSM's Resource Manual for Guidelines for Exercise Testing and Preseciption. Edit 5, 2006.

2. Ainsworth BE, Haskell WL, Whitt MC, et al. Compendium of physical activities: An update of activity codes and MET intensities. Med Sci Sports Exerc 32: S498-S516, 2000.

3. Byrne NM, Hills AP, Hunter GR, Weinsier RL, Schutz Y. Metabolic equivalent: one size does not fit all. J Appl Physiol 99: 1112-1119, 2005, Epub 2005 Apr 14.

4. Colley RC, Tremblay MS. Moderate and vigorous physical activity intensity cut-points for the Actical accelerometer. J Sports Sci 29: 783-9, 2011.

5. Crouter SE, Bassett Jr DR. A new 2-regression model for the Actical accelerometer. Br J Sports Med 42: 217-224, 2008.

6. Crouter SE, Dellavalle DM, Horton M, Haas JD, Frongillo EA, Bassett DR. Validity of the Actical for estimating free-living physical activity. Eur J Appl Physiol. 111: 1381-1389, 2011. Epub 2010 Dec 12.

7. Donnelly JE, Blair SN, Jakicic JM, Manore MM, Rankin JW, Smith BK. American College of Sports Medicine Position Stand: Appropriate physical activity intervention strategies for weight loss and prevention of weight regain for adults. Med Sci Sports Exerc 41: 459-471, 2009.

8. Fairweather SC, Reilly JJ, Grant S, Whittaker A, Paton JY. Using the Computer Science and Applications (CSA) activity monitor in preschool children. Pediatr Exerc Sci 11: 413-420, 1999.

9. Feito Y, Bassett DR, Tyo B, Thompson DL. Effects of body mass index and tilt angle on output of two wearable activity monitors. Med Sci Sports Exerc.43:861-866, 2011.

10. Health, United States/Center for Disease Control. (2008). *FastStats: Obesity and overweight.* Retrieved January 25, 2010, from http://www.cdc.gov/nchs/fastats/overwt.htm

11. Hendelman D, Miller K, Baggett C, Debold E, Freedson P. Validity of accelerometry for the assessment of moderate intensity physical activity in the field. Med Sci Sports Exerc 32: S442-S449, 2000.

12. Hooker SP, Feeney A, Hutto B, Pfeiffer KA, McIver K, Heil DP, Vena JE, Lamonte MJ, Blair SN. Validation of the Actical activity monitor in middle-aged and older adults. J Phys Act Health. 8: 372-381, 2011.

13. Howley ET, Franks BD. Health Fitness Instructor's Handbook. Human Kinetics: Champaign, 1997, p.16.

14. Jakicic JM. Exercise in the treatment of obesity. Endocrinol Metab Clin North Am 32: 962-980, 2003.

15. Jakicic JM, Otto AD. Physical activity considerations for the treatment and prevention of obesity. Am J Clin Nutr 82: 226S-229S, 2005.

16. Jones SL, Wood K, Thompson R, Welk GJ. Effect of monitor placement on output from three different accelerometers. Med Sci Sports Exerc 31: S142, 1999.

17. Karvonen MJ, Kentala E, Mustala O. The effects of training on heart rate. Ann Med Exp Biol Fenn 35: 307-315, 1957.

18. Kayes NM, Schluter PJ, McPherson KM, Leete M, Mawston G, Taylor D. Exploring actical

accelerometers as an objective measure of physical activity in people with multiple sclerosis. Arch Phys Med Rehabil. 90: 594-601, 2009.

19. Klippel NJ, Heil DP. Validation of energy expenditure algorithms in adults using the Actical electronic activity monitor. Med Sci Sports Exerc 35: S284, 2003.

20. Ko S, Stenholm S, Ferrucci L. Characteristic gait patterns in older adults with obesity--results from the Baltimore Longitudinal Study of Aging. J Biomech. 43: 1104-10, 2010.

21. Lee IM, Hsieh CC, Paffenbarger, RS. Exercise intensity and longevity in men: The Harvard alumni health study. JAMA 273: 1179-1184, 1995.

22. Lopes VP, Magalhaes P, Bragada J, Vasques C. Actigraph calibration in obese/overweight and type 2 diabetes mellitus middle-aged to old adult patients. J Phys Act Health 6: S133-S140, 2009.

23. Margaria R, Aghemo P, Rovelli E. Indirect determination of maximal O2 consumption in man. J Appl Physiol 20: 1070-1073, 1965.

24. Pate RR, Pratt M, Blair SN, et al. Physical activity and public health: A recommendation from the Centers for Disease Control and Prevention and the American College of Sports Medicine. JAMA 273: 402-407, 1995.

25. Puyau MR, Adolph AL, Vohra FA, Butte NF. Validation and calibration of physical activity monitors in children. Obes Res 10: 150-157, 2002.

26. Robergs RA, Landwher R. The surprising history of the "HRmax=220-age" equation. J Exerc Physiol online. 5: 1-10, 2002.

27. Spyropoulos P, Pisciotta JC, Pavlou KN, Cairns MA, Simon SR. Biomechanical gait analysis in obese men. Arch Phys Med Rehabil 72: 1065-1070, 1991.

28. Swain DP, Leutholtz BC. Metabolic Calculations Simplified. Williams & Wilkins: Baltimore, 1997.

29. Treuth MS, Schmitz K, Catellier DJ, et al. Defining accelerometer thresholds for activity intensities in adolescent girls. Med Sci Sports Exerc 36: 1259-1266, 2004.

30. Welk GJ. Principles of design and analyses for the calibration of accelerometry-based activity monitors. Med Sci Sports Exerc 37: S502-S511, 2005.

31. Weyand PG, Smith BR, Puyau MR, Butte NF. The mass-specific energy cost of human walking is set by stature. J Exp Biol. 213: 972-979, 2010.

32. Wong SL, Colley R, Connor Gorber S, Tremblay M. Actical accelerometer sedentary activity thresholds for adults. J Phys Act Health. 8: 587-591, 2011.