Actical Accelerometry Cut-points for Quantifying Levels of Exertion in Overweight Adults

by

Jamie Giffuni[†1], Robert G. McMurray[‡,1], Todd Schwartz[‡,2,3], and Diane Berry[‡,3]

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

[†]Denotes graduate student author

The authors report no conflicts of interest

Submit correspondence to: Robert G. McMurray
CB#8700, Fetzer Hall
University of North Carolina
Chapel Hill, NC 27599-8700
Phone: 919-962-1371
FAX: 919-962-0489
Email: exphys@live.unc.edu

Running Head: Accelerometry and Obesity

ABSTRACT

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 Actical activity count cut-points for moderate and vigorous intensity exercise for overweight adults and to compare those cut-points to normal-weight adults. Overweight adults with BMI >25 kg/m² (n=28) and normal-weight adults (n=22) walked at 3.2 and 4.8 kph and ran at 6.4 kph on a treadmill while simulatenously wearing an Actical accelerometer and obtainingmeasurements of oxygen uptake. Counts per minute (cpm) were determined at 3 METS (moderate) and 6 METS (vigorous) using ROC curves. The cpm at 3 METs was 1839 and 1994 cpm for overweight and normal-weight groups, respectively. The cut-points at 6 METs were 3900 and 4381 cpm for overweight and normal-weight groups, respectively. The differences between groups were not statistically significant ($p>0.36$ for both). Correlations between BMI and cpm were significant ($p<0.05$) at the 4.8 & 6.4 kph for the normal group and at 3.2 & 4.8 kph for the overweight group. Although there appears to be some relationship between activity cpm and BMI, the results suggest that the same cut points may be used for normal weight and overweight adults.

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 (6). Physical activity is important for overweight and obese individuals because it is a major component of energy expenditure and weight control (4,8,10,17). 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 (4).

Moderate intensity exercise is considered by many to be the minimal threshold of intensity for improving health (8,9,17). 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 individual's health (9,17). 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 (4,9,10). 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 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 (3,22). 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 (22). Thus, studies of adults and children have developed cut-points, or thresholds, separating different intensities (light, moderate, and vigorous) for various accelerometer devices (2,3,5,13,15,18,19,21), including the Actical® device (Phillips Respironics, Bend OR) (2,3,18). 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 (11,22). Thus, research on cut-points in the overweight and obese population is needed when one considers the differences in ambulatory patterns between normal and obese individuals (22).

The Actical accelerometer is becoming widely used in physical activity research. Regression equations to estimate energy expenditure from activity counts were originally developed using adults and provided reasonable predictions of MET levels (2,13). However, the subjects appear to be of normal weight. One study of obese adults developed regression models to predict METs from counts per minute (cpm), but did not report cut-points for moderate and vigorous intensity exercise (7). In addition, only one study has focused on cut-points for obese adults and that study used the Actigraph accelerometer (15). 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 twenty-eight overweight or obese (BMI >25 kg/m^2) and twenty-two normal weight male and female adults aged 18 to 50 years. Overweight participants were obtained through the ongoing Family Partners for Health study (Principal Investigator: Diane Berry). Normal-weight subjects were obtained 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. 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/m^2) 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 (Borg, 1970).

The accelerometer of choice was the Actical (Respironics Inc., Bend, OR), an omni-directional, small (28 x 27 x 10 cm), lightweight (17 g) accelerometer which measures accelerations in multiple planes. Activity counts were obtained in one-minute epochs. The metabolic systems 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 in the laboratory using a PARVO Medics TrueMax 2400 system (Parva Medics, Salt Lake City, UT). The two systems were tested against each other and the differences in F_EO_2, F_ECO_2 and minute ventilation were less than 2%. 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 Quniton 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 (APL) 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 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 accurate resting heart rate value. Once resting heart rate was obtained, the Robergs and Landwher equation [208.754 – (0.734 * age)] was used to predict maximal heart rate of the participant (19). Eighty-five percent of heart rate reserve was then calculated using the Karvonen formula and used as the termination point of the exercise session (12). 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 oxygen uptake. The exercise protocol involved walking, and possibly jogging, for four minute stages on a level treadmill, at a speed starting at 3.2 kph (2 mph) and increasing 1.6 kph (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 kph (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 (VO_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 VO_2 of 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 VO_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. The average of minutes two and three were used to represent the counts for the stage. For subjects who did not complete four minutes of the final stage, the average of the last two minutes were used. However, for those subjects who had a wide variation of counts in the last two minutes of data, the first of the final two minutes were used to represent the speed.

The metabolic equivalent (MET) is one of the most common methods used to estimate the energy cost of activities (1). The MET is the ratio of work metabolic rate to the standard resting metabolic rate: 1 MET = 3.5 mL O_2/kg/min (1,7,8). 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 (3,8,10,14), and this approach was used for the present study.

Regression equations were computed for each subject to determine activity counts for moderate activity at a cut-point of 3 METs (VO_2 = 14 ml/kg/min) and for vigorous activity at a cut-point of 6 METs (VO_2 = 24.5 ml/kg/min). Only speeds during which the subject completed all four minutes were used in the calculation. Next, a linear regression model with VO_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 (VO_2max) was predicted for each subject using the method described by Margaria et al. (16). This procedure has been validated for use in various populations with an error of ±7%.

The predicted VO_2max 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' characteristics, and the heart rates, oxygen uptakes, and RPEs at each speed. Receiver Operation Characteristic curves (ROC curves) were used to determine the cpm threshold at moderate (3 METs) and vigorous (6 METs) intensity for the normal and overweight groups. The cut-points for the two intensities had the optimal sensitivity and specificity, as defined by the largest area under the curve. A standardized approach was utilized in choosing the lower threshold for activity counts corresponding to moderate intensity physical activity (21). True and false positives classifications were also computed to determine the percent of subjects who were misclassified at each intensity, for both groups. In addition, variation in cpm at 3 and 6 METs was also computed.

Three mixed model ANOVAs were run to compare differences between the two groups in heart rate, VO_2, and accelerometer cpm at speeds of 3.2, 4.8, and 6.4 kph. Since this information was used for descriptive purposes, only the main effects for group and speed were examined. If the ANOVA was significant ($p < 0.05$), Dunnett's 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/m^2; thus, an effect of weight status on the accelerometry counts was also evaluated by correlating BMI and cpm 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 11 males, while the normal weight group had 12 females and 10 males (Table 1). The overweight subjects were significantly older, heavier, and had a lower predicted VO_2max. Height and absolute VO_2max (L/min) were similar between groups (both $p > 0.05$). The majority of overweight subjects completed only three speeds, 3.2, 4.8, and 6.4 kph; while the normal weight subjects were able complete higher speeds. Thus, for comparative purposes, these three speeds were chosen to allow between-group analysis.

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

Variable	**Normal Weight (n=22)**	**Overweight/Obese (n=28)**
Age (years)*	24.0±4.3	32.8±9.6
Height (cm)	173.5±7.3	169.6±8.7
Body mass (kg)*	67.5±7.5	101.5±24.3
BMI (kg/m^2)*	22.4±1.9	35.3±7.9
Predicted VO_2max (L/min)	2.8±0.8	2.8±1.2
VO_2max (mL/kg/min)*	42.2±9.3	28.0±11.4

* $p < 0.0005$: 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 3.2 and 4.8 kph; however, at 6.4 mph the VO_2 of the overweight group was significantly greater than the normal weight group ($p < 0.05$). 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 (cpm) were not significantly different between groups at any speed of ambulation ($p = 0.365$ for all speeds).

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

		Speed (kph)		
	Group	3.2	4.8	6.4
Heart Rate (bpm)†	Normal	89±11	97±12	116±14
	Overweight	103±15	118±18	146±23
VO_2 (ml/kg/min)	Normal	9.49±1.33	12.01±1.55	17.02±2.20
	Overweight	9.72±2.12	12.85±2.13	18.62±2.93*
% Predicted VO_2max	Normal	22±5	29±5	40±6
	Overweight**	35±7	46±7	67±10
Activity counts (cpm) [a]	Normal	1264±403	2529±493	4382±915
	Overweight	1357±536	2604±760	4773±1522

† $p < 0.0005$: Heart rate by speed interaction.
* $p = 0.05$: Group difference at 6.4 kph.
** $p < 0.05$: Group Main effect Overweight vs. Normal Weight
[a] $p < 0.05$: Between all speeds and within each group.

The ROC curves used to determine the thresholds for moderate and vigorous intensity exercise are shown in Figure 1 and Figure 2, respectively. The area under the curve (AUC) was somewhat higher for the normal weight group than the overweight group, especially for the 3-MET curve (Table 3). The moderate and vigorous (3 and 6 MET, respectively) cut-points obtained from the ROC curves for the normal weight and overweight groups are presented in Table 3. The activity count cut-points (cpm) chosen to represent the threshold for moderate and vigorous intensities were slightly higher for the normal weight group (by 155 & 481 cpm, respectively), but the differences were not significant between the groups, at either level of intensity (both $p > 0.05$). Follow-up analyses examining the results for misclassification found that one normal weight subject (4%) was a false negative for moderate activity (cpm < 1994 but VO_2 > 3 METs). Three normal-weight subjects (14%) who were classified as exercising at moderate intensity (3-5.9 METs) actually had cpm in the vigorous intensity category. More misclassifications were evident for the overweight group at moderate intensity, with three subjects (11%) being false negatives, while at vigorous intensity, three subjects (11%) were false positives. Seven overweight subjects (25%) were misclassified as exercising at moderate intensity when their cpm actually placed them in the vigorous intensity category.

Table 3. Activity counts per minute cut-points for the normal-weight and overweight groups.

	Normal Weight		Overweight/Obese	
	3 METs	6 METs	3 METs	6 METs
Optimal Cut-point (CPM)	1994	4381	1839	3900
Sensitivity	0.928	0.985	0.918	0.948
Specificity	0.192	0.182	0.299	0.214

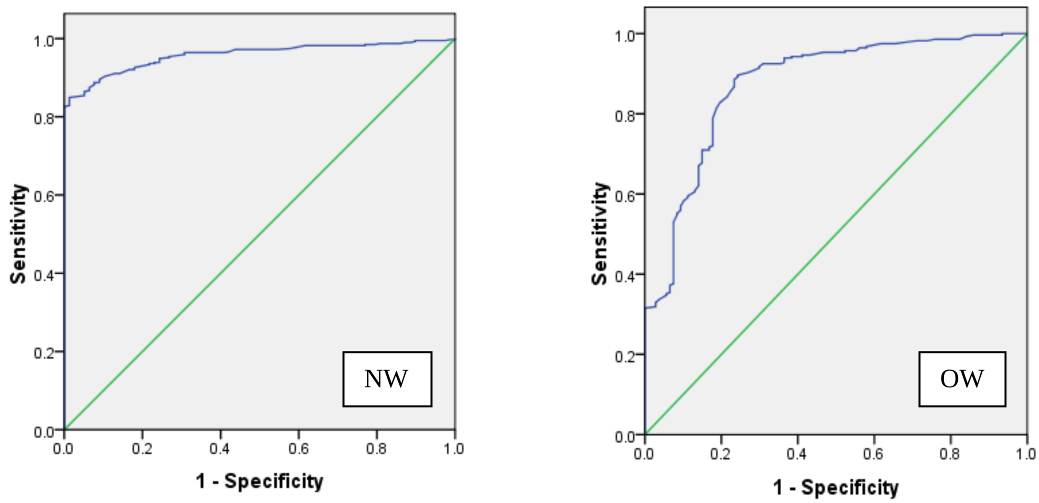

Figure 1. ROC curves of the counts per minute for moderate intensity (3 METs) exercise for the normal (NW) and overweight (OW) groups.

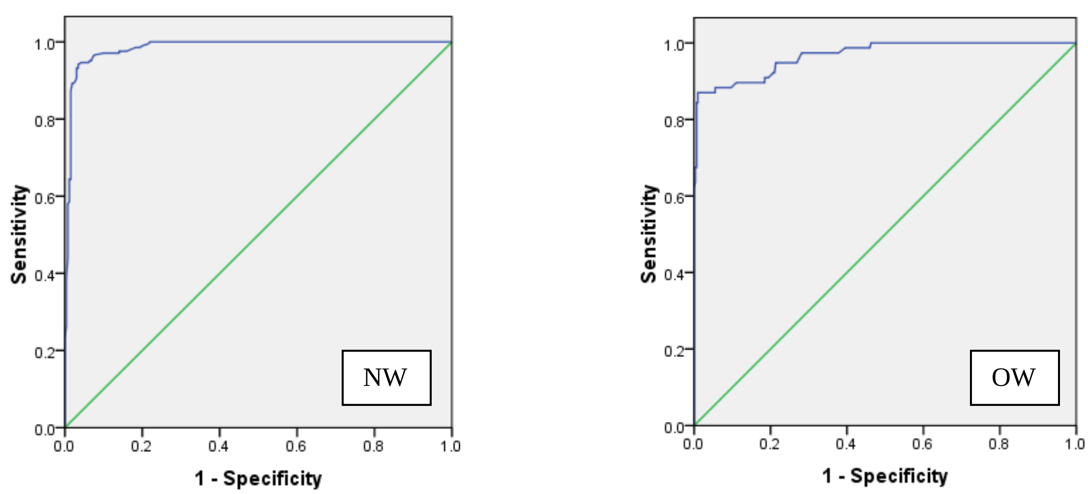

Figure 2.

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

The correlation between BMI and cpm at each of the three speeds of ambulation are presented in Table 4. With both groups combined (Overall), the correlations between BMI and cpm at 3.2 and 4.8 kpm were moderate, but statistically significant ($p = 0.0001$). At 6.4 kpm the correlation was weak and not significant ($p > 0.05$). 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 kph. The correlations at 4.8 kpm were somewhat higher for the overweight group than the normal weight group, but both were statistically significant ($p \leq 0.025$). At 6.4 kpm, the correlation between BMI and cpm was not significant for the overweight group but was significant ($p = 0.025$) for the normal weight group.

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

Speed (kph)	Overall	Normal Weight	Overweight
3.2	0.549*	0.163	0.686*
4.8	0.533*	0.417**	0.658*
6.2	0.218	0.377**	0.142

* p = 0.0001

DISCUSSION

The results of this study revealed large individual 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 higher for the normal-weight group compared to the overweight group

(8 & 11%, respectively) and there were relationships between BMI and accelerometry cpm, the differences were not statistically significant. Thus, our data suggests that similar cpm 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. In support of the findings, there was no difference between groups in stride length, as suggested by the similar heights of the groups. Previous research has shown that positioning the accelerometer on the hip could significantly influence activity counts by as much as 30% (11). 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, resulting in less movement and fewer counts. It is also possible that the significantly greater torso size and central fat mass of the overweight subjects altered the motion of the accelerometer device, and subsequently, activity counts, while positioned on the hip. These last two statements bring uncertainty to the findings.

Colley and Tremblay recently published cut-points for moderate and vigorous intensities using the Actical (2). Their cut-points, obtained on 26 adults, were lower than ours at the 3 MET level (1535 vs. 1839 & 1994 cpm), but similar at the 6 MET level (3960 vs. 3900-4381 cpm). The differences could be related to differences in sample size (26 vs. 50, respectively), or homogeneity (our inclusion of 56% of overweight participants; also the use of differing statistical techniques to determine the cut points. The low number of mis-classifications with our cut-points in our normal weight group suggests that our cut-points are fairly precise. The greater number of mis-classifications 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 correlation data suggest that there may be a relationship between BMI and accelerometer counts that was not evident in the group comparison statistics. The normal group had significant correlations at the faster two speeds; 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 individuals may have altered their normal stride to compensate for a movement pattern that was slower than normal and the forced movements from the treadmill; 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 (20).

Limitations

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 $\alpha = 0.05$ 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 VO_2 of one MET (3.5 mL/kg/min). We were unable to obtain accurate resting 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 (2,7,8,9,17).

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 60% of maximal aerobic capacity as the physiological moderate and vigorous activity thresholds as suggested by the textbooks (8). Using this approach, large differences in the cut-points would have been obtained. For example, 40 % of maximal capacity would have occurred at approximately 6.4 kpm (or ~17 mL/kg/min) for the normal group resulting in essentially 4330 cpm. For the overweight group 40% would be between 3.2-4.8 kpm (or ~ 10 mL/kg/min) for a cpm of about 1800 cpm.

In many cases, accelerometry output is used to predict energy cost (3,5,10,13,18,21). 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 (3,6,11). It may therefore be unsuitable to apply cut-points developed with laboratory exercises to field based (or free living) activities 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 (7). 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.

Conclusion

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 1839-1994 cpm, while the cut-point for vigorous activity (6 METs) ranges from 3900-4381 cpm. These thresholds resulted in a relatively low number of misclassifications. The greater variability 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.

References

1. 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.

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

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

4. 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.

5. 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.

6. 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

7. 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.

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

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

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

11. 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.

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

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

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

15. 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.

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

17. 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.

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

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

20. Spyropoulos P, Pisciotta JC, Pavlou KN, Cairns MA, Simon SR. Biomechanical gait analysis in obese men. Arch Phys Med Rehabil 72: 1065-70, 1991.

21. 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.

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