ASSESSMENT OF CHANGE IN MODERATE TO VIGOROUS PHYSICAL ACTIVITY BY ACCELEROMETRY OVER TIME IN OBESE SUBJECTS: IS INDIVIDUAL ACCELEROMETER CUT POINTS USEFUL?

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Abstract
Objective To determine how the use of individual accelerometer cut points (ICPs) vs. a group-level cut point (GCP) affected the change in minutes of moderate-to-vigorous physical activity (MVPA) over a one-year lifestyle intervention for severely obese subjects. Design The study was an uncontrolled intervention study Method Based on a treadmill calibration protocol, we obtained cut points for MVPA (≥3 metabolic equivalents) for the Actigraph GT1M accelerometer in 42 subjects (11 men, body mass index 39.8 (5.7), age 43.2 (9.2) years). Of these, 23 to 28 subjects had valid assessments of change in MVPA over 4 measurements (baseline, week 4, week 16 and week 46). Results Change in MVPA from baseline to subsequent time-points did not differ ($p = 0.649$) and relationships between change in MVPA were moderate to strong (Spearman's $\rho = 0.77$ to 0.93, $p < 0.001$) when MVPA was derived from the ICPs vs. the GCP. Still, the absolute differences in change in MVPA between the two cut point approaches were considerable. Conclusions The use of ICPs and the GCP to determine changes in MVPA over time yielded quite similar results, thus the most feasible cut point approach (to apply a GCP) might be preferred in future studies.

Keywords: Exercise; Intervention studies; Obesity; Accelerometer; Actigraph

INTRODUCTION
Accelerometry has become a popular tool for measuring free-living physical activity (PA) in diverse study settings. Accelerometer count cut points to determine intensity-specific PA (i.e. to separate sedentary behavior, light, moderate and vigorous PA defined as <1.5, 1.5-2.9, 3-5.9 and ≥6 metabolic equivalents (METs), respectively (Haskell et al., 2007; US Department of Health and Human Services, 2009; Butte et al., 2012)) are often used as a meaningful outcome in such studies.

In any accelerometer measurement, measurement-variability of both technical and biological origin will be present. Of the different sources of variation (inter-instrument-, intra-instrument- and between-subject variation), variation among subjects has been reported to be by far the greatest source of variation, explaining 63 to 89% of the total variation in counts during walking using Actigraph instruments (Actigraph, Fort Walton Beach, FL, USA, formerly known as Computer Science and Applications (CSA) and Manufacture Technology Incorporated (MTI) models) (Welk et al., 2004; Barnett and Cerin, 2006). Hence, an accelerometer cut point calibration to individual subjects has the potential to increase measurement precision. However, in a previous study (Aadland and Steene-Johannessen, 2012), we were not able to conclude whether individual calibration would be a useful approach to determine free-living minutes of moderate to vigorous PA (MVPA), for which there is no criterion measure (Westerterp, 2009; Warren et al., 2010). We showed that very different PA durations may be expected based on application of individual cut points (ICPs) vs. a group-level cut point (GCP) in a cross-sectional setting.

Still, individual calibration has mainly been recommended for intervention studies because they require precise measurements at multiple time points to detect changes over time (Ward et al., 2005; Welk, 2005; Barnett and Cerin, 2006). However, such a procedure might not be necessary or feasible with repeated measurements, as the same cut point would be applied repeatedly within a given subject with both approaches. Thus, it may be hypothesized that changes in PA over time would be less affected than absolute PA levels.

The aim of the present study was to compare the use of ICPs vs. a GCP for assessment of change in free-living minutes of MVPA over time. The study is based on four measurements of PA collected over a one-year lifestyle intervention for subjects with severe obesity. We hypothesized that application of ICPs vs. a GCP would provide similar results for changes in PA over time.

METHODS
Participants
Forty-nine severely obese patients were enrolled at the Red Cross Haugland Rehabilitation Center (RCHRC) 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 body mass index (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 subject's 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. Of the 49 subjects recruited to the study, 44 subjects performed the treadmill calibration procedure. After two subjects were excluded owing to accelerometer malfunction, 42 subjects (11 men) had valid accelerometer calibration data. The characteristics of the subjects are shown in table 1.

Table 1. Subject characteristics (mean (SD)).

	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)	124.1 (12.9)	127.6 (10.1)	122.9 (13.7)
Fat mass (kg)	54.8 (13.2)	46.6 (10.9)	57.6 (12.9)
Lean mass (kg)	64.7 (12.2)	81.6 (8.8)	58.8 (6.1)
VO_{2max} (l/min)	3.29 (0.66) (n = 32)	4.16 (0.60) (n = 8)	3.00 (0.37) (n = 24)
VO_{2max} (ml/kg/min)	27.61 (5.19) (n = 32)	32.30 (5.41) (n = 8)	26.05 (4.15) (n = 24)

BMI = body mass index; WC = waist circumference; VO_{2max} = maximal oxygen consumption; PA level = physical activity level; ICP = individual cut point; METs = metabolic equivalents

Overview of the study protocol

The intervention consisted of three intermittent inpatient periods over the course of one year. The time line of the study was an inpatient period from baseline to 6 weeks, a home period of approximately 14 weeks, an inpatient period from weeks 20 to 23, a home period of approximately 27 weeks and an inpatient period from weeks 50 to 53.

Details regarding the intervention can be found elsewhere (Aadland et al., 2013). In short, the program at RCHRC had three main components: diet, PA and cognitive behavior therapy. Regarding PA, subjects participated in a supervised and structured exercise program during the inpatient periods and were also encouraged to perform PA on their own. A plan was developed for PA to be performed at home, however, no systematic follow-up was offered during these periods.

The calibration protocol was performed during week 4. Subjects with lack of experience with respect to walking on a treadmill were advised to practice treadmill walking prior to performing the calibration study. The PA level was measured one month prior to the first inpatient period (baseline), during the first inpatient period (week 4), and approximately one month before inpatient periods 2 (week 16) and 3 (week 46).

Treadmill calibration protocol and analysis

The subjects visited the lab after a minimum of one hour of fasting and were not permitted to perform 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 accelerometer (Actigraph, Fort Walton Beach, FL, USA). Technical specifications of the accelerometer can be found elsewhere (John and Freedson, 2012). All subjects wore an accelerometer attached in the mid axillary line of the right hip at the height of the umbilicus. Thirty different instruments were used. The accelerometers were set at a 10-second epoch and a normal filtering option.

The test protocol consisted of two parts. First, the subjects were rested in a sitting position for 10 minutes to measure their resting oxygen consumption according to the originally proposed definition of 1 MET (Gagge et al., 1941). Then, the subjects walked on the treadmill with no inclination for five minutes at 2, 3, 4, 5 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). Barometric pressure was calibrated each test day and 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 (Medbř et al., 2012).

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 from the vertical axis using the comma separated values (CSV)-files exported from the ActiLife v.5.3 software (Actigraph, Fort Walton Beach, FL, USA). The oxygen consumption when walking was divided by the oxygen consumption at rest to express the values for the metabolic cost of walking as individually adjusted MET values.

Measurements

Body weight and body composition was measured with subjects in the fasted state, wearing light clothes, in the morning and after voiding. Values were reported to the nearest 0.1 kg using bioelectrical impedance analysis (BC 420 S MA, Tanita Corp, Tokyo, Japan). Maximal oxygen consumption (VO_{2max}) was measured using a modified Balke-protocol (Aadland et al., 2013).

Physical activity was measured using the Actigraph GT1M accelerometer. At each time-point, subjects were instructed to wear the accelerometer at the right hip over seven consecutive days, except during water activities (swimming, showering) or while sleeping. All files were analyzed using the ActiLife v. 5.3 software. A wear time of ≥ 10 hours/day for ≥ 4 days was used as the criterion for a valid measure. Periods of ≥ 60 minutes (allowing for ≤ 2 minutes of non-zero counts) were defined as non-wear time (Trost et al., 2005; Sirard et al., 2011). Physical activity is reported as average counts/min and minutes of MVPA/day.

Statistical analyses

Subject characteristics are presented as the mean (standard deviation). Data on PA (actual values and changes over time) are presented as the median and 95% bootstrapped confidence intervals (CI) because data on PA derived from ICPs were skewed. The main effect of cut point-approach (ICPs vs. GCP) was tested on the ranks of values over all time-points using a repeated linear mixed model with a restricted maximal likelihood estimation and compound symmetry as the covariance structure. Relationships between MVPA derived from ICPs vs. the GCP on each time-point and changes over time were tested using the Spearman rank order correlation coefficient (ρ). A Bland-Altman plot (Bland and Altman, 1986) was used to compare the differences between changes in MVPA over time for the GCP vs. ICPs as a function of the mean MVPA of the two cut point-approaches over the two time points examined. The standard error of the measurement (SEM) and limits of agreement (LoA) was calculated according to Hopkins (SEM = SD of the differences /√2; LoA = SD of the differences * ±1.96) (Hopkins, 2000).

The ICPs and the GCP were obtained from ordinary linear regression and a repeated linear mixed model regression, respectively, as previously described (Aadland and Steene-Johannessen, 2012). Each dataset was checked with a scatterplot. Despite a quadratic fit was indicated in some individuals, both ICPs and the GCP was restricted to linear terms, because a linear fit probably will be more robust on an individual level having only five observations. The estimated ICPs varied from -405 to 2730 counts/min (negative values was replaced with 100 counts/min for three subjects) with a mean of 1151 (685) counts/min. The applied GCP was 685 counts/min based on the following model: METs = 2.5276 + 0.000690*counts/min (CI for intercept 2.2456 to 2.8096, p <.001; CI for slope 0.000626 to 0.000753, p < .001).

All analyses were performed using SPSS v. 20 (SPSS Inc., Chicago, USA). ≤P 0.05 indicated significant differences.

RESULTS

A total of 42, 43, 36 and 30 subjects had a valid free-living PA accelerometer-measurement at baseline, week 4, 16 and 46, respectively. Of these, 31, 38, 32 and 28 subjects had both valid calibration data and free-living PA data. Thus, the comparative analysis of MVPA at the different time-points is based on these observations. The number of subjects that provided data on change in MVPA over time was 28, 23 and 23 subjects for change from baseline to week 4, 16 and 46, respectively, thus, these observations form the basis of analyses of changes over time.

Application of the GCP resulted in a greater overall PA duration compared to application of ICPs (table 2) (main effect of cut point-approach p = .019). Weak relationships were detected between MVPA derived from the GCP vs. ICPs on each time-point (ρ = -0.03 to 0.35, p = .033 to .870).

Table 2. Comparison of physical activity (median and 95% bootstrapped CIs) over the one-year intervention measured with the GCP and the ICPs.

	Baseline	Week 4	Week 16	Week 46
Average counts/min	314 (279 to 327)	432 (404 to 484)	302 (266 to 364)	320 (293 to 379)
Minutes of MVPA/day				
GCP	116 (105 to 125)	141 (130 to 150)	108 (98 to 113)	123 (105 to 130)
ICPs	67 (54 to 95)	127 (98 to 138)	72 (57 to 106)	95 (68 to 118)
Change in minutes of MVPA/day from baseline				
GCP	-	27 (15 to 47)	-4 (-18 to 5)	13 (-1 to 37)
ICPs	-	34 (24 to 50)	-5 (-18 to 8)	11 (-5 to 20)

MVPA = moderate to vigorous physical activity; GCP = group cut point; ICPs = Individual cut points

Both cut point-approaches reflected the same patterns of change in MVPA over time (table 2) (main effect of cut point-approach for change over time p = .649). Relationships between changes over time for the two cut point-approaches were moderate to strong (ρ = 0.77, ρ = 0.90 and ρ = 0.77 (all p < .001) for difference to 4, 16 and 46 weeks, respectively). Still, the Bland-Altman plot (figure 1) shows that there was substantial individual variation in differences between the two cut point-approaches, with SEM = 17.6 and 95% Loa from -50.3 to 47.5 minutes of MVPA/day.

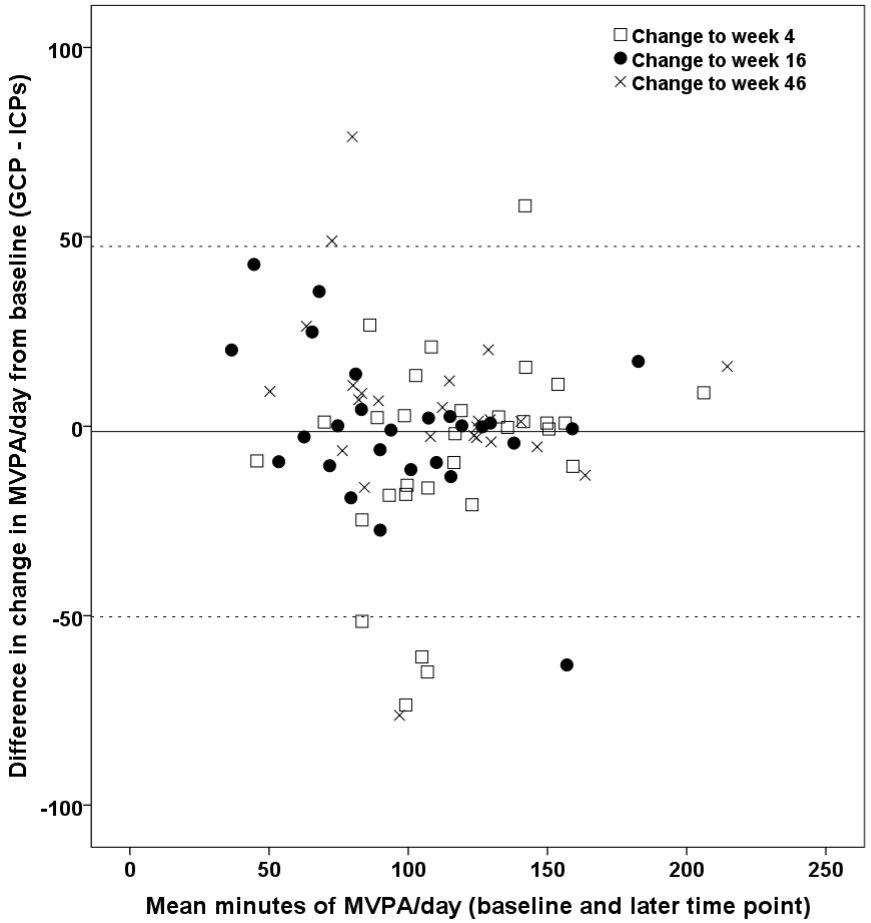

Figure 1. Bland-Altman plot showing the individual differences between changes in minutes of MVPA/day over time (GCP minus ICPs) vs. mean minutes of MVPA/day for the two cut point approaches at baseline and the later time point under study. MVPA = moderate to vigorous physical activity; GCP = group cut point; ICPs = Individual cut points.

DISCUSSION

The main finding of this study was that the use of ICPs or a GCP to determine longitudinal changes in minutes of MVPA in severely obese subjects yielded quite similar results, at least at a group level. Thus, although it has been suggested that individual calibration might be important to arrive at accurate values for changes in PA over time in intervention studies (Ward et al., 2005; Welk, 2005; Barnett and Cerin, 2006), the present study suggests that performing individual accelerometer calibration is not worth the effort in such study settings. This finding is in accordance with the study hypothesis.

Although the quantification of changes in MVPA over time seems to agree reasonable well between the cut point approaches, the Bland-Altman plot shows considerable individual variation in change in PA over time between a given ICP and the GCP. According to the limits of agreement, one may expect deviations of approximately 100% for subjects having a PA level of 50 minutes of MVPA/day, although the typical deviation is much lower (17.6 minutes of MVPA/day). The main challenge regarding the interpretation of this finding is that there are no valid criterion measure of intensity-specific PA (Westerterp, 2009; Warren et al., 2010), meaning that a direct comparison of the precision of a GCP vs. the ICPs could not be performed. Although accelerometer-determined PA levels are found to be moderately correlated with measurements made using doubly labeled water (Plasqui and Westerterp, 2007), this technique is not suitable to measure minutes of PA at different work rates, as doubly labeled water only measure the total energy expenditure over a given time period (Westerterp, 2009; Warren et al., 2010). Therefore, the question regarding which cut point for a given subject that best represents the "true" cut point is speculative. The GCP is by definition not the true value as it is an average estimate based on a given sample. The ICPs could be claimed to be true, and we have previously shown that resting oxygen consumption, work economy and body mass index explained 59% of the variation in ICPs between subjects (Aadland and Steene-Johannessen, 2012). However, although some of the unexplained variance probably is due to unmeasured variation in gait characteristics (i.e. "true" variation), there will also be a certain amount of measurement error inherent in the determination of the ICPs. Thus, I believe it is reasonable to state that neither measure provides us with the true PA level, but both measures provide us with a more or less similar degree of the true PA.

In lack of a criterion measure, a possible way to test the usefulness of the cut points could be to perform a clinical validation using a outcome known to be affected by PA. We have previously found a relationship of r= 0.65 (p =.002) between change in PA level (average counts/min) and VO_{2max} over the present intervention period (Aadland et al., 2013). A reanalysis of this relationship using minutes of MVPA/day shows very similar relationships for ICPs ($\rho = 0.56$, $p = .011$) and the GCP ($\rho = 0.58$, $p = .007$) with VO_{2max} (results not shown). Although the comparison between the cut point approaches with VO_{2max} is based on a small sample ($n = 20$) and must be interpreted carefully, the finding supports the hypothesis that both cut points provide us with similar degree of the true change in PA over time. Therefore, the previously made conclusion in Aadland and Steene-Johannessen (2012); "if we believe that individual calibrations increase the measurement precision, we have to accept that use of a GCP may be more or less useless to determine minutes of MVPA on an individual level" need to be moderated, as both methods may be equally useful.

Nevertheless, as the present study does not show any evidence of improved performance for ICPs vs. a GCP, I suggest the most feasible approach (i.e., a common cut point at the group-level) being used in intervention studies. Moreover, the same conclusion are probably reasonable for cross-sectional studies, and in many cases (e.g., in large epidemiological studies) this type of individual calibration would not be feasible irrespective of whether it could increase measurement precision or not. However, simpler calibration procedures, placing less burden on participants and researchers, could be valuable (Brage et al., 2007).

Strengths and weaknesses.

The strengths of the present study are the use of precise and sophisticated measurements of the metabolic cost of treadmill walking and four repeated measurements of free-living PA.

The present study has several limitations, in addition to lack of a criterion measure for intensity-specific PA. As observed in the laboratory, the attachment of the accelerometers can be challenging for severely obese subjects, and tilting of the instrument is known to reduce the level of counts (Metcalf et al., 2002). Moreover, musculoskeletal disorders and other factors that might interfere with walking capacity and work economy is more common in severely obese subjects, compared to less obese and normal-weight subjects (Hulens et al., 2003). These factors may have produced

greater variability in this population compared to what could have been found in other populations. Thus, further research should verify or falsify our findings in a sample of less obese subjects. In addition, some issues regarding the performance of the calibration protocol and calculation of the ICPs deserve a comment. First, the extrapolation of the accelerometer counts to three METs may have caused some uncertainty in the count thresholds in 14 subjects who spent more than three METs at two km/h. However, most subjects spent close to three METs at two km/h (n = 7 < 3.20; n = 11 < 3.50 METs). Second, linear models were used to calculate ICPs, despite a quadratic fit between counts and metabolic cost was indicated in some individuals. However, applying ICPs derived from quadratic models did not change any findings. Third, the calibration protocol was performed once at week 4, whereas PA measurements were performed over one year. Thus, variation in body weight, physical fitness, resting metabolic rate or work efficiency over time could have influenced the relationship between accelerometer counts and work rate. However, performing repeated calibration protocols will probably not be feasible in any study setting, thus, these sources of variability would be inherent in many intervention studies, although simpler calibration-procedures could be suited (Brage et al., 2007).

CONCLUSIONS

The present study shows that the use of ICPs or a GCP to determine change in minutes of MVPA/day over a one-year lifestyle intervention for severely obese subjects yielded quite similar results, although there was a certain degree of difference between the two approaches on an individual level. I conclude that both approaches seem to reflect the change in PA over time equally well in this study. Thus, although recognizing that the findings might be specific to the sample included, the results suggest that the most feasible approach (a common cut point on a group level) be used in future studies.

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Conflict of interest

I declare no conflict of interest.

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