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Clinical Study

Treadmill Calibration of the Actigraph GT1M in Young-to-Middle-Aged Obese-to-Severely Obese Subjects

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To understand the impact of physical activity (PA) on health, valid accelerometer count cut points must be applied to measure PA. Because cut points may be population specific, we aimed to establish accelerometer cut points for moderate PA (MPA) and vigorous PA (VPA) (defined as ≥3 and ≥6 metabolic equivalents, resp.) in young-to-middle-aged obese-to-severely obese subjects. Data from 42 subjects (11 men; body mass index 39.8 ± 5.7; age 43.2 ± 9.2 years) who performed a treadmill calibration using the Actigraph GT1M, were analyzed using ordinary linear regression (OLR), linear mixed model regression (MIX), and receiver operating characteristics curves (ROC 1; ROC 2). Cut points obtained from the models were quite different (612 to 1646 counts/min for MPA; 3061 to 7220 counts/min for VPA). We argue that the MIX approach, which resulted in cut points of 612 and 4980 counts/min for MPA and VPA, respectively, is the most appropriate method to establish accelerometer cut points in this setting. We conclude that accelerometer cut points are lower in young-to-middle-aged obese-to-severely obese subjects compared to young normal-weight subjects and that care should be taken when analyzing PA level in groups that vary in age and degree of obesity.

1. Introduction

Accelerometers have changed physical activity (PA) reporting from a self-reported estimation of intensity and duration to an objective measurement of bodily movement. Movements are quantified based on changes in accelerations and reported in the more or less arbitrary unit "counts." Because the health benefits of PA are determined, at least in part, by the work rate or the intensity of the activity [1], the time spent at different work rates is one meaningful way to report the data. Thus, it is essential to establish accelerometer count cut points to separate light, moderate (MPA), and vigorous (VPA) PA, currently recommended to be defined as <3, 3–5.9, and ≥6 metabolic equivalents (METs), respectively [1, 2].

Numerous studies have suggested cut points for Actigraph GT1M (formerly known as the Computer Science and Applications (CSAs) and Manufacture Technology Incorporated (MTI) models) measurements in adults [3–10]. Most of these studies have used treadmill walking and running in young normal-weight subjects and have found cut points between 1267 and 2260 for MPA and cut points between 5659 and 6252 for VPA [3–7]. According to Metzger et al. [11], the weighted averages of these established cut points are 2020 and 5999 counts/min for MPA and VPA, respectively. However, the equations for determining cut points may be population specific [12]. The metabolic cost of walking increases with age and body weight [13–15], and this is not captured by an accelerometer [16, 17]. Further, the resting metabolic rate declines with increased age and obesity [18], and both body fatness and age may influence upper body accelerations during walking [19, 20]. Collectively, these factors may invalidate current cut points for use within obese and middle-aged to older populations. In line with this, Lopes et al. [10] have recently found considerably lower cut points than those previously established (1240 and 2400 counts/min for MPA and VPA, resp.) for middle-aged to old overweight and obese subjects (mean ± standard deviation age 63 ± 7 years and body mass index (BMI) ∼30 ± 5 kg/m^2). One reason for the lower cut points found in this study may be the use of individual resting metabolic rate as the 1 MET equivalent rather than the standardized value of 3.5 mL/kg/min. Although definitions and concepts regarding PA intensity are frequently discussed [12, 21–23], the normalization of energy expenditure to body weight is probably critical to arrive at sound PA intensity thresholds and PA recommendations for the obese [18, 24]. This is further indicated by a greater misclassification of activity intensity from using a standardized MET value in overweight and obese subjects compared to normal-weight subjects [21]. A similar normalization approach has been recommended for children because their 1 MET values exceed 3.5 mL/kg/min [25, 26].

As research targeting demographic covariates in calibration studies is warranted [12, 27], we performed a treadmill calibration study using the Actigraph GT1M in 44 young-to-middle-aged (24 to 62 years) obese-to-severely obese (BMI 30 to 50) subjects. The primary aim of the study was to establish cut points for MPA and VPA in this population. As several statistical approaches have been proposed for value calibration [28], a secondary aim was to explore how different statistical analyses would affect the proposed cut points in this sample.

2. Methods and Material

2.1. Subjects. Forty-nine obese-to-severely obese patients were enrolled at the Red Cross Haugland Rehabilitation Center in Norway between February 2010 and February 2011 to begin a lifestyle treatment program for obesity. The inclusion criteria for participation included an age between 18 and 60 years and a BMI > 40 kg/m^2 without comorbidities, or a BMI > 35 with comorbidities. The exclusion criteria included pregnancy, heart disease, drug or alcohol abuse, previous bariatric surgery, and mental disorders and physical impairments that could reduce the ability to comply with the program. Written informed consent was obtained from each subject prior to inclusion in the study. This study met the standards of the Declaration of Helsinki and was approved by the Regional Committee for Medical Research Ethics.

2.2. Procedures. The lifestyle treatment program was an intermittent in-patient program, and the first stay lasted six weeks. Maximal oxygen consumption ($V_{O_{2\max}}$) was measured in the first week, and the subjects who had little experience walking on a treadmill were advised to practice treadmill walking before the calibration study was performed. The calibration study was performed in the fourth week of the stay. The subjects visited the lab after a minimum of one hour of fasting and were restricted from intense PA prior to the testing. They were weighed to the nearest 0.1 kg (BC 420 S MA, Tanita Corp, Tokyo, Japan) and were equipped with a heart rate monitor chest belt (Polar Electro Oy, Kempele, Finland) and an Actigraph GT1M uniaxial accelerometer (Actigraph, Fort Walton Beach, FL, USA). Technical specifications of the accelerometer can be found elsewhere [29]. The accelerometer was attached in the mid axillary line of the right hip at the height of the umbilicus. The accelerometers were set at a 10-second epoch and a normal filtering option. Thirty different accelerometer units were used.

The test protocol consisted of two parts. The subjects were first rested in a sitting position for 10 minutes to measure their resting oxygen consumption according to the originally proposed definition of 1 MET [30]. After this, the subjects walked on the treadmill with no inclination for five minutes at each of the five speeds between 2 and 6 km/h. Multiple treadmill speeds were checked manually to validate the treadmill speed. Oxygen consumption for the last seven minutes at rest and the last four minutes at each speed on the treadmill was measured using the Metamax I and the Metasoft v. 1.11.05 software (Cortex Biophysic, Leipzig, Germany). A one-point gas calibration using ambient air and a volume calibration using a three-liter syringe (SensorMedics Corporation, CA, USA) were performed between each test. The Metamax 1 analyzer has been shown to have no systematic error and a random error of 4% compared to the Douglas bag technique [31].

The last two minutes at rest and the last two minutes at each treadmill speed were used to calculate the oxygen consumption and accelerometer counts. Both measurements were originally reported for 10-second periods and were summed to determine the mean values of the oxygen consumption/min and counts/min. The counts/min was calculated using the CSV files constructed from the AGD-files (ActiLife v. 5.3, Actigraph, Fort Walton Beach, FL, USA).

2.3. Statistical Analyses. The data are presented as the mean ± standard deviation (SD) (95% confidence intervals (CI)). Prior to the main analysis, we split the sample randomly in two and performed a cross-validation to determine how robust the predictions would be. Because the results were stable, all analyses were based on the total sample.

The statistical analyses to determine cut points were performed in two steps. The aim of step 1 was to compare cut points from different statistical models. The aim of step 2 was to explore how body size and age affected the relationships between counts/min and work rate.

Step 1. Cut points were derived using three different approaches as suggested by Welk [28]: ordinary linear regression (OLR), linear mixed model regression (MIX), and receiver operating characteristics (ROC) curves. The oxygen consumption from walking was divided by the oxygen consumption at rest to express the values for the metabolic cost of walking as individually adjusted MET values. MET values were used as the dependent variable in the regression analyses and for classifying the subjects in the ROC analyses, where 3 and 6 METs indicated MPA and VPA, respectively. The MIX analysis was based on restricted maximum likelihood estimation. Treadmill speed was defined as a repeated variable (defining an autoregressive (AR1) covariance structure) and the first and second order terms of the counts/min were defined as fixed effects. No random effects were included. The second order term was not significant in the OLR model and was omitted.

Cut points were established in two steps using the ROC procedure; MET values were categorized above 3 METs for MPA and above 6 METs for VPA. Further, two models were applied to determine the best cut points. In model 1 (ROC 1), the best cut points were read from the curve coordinates that gave the highest product of sensitivity (true positives/total positives) and specificity (true negatives/total negatives). Because this method is vulnerable to class skew, we also applied an accuracy definition (true positives + true negatives/total positives and negatives) [32] (ROC 2).

Step 2. The effects (main effects and interactions with counts/min) of body weight and age were explored by including these variables as covariates in the linear mixed model described above. The covariates were included in separate models. Including both covariates in the same model did not change any effects.

Differences in resting metabolic rate between men and women and differences in subject characteristics between age groups were tested with an independent sample's t-test. Relationships between resting metabolic rate and age and body weight were tested with partial correlation. The effect of speed on the metabolic cost and counts/min were tested with the linear mixed model as described above. To determine the effect of speed, speed was defined as a factor; to determine the effect of body weight and age, speed was defined as a continuous covariate and the second order term of speed was included in models for metabolic cost.

The analyses were performed using the SPSS v.19.0 software (SPSS Inc., Chicago, USA). P values < 0.05 indicated significant differences.

3. Results

3.1. Subject Characteristics. Forty-four subjects performed the treadmill calibration. Of these, two subjects were excluded from the analysis due to accelerometer malfunction, which left 42 subjects for the analysis (11 men). The subject characteristics are shown in Table 1. The relative resting oxygen consumption was significantly higher in the men compared to the women ($P = .013$ for L/min and $P = .026$ for mL/kg/min). The absolute resting oxygen consumption (L/min) was significantly correlated with body weight (partial $r = 0.73$, $P < .001$) after controlling for age; age was not related to resting oxygen consumption after controlling for body weight (partial $r = -0.07$, $P = .689$).

3.2. Effect of Treadmill Speed and Demographic Factors on Oxygen Consumption and Counts/min. The MET values, the O_2 consumption, and the counts/min increased significantly as the treadmill speed increased, and all the measurements were significantly different from their preceding measurements ($P < .001$) (Table 2). After controlling for treadmill speed, age was positively related to all measures of metabolic cost and negatively related to accelerometer counts (Table 3). Body weight was positively related to absolute O_2-consumption (L/min).

Table 1: The subject characteristics. Mean ± SD. ($V_{O_2\,max}$: n = 32 and 24 for the total group and for women, resp.). BMI: body mass index; WC: waist circumference; $V_{O_2\,max}$: maximal oxygen consumption.

	Total sample	Men	Women
N	42	11	31
Age	43.2 ± 9.2	42.1 ± 8.5	43.6 ± 9.5
Height (cm)	172.2 ± 9.1	182.3 ± 8.0	168.6 ± 6.4
Weight (kg)	118.2 ± 18.2	127.1 ± 16.0	115.1 ± 18.0
BMI (kg/m^2)	39.8 ± 5.7	38.3 ± 4.9	40.4 ± 6.0
WC (cm)	127.6 ± 13.2	131.8 ± 11.3	126.1 ± 13.7
$V_{O_2\,max}$ (L/min)	3.29 ± 0.66	4.16 ± 0.60	3.00 ± 0.37
$V_{O_2\,max}$ (mL/kg/min)	27.61 ± 5.19	32.30 ± 5.41	26.05 ± 4.15
Resting V_{O_2} (L/min)	0.36 ± 0.07	0.42 ± 0.09	0.34 ± 0.05
Resting V_{O_2} (mL/kg/min)	3.04 ± 0.40	3.26 ± 0.43	2.96 ± 0.36

3.3. Suggested Cut Points from the Different Statistical Approaches (Step 1). The following regression equation was derived from the OLR model: METs = 2.573 + 5.933E − 4*counts/min ($F = 291.9$ ($P < .001$), $R^2 = 0.60$, CI for intercept 2.369 to 2.777, CI for slope 5.248 to 6.618, SD of residuals = 0.79 METs). Inclusion of counts/min^2 did not improve the model ($F = 1.2$, $P = .279$). The regression equation derived from the MIX model (fixed effects parameter estimates) (Figure 1) was METs = 2.700 + 4.663E − 4*counts/min + 3.943E − 8*counts/min^2 (CI for intercept 2.387 to 3.013, $F = 295.0$, $P < .001$; CI for counts/min 3.152E − 4 to 6.174E − 4; $F = 37.1$, $P < .001$; CI for counts/min^2 1.542E − 8 to 6.343E − 8, $F = 10.5$, $P = .001$, SD of residuals = 0.83 METs). The residuals from both regression models were normally distributed.

Categorizing the observations according to MPA and VPA resulted in 156 positive and 45 negative cases and 16 positive and 185 negative cases, respectively. The areas under the ROC curves were 0.91 ($P < .001$, CI 0.87 to 0.95) and 0.87 ($P < .001$, CI 0.80 to 0.94) for MPA and VPA, respectively.

The suggested cut points and the corresponding sensitivity, specificity, and accuracy derived from the OLR, MIX and ROC curves are shown in Table 4. This table shows that the cut points for 3 METs derived from the regression models were fairly similar, while the cut points derived from the ROC analysis were considerably greater. The cut points derived from the regression models were also quite similar for 6 METs, while those from the ROC analysis differed from those of the regression analysis and from each other.

To determine the impact of accounting for the individual resting O_2 consumption, the cut points derived from individual MET values were compared to the MET values using the standardized 1 MET value of 3.5 mL/kg/min. Results using the MIX procedure showed that cut points were ∼900 (612 versus 1494 counts/min) lower at 3 METs and ∼1200 counts/min (4980 versus 6174 counts/min) lower

Table 2: Mean ± SD (95% CI) counts/min, individual MET values, and O_2 consumption at different treadmill speeds. All values are significantly different from the preceding values ($P < .05$) ($n = 41$ at 2 and 5 km/h; $n = 35$ at 6 km/h).

Speed (km/h)	Counts/min	Individual MET values	O_2 consumption (mL/kg/min)	O_2 consumption (L/min)
2	607 ± 468 (459 to 755)	2.82 ± 0.42 (2.69 to 2.96)	8.47 ± 0.98 (8.16 to 8.77)	1.00 ± 0.19 (0.94 to 1.06)
3	1425 ± 523 (1262 to 1588)	3.29 ± 0.53 (3.12 to 3.45)	9.84 ± 1.16 (9.48 to 10.20)	1.16 ± 0.23 (1.09 to 1.23)
4	2513 ± 650 (2311 to 2716)	3.88 ± 0.63 (3.68 to 4.08)	11.63 ± 1.42 (11.19 to 12.07)	1.37 ± 0.28 (1.29 to 1.46)
5	3729 ± 882 (3451 to 4008)	4.80 ± 0.86 (4.53 to 5.07)	14.40 ± 1.82 (13.83 to 14.97)	1.70 ± 0.37 (1.59 to 1.82)
6	4611 ± 1108 (4231 to 4992)	5.83 ± 0.81 (5.55 to 6.11)	17.81 ± 1.75 (17.21 to 18.41)	2.05 ± 0.34 (1.94 to 2.17)

Table 3: The effect (unstandardized regression coefficients (P value)) of walking speed, age, and body weight on metabolic cost and accelerometer counts during treadmill walking at 2, 3, 4, 5, and 6 km/h.

	METs	V_{O_2} (L/min)	V_{O_2} (mL/kg/min)	Counts/min*
Walking speed (km/h) (1st order)	−0.002 (.971)	0.004 (.852)	−0.044 (.770)	1006.662 (<.001)
Walking speed (km/h) (2nd order)	0.136 (<.001)	0.049 (<.001)	0.415 (<.001)	—
Age	0.025 (.041)	0.007 (.031)	0.060 (.015)	−27.439 (.027)
Body weight	0.003 (.582)	0.013 (<.001)	0.004 (.747)	2.437 (.672)

*The second order term of walking speed was omitted due to a nonsignificant association with the dependent variable.

Table 4: The suggested cut points, sensitivity, specificity, and accuracy from the different statistical analyses. OLR: ordinary linear regression; MIX: mixed model regression; ROC 1: cut point with the highest product of sensitivity and specificity; ROC 2: cut point with the highest accuracy.

		Cut point	Sensitivity	Specificity	Accuracy
3 METs	OLR	720	0.923	0.489	0.826
	MIX	612	0.936	0.422	0.821
	ROC 1	1646	0.795	0.911	0.821
	ROC 2	1310	0.878	0.733	0.846
6 METs	OLR	5779	0.125	0.984	0.915
	MIX	4980	0.375	0.957	0.910
	ROC 1	3061	0.938	0.686	0.706
	ROC 2	7220	0.063	1.000	0.925

at 6 METs when using the individual MET values compared to standardized MET values.

3.4. The Effect of Demographic Factors on the Cut Points (Step 2). To explore the impact of body weight and age on the suggested cut points, these variables were included in the MIX model (together with counts/min) to explain MET values. The inclusion of body weight did not improve the model (main effects: $F = 0.3$, $P = .598$; interaction effects: $F = 0.1$ to 0.6, $P = .463$ to .721). However, we found a significant main effect ($F = 13.3$, $P = .001$) and interactions with age (age∗counts/min: $F = 4.2$, $P = .045$; age∗counts/min^2: $F = 5.3$, $P = .032$). Because of the significant interactions, the group was split in two age groups (group 1: age 24–42 (35.7 ± 5.7) years, $n = 20$; group 2: age 43–62 (50.0 ± 5.5) years, $n = 22$) for the calculation of age-specific cut points. These analyses showed that cut points in the oldest age group were substantially lower (∼1050 counts/min) than cut points in the youngest age group (Table 5). However, because of the small sample sizes, the relatively large confidence intervals for the parameter estimates and a significantly different body weight in the two groups (127.3 ± 16.7 versus 120.9 ± 20.4 for group 1 and 2, resp.; $P = .014$), the subgroup results were not further explored.

4. Discussion

This study had two main findings. First, the cut points derived from the different statistical analysis deviated considerably from each other. Second, most cut points were substantially lower than what is found in earlier studies. This was a result of using individual MET values, rather than the standardized value of 3.5 mL/kg/min to define walking intensity and the older age of our sample compared to earlier studies. Together, this indicates that age- and weight-specific cut points may be appropriate.

Most calibration studies have used an OLR analysis to establish cut points for the work rate. This approach is inappropriate because each subject is measured repeatedly, which violates the independence assumption of this statistical procedure. Therefore, Welk [28] has suggested to apply a MIX analysis or ROC curves to analyze data from such calibration protocols. Consistent with the present study, however, Welk found that the cut points derived from regression analyses were fairly similar, while the results from ROC analyses deviated from the regression models. Further, in the present study, the cut points yielded quite different results for sensitivity and specificity. By definition, cut points derived from the ROC analyses had a balanced tradeoff between sensitivity and specificity. However, the cut points derived from the regression analysis for MPA yielded high sensitivity (>0.90) and low specificity (<0.51), while those for VPA yielded low sensitivity (<0.56) and high specificity (>0.91).

However, a ROC analysis based on maximized sensitivity and specificity may not have been the method of choice for

Table 5: The suggested regression equations and cut points obtained for two subgroups of differing age; group 1: age 24–42 (35.7 ± 5.7) years, $n = 20$; group 2: age 43–62 (50.0 ± 5.5) years, $n = 22$. β: regression coefficient; CI: confidence interval; SEE: standard error of the estimate; MPA: moderate physical activity; VPA: vigorous physical activity.

Age group	Parameter	β	95% CI	P	SEE	Cut-point MPA	Cut-point VPA
	Intercept	2.436	2.074 to 2.798	<.001			
24–42 years	Counts/min	4.170E − 4	2.350E − 4 to 5.986E − 4	<.001	0.63	1208	5525
	Counts/min^2	4.128E − 8	1.377E − 8 to 6.879E − 8	.004			
	Intercept	2.921	2.457 to 3.385	<.001			
43–62 years	Counts/min	5.149E − 4	2.759E − 4 to 7.539E − 4	<.001	0.88	152	4465
	Counts/min^2	3.912E − 8	−1.372E − 9 to 7.961E − 8	.058			

the present study due to the large class-skewing effect, especially for the VPA cut point [32]. Therefore, one could argue that applying an accuracy definition (ROC 2) that accounts for both the positive and negative cases would be a more balanced method and be the most appropriate approach. However, this was seemingly not the case, indicated by the suggested cut point for VPA of 7220 counts/min using the ROC 2 approach. As shown in Figure 1, only one person exceeded accelerometer counts of 7000 counts/min, and this cut point clearly does not fit the observations very well. Thus, this result is not meaningful. Due to the lack of data at high intensities (at or above 6 METs), we also analyzed cut points for 5 METs, where data were less skewed (not shown). For this intensity threshold, the results from the ROC 2 analysis were consistent with those of the regression analyses. This finding demonstrates that the ROC 2 analysis worked well for intensities that had more observations. Thus, because the ROC models are sensitive to class skew and the number of observations near the level of the state variable, the models will have a poor performance if few subjects reach the 6 MET level, which could be a problem for calibration studies in populations with low fitness levels. However, neither a higher walking speed (>6 km/h) nor running was suitable in the present study performed in severely obese subjects. Regression models would probably be a better choice in such cases, as extrapolation in these models will work reasonably well if the data can be assumed to be more or less linear within a narrow range. In addition, regression models allow for examination of covariates, which makes these models more informative and useful. As such, we preferred to use the regression models to establish the cut points in our sample.

Regarding which regression model to use, two arguments can be made in favor of the MIX model. First, the repeated structure of the data did not meet the assumptions underlying the OLR procedure; thus the MIX model would clearly be the preferred and correct method of choice. Second, a significant quadratic relationship between counts/min and MET was found using the MIX model. This was not captured by the OLR model, when dependency among the observations was ignored. As such, we argue that a linear mixed model should be used in future calibration studies of this type. Hence, the results obtained from the mixed model are discussed in the following sections.

The cut points in our study were ~1400 (MPA) and ~1000 counts/min (VPA) lower than those found in earlier

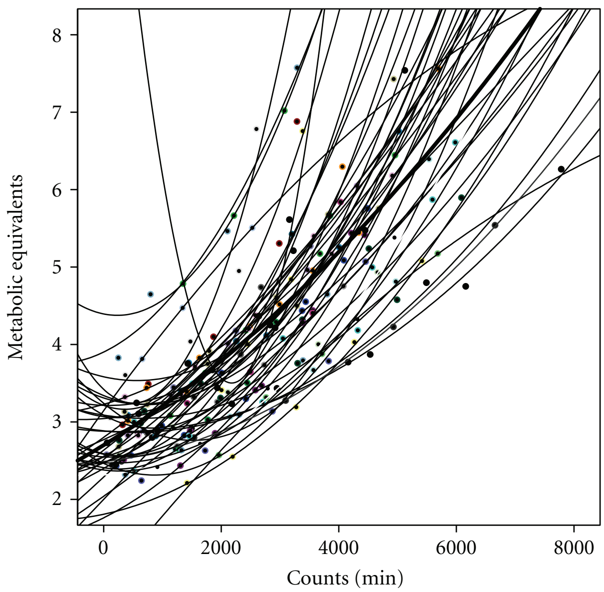

Figure 1: A scatterplot of counts/min versus individual MET values for the 42 obese-to-severely obese subjects walking on a treadmill at 2–6 km/h. The bold line indicates the regression equation derived from the linear mixed model (METs = 2.700 + 4.663E − 4*counts/min + 3.943E − 8*counts/min^2).

calibration studies using treadmill walking and running in young normal weight subjects [3–7]. This was mainly an effect of using individual MET values instead of the standardized value of 3.5 mL/kg/min and having an older aged sample. As the resting metabolic rate expressed per kg body weight declines with increasing BMI or fat mass [18], the metabolic cost of PA will be systematically biased toward an underestimation in obese individuals. Thus, we believe our correction for individual resting metabolic rate in this sample is an important step forward. Such correction is also recommended in children to avoid an overestimation of PA level due to their higher resting metabolic rate (4–6 mL/kg/min) [25, 26]. An alternative strategy is to assign different MET cut points (e.g., 4 and 7 METs for MPA and VPA, resp., in children [33]) to compensate for differences in resting values. However, this procedure will not capture individual differences, so we believe the use of individual MET values is a more valid approach.

Our results were expected, because both age and weight increased the metabolic cost of walking without a corresponding increase in the accelerometer counts, as also shown by others [16, 17]. This is partly consistent with an earlier study in moderately obese middle-aged to older subjects (BMI 31 ± 5.17; age 62.6 ± 6.5 years), which found cut points of 1240 and 2400 counts/min for MPA and VPA, respectively [10]. However, Lopes et al. [10] reported a very low VPA cut point. This could (at least partly) be explained by their substantially steeper slope for counts/min compared to earlier studies (0.0013 versus ~0.0006–0.0008 [3–7]), which could be due to their use of a single accelerometer unit. This reduces the external validity of their results.

We found a marked effect of age, with increased age giving lower cut-point thresholds. This is a result of age being positively related to the relative oxygen consumption (indicating lower work economy with increased age) and negatively related to counts/min (indicating lower trunk vertical accelerations with increased age) during walking. The lower work economy with increased age is in line with previous studies [14, 15]. However, the negative effect of age on accelerometer counts contrasts an earlier study [17], which did not find any difference between groups of 20–29-, 40–49- and 60–69-year-old subjects over a wide range of speeds. We have no explanation for this discrepancy. Clearly this indicates a need for future calibration studies, including large samples of men and women differing in body size and age.

A possible factor explaining some variation between studies may be the use of different generations of the Actigraph accelerometer, given that all studies in normal-weight subjects have used the earlier CSA 7164 model. Although the GT1M model has been shown to be slightly less responsive to low accelerations and walking speeds compared to earlier models, this difference is probably of minor importance for explaining the contrasting results [34–36].

The attachment of single-axis accelerometers becomes more difficult as body fat increases because the abdominal fat mass may increase the likelihood of accelerometer tilting. This effect results in lower count values [37] and may have led to an underestimation or a larger count variation in the present study, than has been seen in studies of normal-weight subjects. Earlier studies using walking protocols have reported similar (0.59) [8] or somewhat larger (0.74) [7] explained variances in energy expenditure. These findings indicate the possible influence of instrument tilting, although gait patterns, as observed in the lab, are probably more important for explaining this variation in the data.

One important implication of our findings is that, in terms of energy expenditure, obese and middle-aged to older individuals may in fact be more active than is currently believed. Current evidence suggests that overweight, obese, and older individuals are less active than normal-weight and young individuals [33, 38–40]. For example, an analysis of the free living PA level in our nonrepresentative sample of obese subjects shows that 14% exceeded the recommended PA level (30 minutes of MPA/day in bouts of 10 min) using the MPA cut point of 2020 counts/min [11] and that 69% exceeded this level using our established cut point of 612 counts/min. If our findings are valid, comparison of PA level between different populations using the same cut points is problematic and may systematically bias the results toward an underestimation in the middle-aged, older, overweight, and obese subjects.

4.1. Strengths and Weaknesses. The main strength of the present study was the comparison of three different statistical methods for determining the cut points from the accelerometer data. Further, we believe the inclusion of a sample varying in age and obesity status strengthens the validity of our results, although we did not include a young normal-weight comparison group. Importantly, our sample contrasts earlier studies performed in young normal-weight subjects and advances our understanding of PA measurements using accelerometry.

One weakness of the present study may have been the protocol used for establishing the individual resting oxygen consumption. Compared to the findings of Byrne et al. [18], the 1 MET values in the present study seem to have been overestimated. By applying the suggested regression equation from that study and correcting for sitting (multiplying by a factor of 1.08) in our sample, MET values of 2.60 and 2.31 mL/kg/min would be predicted for men and women, respectively. These values are lower than our corresponding findings of 3.26 and 2.94 mL/kg/min, which is likely partly due to the fewer number of restrictions that we placed on subjects prior to testing and the relatively short duration of the resting protocol (10 minutes). This effect may have led to overestimation of our 1 MET values and our suggested cut points. A second weakness may be that the GT1M accelerometer has been replaced with new tri-axial accelerometers (GT3X/GT3X+), which may reduce the interest for our findings. However, cut points established in earlier accelerometer models are valid for use with the vertical axis of the new accelerometers, and only one study has to date published vector magnitude cut points [41]. A third weakness is that the study was not powered to explore sex differences. Although we did not aim to compare men and women, the analysis indicated that differences between the sexes may exist (not shown), which could have been revealed by a balanced or larger sample size. Previous studies have reported similar cut points in men and women [3–5, 7]. However, those studies used a standardized MET value as the reference for metabolic cost. The difference in resting metabolic rate between men and women in the present study challenges the use of common cut points, as lower resting metabolic rate in the women causes somewhat lower cut points (481 and 4717 counts/min for MPA and VPA, resp.) than in the male group (1067 and 5314 counts/min for MPA and VPA, resp.) (calculated with the MIX approach). Because 74% of the subjects in the present study were women, it should be kept in mind that the cut points reported might pertain to women more than men. However, cut points for the mixed group of men and women are reported so that the results are comparable with previous studies.

Further research should determine intensity cut points in a larger sample of men and women who vary in their age and degree of obesity. Additional studies of this type should also be performed using the linear mixed model regression procedure. Finally, calibration studies should be continuously performed as new makes and models of the accelerometer are brought into use.

5. Conclusion

The MPA and VPA cut points from accelerometer counts differ when different statistical methods are applied to the same data. We suggest that cut points obtained from a linear mixed model analysis be used; thus, cut points of 612 and 4780 counts/min should be used to define MPA and VPA, respectively, in young-to-middle-aged obese-to-severely obese subjects using the Actigraph GT1M. However, one must recognize that if the same cut points are applied in groups that vary in age, the findings may be disturbed.

Conflict of Interests

The authors declare no conflict of interests.

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