

Concurrent validity of the PAM accelerometer relative to the MTI Actigraph using oxygen consumption as a reference

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The purpose of this study was to examine the concurrent validity of the Personal Activity Monitor (PAM) accelerometer relative to the Actigraph accelerometer using oxygen consumption as a reference, and to assess the test-retest reliability of the PAM. Thirty-two fit, normal weight adults (aged 21–54) performed two activities, treadmill walking and stair walking, while wearing the PAM, the Actigraph and the Cosmed K4b². Correlation coefficients and agreement in absolute energy expenditure (EE) levels between PAM, Actigraph and Cosmed were calculated. The test-retest reliability was examined among 296 PAM's using a laboratory shaker. Intraclass correlation coefficients (ICC) and coefficient of variation (CV) were determined. Correla-

tions for treadmill walking and stair walking, respectively, were $r^2 = 0.95$ and $r^2 = 0.65$ for PAM with Actigraph, $r^2 = 0.82$ and $r^2 = 0.93$ for PAM with VO₂ and $r^2 = 0.64$ and 0.74 for Actigraph with VO₂. Both the PAM and Actigraph underestimated EE during treadmill and stair walking by a substantial amount. The test-retest reliability of the PAM was high [ICC = 0.80; 95% confidence interval (CI) (0.28;0.92) and intra-CV = 1.5%]. The PAM and Actigraph accelerometer are comparable in assessing bodily movement during treadmill and stair walking. The PAM is a valid device to rank subjects in EE and can be useful in collecting objective data to monitor habitual physical activity.

In order to monitor trends in physical activity levels on a population level, there is a need for valid and reliable methods to quantify physical activity. Recently, accelerometry-based activity monitors are used with increasing regularity to assess physical activity objectively under free-living conditions. Accelerometry is based on the intensity, frequency and duration of bodily movement (Meijer et al., 1991; Chen & Bassett, 2005). Favorable aspects of this method are the real-time data acquisition, the convenience and the relatively low-cost compared with other objective methods (e.g. doubly labeled water). The MTI Actigraph, formerly known as Computer Science and Applications (CSA) is one of the most widely used accelerometers in physical activity research. A number of studies have validated the Actigraph to indirect calorimetry or relative to other accelerometers under both laboratory (Melanson & Freedson 1995; Freedson et al., 1998; Nichols et al., 1999, 2000; Leenders et al., 2000, 2003; Welk et al., 2000) and field (Janz, 1994; Bassett et al., 2000; Hendelman et al., 2000; Sirard et al., 2000; Crouter et al., 2006) conditions. The literature suggests that the uni-axial accelerometers like the MTI Actigraph

provide similar information under both conditions and are best placed on the hip or the lower back. One of the key limitations of accelerometers is that not all activity is reflected in acceleration or deceleration, e.g. non-ambulatory physical activities with arm and or limb movements, walking on a gradient or weight-bearing activities (Troost et al., 2005). Various studies have demonstrated a significant underestimation of daily energy expenditure (EE) compared with the doubly labeled water method (Ekelund et al., 2001; Leenders et al., 2001, 2006). Therefore, the use of accelerometers in free-living individuals seems more valuable for comparing activity levels between groups of individuals than to quantify EE (Bassett et al., 2000; Matthews et al., 2002).

The Personal Activity Monitor (PAM, PAM B.V. Doorwerth, the Netherlands, Fig. 1) is a recently developed uni-axial accelerometer for general use. The PAM is based on similar technology as the Actigraph, and provides the user with a proxy measure for 24h physical activity (i.e. the PAM score) which is shown in its display. The PAM is easy to use by consumers as well as scientists. Extra features of the PAM are its memory capacity to store



Fig. 1. Personal Activity Monitor (PAM) with reader interface unit.

data up to 3 months and the ability to upload the PAM scores to a personal website providing tailored physical activity feedback. If proven valid and reliable, the PAM could be used for monitoring physical activity and at the same time providing immediate feedback. To date, no papers have been published on the validation and reliability of the PAM accelerometer. Considering the PAM and the Actigraph use the same uni-axial technology, we expect similar performance and limitations in assessing physical activity.

The purpose of this study is threefold. The primary purpose of this study is to test the validity of the PAM accelerometer relative to the Actigraph accelerometer in assessing physical activity while using indirect calorimetry as a reference in adults, performing treadmill walking and stair walking. Second, we compared all three instruments on their calculated MET scores during the same activities and finally the test-retest reliability of the PAM was examined on a laboratory shaker.

Methods

Participants

Subjects were recruited through leaflets, personal contact, phone and e-mail within the VU University Medical Center. Detailed information about the study objective and the protocol of the study was provided to the subjects. Inclusion criteria were ability to walk and to walk stairs, not being pregnant and non-usage of β -blockers. All participants read and signed an informed consent statement. The study protocol was approved by the Medical Ethics Committee of the VU University Medical Center. Participants were instructed not to eat or smoke during the 3 h preceding the tests.

Procedures

A structured protocol of anthropometric and resting physiological assessments was applied, followed by PAM, Actigraph and oxygen uptake (VO_2) monitoring during treadmill walking and stair walking, under controlled laboratory settings.

Body height was measured to the nearest 0.1 cm using a stadiometer (model Seca 125, Seca GmbH & Co., Hamburg, Germany) and body weight was measured to the nearest 0.2 kg with the subjects dressed in light clothing without shoes, using a calibrated scale (model Seca 888, Seca GmbH & Co, Hamburg, Germany). Percentage body fat was estimated from the sum of four skinfold thickness measurements on the right side of the body [biceps, triceps, subscapula, suprailiac (Durnin & Womersley, 1974)], using a Harpenden skinfold caliper (model HSB-BI, British Indicators, West Sussex, UK).

New PAMs ($N = 296$) were tested and retested on a laboratory shaker (Edmund Bühler, SM 25, 36 mm amplitude). The accelerometers were clipped on a specifically designed framework, with their axis of measurement along the radius of the shaker. Sixty PAM's at a time were put on the laboratory shaker simultaneously and were tested twice, at 3 Hz for a period of 10 min. Because the default PAM score is based on a 24 h period, the PAMs were set to be eight times more sensitive to enable higher PAM scores and improve discrimination in a short period of time. Before each testing session the laboratory shaker was warmed up for 15 min to reduce the possible variability in speed and amplitude of the shaker.

Accelerometers

The PAM (model AM101, $58 \times 42 \times 13$ mm, 28 g, Fig. 1) measures accelerations in the vertical plane with a sensitivity of 2 mV/G by means of a piezoelectric sensor. The acceleration signal is filtered (0.1–5 Hz), rectified and integrated in a capacitor. The voltage of the capacitor is measured each second and digitized by an Analog-to-Digital Converter (ADC) which gives an ADC score per second. In a micro-processor the ADC score is averaged per 24 h resulting in a PAM score. For this study, the manufacturer created an extra output possibility on the PAM. This enabled us to monitor the ADC scores per second via a wired connection to a PDA (model m515, Palm Europe Ltd., Wokingham, UK). This single modification did not affect the assessment. In this paper, the ADC scores will be referred to as PAM scores. The participants carried the PDA in a pouch on the lower back.

The MTI Actigraph (Manufacturing Technologies Inc., Fort Walton Beach, FL, USA) (model AM-7164, $50 \times 41 \times 15$ mm, 43 g) is, like the PAM accelerometer, an uni-axial accelerometer with a similar mechanism that converts accelerations in activity counts (Meijer et al., 1991; MTI Health Services, 2004; Chen & Bassett, 2005). It can detect acceleration ranging in magnitude from 0.05 to 2.00 G with a frequency response from 0.25 to 2.50 Hz. Activity counts of the Actigraph were stored in 1 s epochs. Both accelerometers were directly clipped to a waist belt and were oriented in the vertical direction. The PAM was positioned at the spina iliaca anterior superior and the Actigraph was placed right of the PAM.

Indirect calorimetry

Oxygen uptake (VO_2) was measured on a breath-by-breath basis using a portable metabolic unit, the Cosmed K4b² (COSMED s.r.l., Rome, Italy), in this article referred to as Cosmed. The Cosmed has been shown to be a valid device compared with the Douglas bag method during cycle ergometry (McLaughlin et al., 2001). Before each test, the oxygen and carbon dioxide analyzers were calibrated according to the manufacturer's instructions. These instructions consisted of a four-step calibration process namely a room air calibration, a

Concurrent validity of the PAM accelerometer

reference gas calibration using 15.93% oxygen and 4.92% carbon dioxide, a delay calibration and finally a turbine calibration performed with a 3.00 L syringe (Hans-Rudolph, Kansas City, Missouri, USA). The participants wore a chest harness with the Cosmed and breathed through a flexible face mask (Hans-Rudolph) that covered the subject's mouth and nose. The Cosmed measured resting VO_2 and VO_2 during the performance of two selected activities.

Activities

Two light-to-moderate intense daily activities (Ainsworth et al., 2000) were selected:

1. Walking on a non-graded treadmill at three speeds; slow pace walking at 3 km/h (1.9 mph), moderate to brisk walking at 5.1 km/h (3.2 mph) and brisk to fast walking, but not running, at 7 km/h (4.4 mph);
2. Walking up and down stairs with a speed of 80 and 100 steps per minute (s.p.m.) utilizing a metronome; the stairs consisted of 11 steps with a stepheight of 18 cm.

Each participant began the testing procedure with a 10-min rest period in a sitting position to get used to the equipment. The intensities of each of the two activities were performed consecutively for 5 min. The participants had a minimum of 5 min rest between walking and walking the stairs. The order in which the activities were performed was the same for all participants.

Data analysis

Data of the last minute of each activity was averaged for the PAM, Actigraph and Cosmed. Standardized longitudinal regression coefficients were computed using generalized estimating equations (GEE) between all three measures, and for both activities. These regression coefficients can be interpreted as Pearson's correlation coefficients, with the advantage that GEE takes into account that multiple observations per subject (e.g., walking at 3, 5 and 7 km/h) are not independent (Twisk, 2003). Scatter plots were used to graphically show the variability in individual counts per minute of the PAM and Actigraph vs the measured VO_2 data. As VO_2 does not increase linear with body weight we considered the 0.67 power to be a more appropriate basis for analyses (Rogers et al., 1995). VO_2 data ($\text{mL/kg}^{0.67}/\text{min}$) were converted to metabolic equivalents (METs) by dividing the average VO_2 values during activity by the resting metabolic rate, i.e. the individual VO_2 in rest. One kilogram was added to the measured body weight in all calculations to account for the extra weight of the equipment worn by the participant. To enable the comparison of the estimated EE from the PAM and Actigraph with directly measured EE by the Cosmed, regression equations were used.

To predict the EE from the PAM-data the manufacturer equation was used:

$$\text{EE}(\text{METs}) = ((\text{PAM score}/100) + 1)/0.9$$

For the Actigraph, we used the regression equations of Freedson et al. (1998), Hendelman et al. (2000) and the two-regression model of Crouter et al. (2006) to estimate EE based on the counts per minute from the Actigraph accelerometer. These regression equations were developed either during walking and running (Freedson et al., 1998; Hendelman et al., 2000; Crouter et al., 2006) or during moderate intensity lifestyle activities (Hendelman et al., 2000; Crouter et al., 2006). Mean MET with 95% confidence intervals were computed for all intensities. Paired *t*-tests were used to test the differences between the criterion (Cosmed), and the EE estimated by the accelerometers, to indicate whether the accelerometers over- or underestimated EE. One-way analyses of variance (ANOVA) with Bonferroni's adjustment was used to examine the sensitivity of the PAM, Actigraph and measured oxygen uptake to changes in speed of treadmill walking and stair walking.

The coefficient of variation (CV) was calculated as an estimate of the intra- and inter-PAM variability of the data obtained on the laboratory shaker. The intraclass correlation coefficient (ICC) was calculated to describe the between-test variation. The ICC (model 3,1) is determined by a two-way mixed effects model for absolute agreement. An ICC close to one represents good repeatability. Using both CV and ICC gives good insight into the magnitude of (dis)agreement between the PAM's (Rankin & Stokes, 1998). GEE were performed using SPIDA (version 6.05, Statistical Computing Laboratory, Macquarie University, New South Wales, Australia) whereas all other analyses were performed using SPSS (version 11.0; SPSS Inc., Chicago, Illinois, USA).

Results

Physical characteristics of the 32 participants are listed in Table 1. The study population consists of fit, normal weight young adults. Table 2 shows mean values of the Cosmed, PAM and Actigraph during treadmill walking and stair walking at different speeds. ANOVA showed that indirect calorimetry and both accelerometers could distinct the different intensities of treadmill walking and stair walking ($P < 0.001$).

High correlations between both accelerometers were found for treadmill walking ($r^2 = 0.95$) and stair walking ($r^2 = 0.65$) (Fig. 2). Both for treadmill walking and stair walking the correlation between the

Table 1. Physical characteristics of the participants

| Variable | Total ($n = 32$) | Men ($n = 14$) | Women ($n = 18$) |
|--|---------------------------|---------------------------|---------------------------|
| Age (year) | 29.4 ± 7.3 (21–54) | 29.7 ± 7.4 (21–50) | 29.2 ± 7.4 (21–54) |
| Height (cm) | 177.4 ± 8.7 (164.7–194.6) | 184.3 ± 6.5 (171.5–194.6) | 171.9 ± 5.9 (164.7–190.1) |
| Weight (kg) | 71.7 ± 13.7 (51.4–98.7) | 82.9 ± 11.3 (63.8–98.7) | 63.0 ± 7.7 (51.4–80.4) |
| BMI (kg/m^2) | 22.7 ± 3.2 (16.9–31.2) | 24.4 ± 2.9 (20.7–31.2) | 21.3 ± 2.8 (16.9–29.2) |
| Body fat (%) | 24.5 ± 6.3 (11.7–37.2) | 20.0 ± 5.8 (11.7–30.4) | 27.9 ± 4.2 (19.4–37.2) |
| Resting VO_2 ($\text{mL}/\text{kg}/\text{min}$) | 2.6 ± 0.9 (1.2–5.2) | 3.0 ± 1.0 (2.0–5.2) | 2.3 ± 0.7 (1.2–3.4) |

Values are means ± SD with range in parentheses; *n*, number of participants. BMI, body mass index; VO_2 , oxygen uptake.

Table 2. Mean values of the Cosmed K4b², PAM and Actigraph accelerometer for treadmill walking and stair walking

| Activity | n | VO ₂ (mL/kg ^{0.67} /min) | PAM score/min | Actigraph, (count/min) | CV for 10-s Actigraph counts |
|-----------------------------|----|--|----------------|------------------------|------------------------------|
| Walking at 3 km/h | 32 | 40.0 (7.0) | 766.7 (222.3) | 1029.0 (258.2) | 22.8 (4.4) |
| Walking at 5 km/h | 31 | 56.1 (8.6) | 2141.2 (312.1) | 3512.7 (626.0) | 7.4 (10.4) |
| Walking at 7 km/h | 31 | 94.1 (10.3) | 4267.4 (562.7) | 5836.1 (1126.7) | 7.4 (18.8) |
| Stair walking at 80 s.p.m. | 32 | 84.4 (9.5) | 1291.6 (253.3) | 3206.6 (433.9) | 30.6 (16.9) |
| Stair walking at 100 s.p.m. | 32 | 100.7 (10.9) | 1845.9 (405.9) | 3888.7 (548.9) | 30.7 (19.5) |

Values are means with SD in parentheses.

CV, coefficient of variation; PAM, Personal Activity Monitor; s.p.m., steps per minute.

PAM and indirect calorimetry was slightly higher ($r^2 = 0.93$ and 0.74 , respectively) than the correlation between the Actigraph and indirect calorimetry ($r^2 = 0.82$ and 0.64 , respectively). All correlations had P -values below 0.001. The scatter plots in Figs 3 and 4 show the relation between, respectively, the PAM and Actigraph accelerometer with measured VO₂ mL/kg^{0.67}/min.

In Table 2, mean activity counts per minute and CV of the counts per 10-s for each activity from the Actigraph are shown. For an activity with a CV of ≤ 10 , Crouter's walking/running equation was used and for a CV above 10, Crouter's lifestyle leisure-time physical activity regression equation was used. Only the walking speeds 5 and 7 km/h were processed with Crouter's walking/running regression equation. Table 3 and Fig. 5 show that the predicted EE of the PAM as well as the Actigraph, underestimated the measured EE by indirect calorimetry for both activities. The PAM underestimated measured EE for treadmill walking at 3, 5 and 7 km/h by 48%, 30% and 30%, respectively. The predicted EE for stair walking at 80 and 100 steps was also underestimated by the PAM by 67% and 65%. The different regression equations to predict EE by Actigraph counts underestimated the EE for treadmill walking at 3, 5 and 7 km/h: Freedson by 44%, 25%, 37%; Hendelman by 17%, 23%, 45% and Crouter by 3%, 32%, 45%, respectively. Only Crouter's equation to predict EE for walking at a speed of 3 km/h was not significantly different from the measured MET ($P = 0.58$). Crouter's equation underestimated walking the stairs at 80 and 100 s.p.m. by 25% and 31% while Freedson's and Hendelman's equation predicted EE less than half of the measured EE.

On the laboratory shaker, mean PAM scores of 34.4 (SD = 1.5) and 35.1 (SD = 1.5) were found for the test and retest, respectively. An overall ICC of 0.80 (95% confidence interval: 0.28; 0.92), was found, ranging from 0.66 to 0.89 between the batches. The mean inter-instrument CV was 4.4% (range 2.8–5.5%) and the overall intra-instrument CV was 1.5%. The limits of agreement ranged from 31.3 to 37.4 and from 32.1 to 38.0 for the test and retest, respectively.

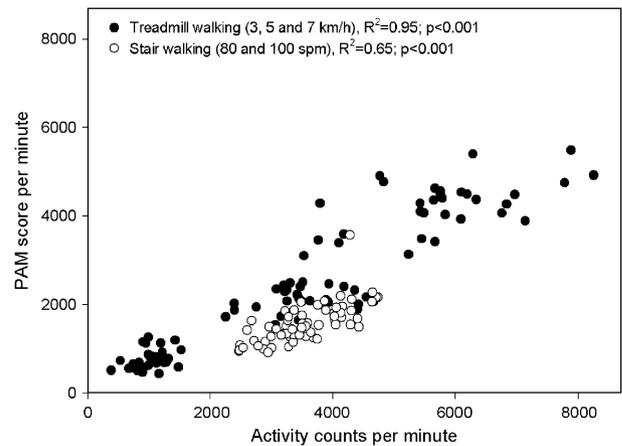


Fig. 2. The relation between the Personal Activity Monitor (PAM) accelerometer (PAM score per minute) and the Actigraph accelerometer (Activity counts per minute) for treadmill walking and stair walking.

Discussion

This study examined the validity of the PAM relative to the Actigraph, using indirect calorimetry as reference. High correlations for the PAM accelerometer with indirect calorimetry for treadmill walking ($r^2 = 0.93$) and stair walking were found ($r^2 = 0.74$). These correlations were slightly higher, compared with the correlations for the Actigraph with indirect calorimetry, $r^2 = 0.82$ and 0.64 , respectively. The observed correlations for the PAM and Actigraph during walking are high compared with previous reports of accelerometers, where correlations (r^2) were found ranging from 0.48 to 0.88 (Melanson & Freedson, 1995; Freedson et al., 1998; Nichols et al., 2000; Welk et al., 2000; Brooks et al., 2005).

Furthermore, the PAM showed a mean error score (measured EE by indirect calorimetry minus predicted EE by accelerometer) for treadmill walking of 2.2 MET. Although this indicates that the PAM does not give an accurate estimation of EE for both activities, the results for treadmill walking were comparable with the mean error scores of the Actigraph by Freedson (2.3 MET), Hendelman (2.2

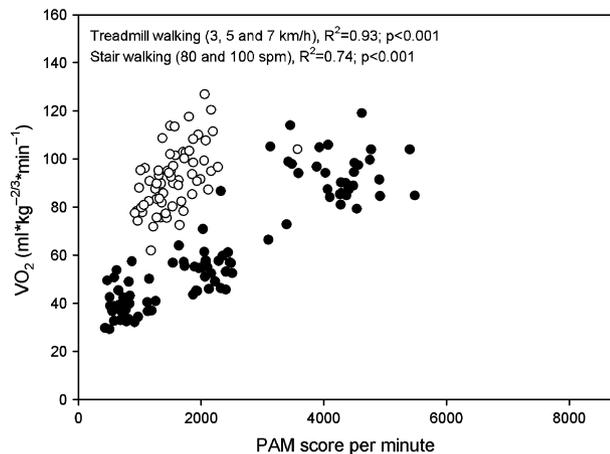


Fig. 3. The relation between the Cosmed (VO_2) and the Personal Activity Monitor (PAM) accelerometer (PAM score per minute) for treadmill walking and stair walking.

MET) and Crouter (2.1 MET). The higher mean error score for stair walking (6.3 MET) displays the underestimation relative to the measured EE. Lower mean error scores for stair walking were found for the Actigraph regression equations of Freedson (5.2 MET), Hendelman (5.0 MET) and Crouter (2.6 MET). These results imply that the PAM and Actigraph should not be used to predict EE in free-living conditions, instead using these instruments only to assess patterns of physical activity.

The underestimation of predicted EE by both the accelerometers in this study was quite distinct and larger than in the leading EE validation studies (Freedson et al., 1998; Bassett et al., 2000; Hendelman et al., 2000; Crouter et al., 2006) of the Actigraph. In these studies, the VO_2 values of each activity were divided by the standard (70 kg, 40-year-old male) value for resting VO_2 of 3.5 mL/kg/min (Jette et al., 1990). In this study, we chose for a more accurate approach to determine the MET per activity by dividing the VO_2 values of each activity by the individual resting metabolic rate (RMR) based on a recent study of Byrne et al. (2005) which showed that the 1-MET value of 3.5 mL/kg/min overestimates the actual resting VO_2 value on average by 35%. Even though we measured resting VO_2 during a 10-min rest period in sitting position instead of the supine position, it is reasonable to speculate that this resting VO_2 is more accurate than the standard 3.5 value (Strickland & Uliaszek, 1990; Byrne et al., 2005). Furthermore, the average VO_2 in rest (2.6 ± 0.4 mL/kg/min) found in Byrne's study (Byrne et al., 2005), including 642 women and 127 men, was comparable with the average resting VO_2 observed in our study (2.6 ± 0.9 mL/kg/min).

The relatively high correlation between the output of the PAM and Actigraph accelerometer during treadmill walking ($r^2 = 0.95$) and stair walking

Concurrent validity of the PAM accelerometer

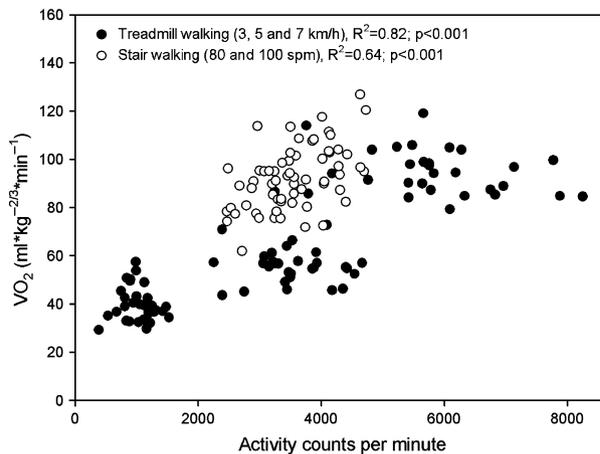


Fig. 4. The relation between the Cosmed (VO_2) and the Actigraph accelerometer (Activity counts per minute) for treadmill walking and stair walking.

($r^2 = 0.65$) demonstrates a comparable way of assessing bodily movements. However, when the counts were converted to METs to compare EE, a difference in absolute MET scores was found for both activities. This underestimation of the PAM relative to the Actigraph accelerometer is largely caused by the different regression equations used but may also be explained by a difference in frequency optimum of the accelerometers (Chen & Bassett, 2005). The Actigraph detects accelerations from 0.05–2.0 G and is band limited with a frequency response from 0.25 to 2.5 Hz, whereas the PAM has its optimum of sensitivity from 2 to 7 Hz. The frequency of stair walking at 80 and 100 s.p.m. corresponds to 1.3 and 1.6 Hz, which is outside the frequency optimum of the PAM. This could also explain the greater mean error of the PAM for walking at 3 km/h (1.2 Hz), compared with walking at a speed of 5 (2 Hz) and 5 km/h (2.8 Hz). This hypothesis would imply that the PAM has difficulties assessing physical activities with lower frequency movements such as very slow walking and ambulant household activities and seems therefore more suitable to monitor moderate to vigorous physical activity behavior.

A high test–retest reliability of the PAM at 3 Hz was found (ICC = 0.80), which is similar to the range of values reported previously for the CSA (Metcalf et al., 2002) and Tritrac (Powell et al., 2003) using motorized vibration tables. Additionally, compared with previous reliability studies (Metcalf et al., 2002; Powell et al., 2003) low intra-instrument (1.5%) and inter-instrument (4.4%) CV's were found. These intra- and inter-instrument CV's of the PAM can be considered as good (Metcalf et al., 2002).

Walking speed is enforced when walking on a treadmill. This enforcement may differ in its impact on accelerometer and oxygen uptake scores. Therefore, the participants were asked also to walk up and

Table 3. METs from indirect calorimetry and differences in energy expenditure of indirect calorimetry minus the energy expenditure estimates of the PAM and Actigraph for treadmill walking and stair walking

| Activity | Measured MET | Cosmed minus PAM | | Cosmed minus Actigraph (Freedson's equation) | | Cosmed minus Actigraph (Hendelman's equation) | | Cosmed minus Actigraph (Crouter's equation) | |
|-----------------------------|--------------|------------------|------------|--|------------|---|------------|---|-------------|
| | Mean (SD) | Mean Δ | 95% CI | Mean Δ | 95% CI | Mean Δ | 95% CI | Mean Δ | 95% CI |
| Walking at 3 km/h | 4.02 (1.31) | 1.91 | 1.39; 2.43 | 1.77 | 1.29; 2.25 | 0.68 | 0.20; 1.16 | 0.13* | -0.35; 0.64 |
| Walking at 5 km/h | 5.66 (1.69) | 1.74 | 1.11; 2.38 | 1.46 | 0.79; 2.12 | 1.33 | 0.68; 1.97 | 1.85 | 1.20; 2.49 |
| Walking at 7 km/h | 9.71 (3.79) | 3.02 | 1.73; 4.32 | 3.68 | 2.23; 5.12 | 4.45 | 3.02; 5.88 | 4.46 | 3.01; 5.90 |
| Stair walking at 80 s.p.m. | 8.56 (2.80) | 5.76 | 4.74; 6.79 | 4.58 | 3.56; 5.59 | 4.33 | 3.32; 5.34 | 2.10 | 1.08; 3.11 |
| Stair walking at 100 s.p.m. | 10.26 (3.53) | 6.74 | 5.44; 8.03 | 5.73 | 4.47; 7.00 | 5.75 | 4.48; 7.02 | 3.17 | 1.90; 4.44 |

All means and differences are expressed in MET.

MET, measured gross energy expenditure; PAM, Personal Activity Monitor, SD, standard deviation; 95% CI, 95% Confidence Interval.

* P > 0.05.

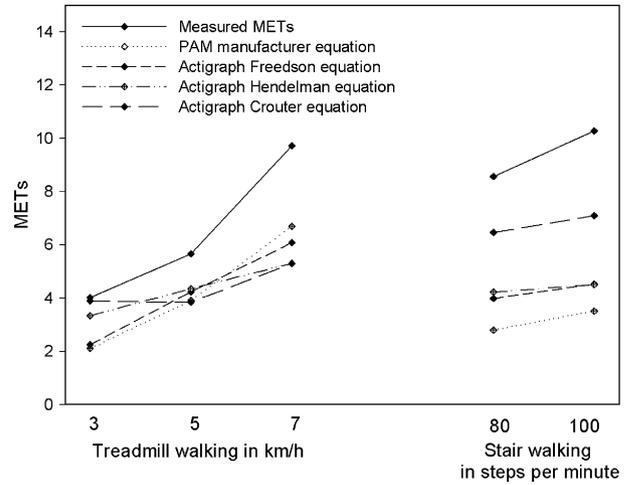


Fig. 5. Measured and estimated energy expenditure (MET) for treadmill walking and stair walking.

down a 25-m hallway at their own pace. An average self-determined walking speed of 5 km/h was found (data not shown), which is comparable with findings of a recent study (Brooks et al., 2005). No significant differences were found, nor for the actual EE neither the estimated EE by the PAM and Actigraph, when walking at ones own pace and treadmill walking at 5 km/h. Hence, the results found for walking on a treadmill (at 5 km/h) seem applicable for walking in free-living conditions.

Several studies found that the Actigraph underestimates EE in free-living conditions (Welk et al., 2000; Ekelund et al., 2001; Leenders et al., 2001). This is probably due to the large variability in acceleration counts and minute-to-minute variation for lifestyle activities other than walking. The results for the two-regression models of Crouter emphasize that the accuracy of the EE estimation from activity counts can be improved, using a walking or a lifestyle equation based on the variation in activity counts. However, in our study walking at 3 km/h showed the best results for EE estimation with the lifestyle equation. The MET values produced by the Actigraph equations differed per activity, because each equation is based on different activities. For that reason (overestimation), and considering the limitations of the accelerometer, the estimation of daily EE could be improved by using activity dependent regressions, instead of solely one for 24 h EE.

Differences in activity counts between subjects can partially be attributed to placement of the accelerometers on the hip. A study of Metcalf et al. (2002) showed that the angle in which the Actigraph was worn, had a lowering effect of 6% on the Actigraph score when angled at 15° and even 29% when angled at 45°. In this study, the positioning of the accelerometers was checked, before and in-between the activities. However, individual differences in locomotion

tion patterns may, during the activities, have resulted in differences in the angle in which the accelerometers were worn. Nevertheless, the output from both accelerometers was consistent during the activities, which suggest that the variation between subjects is more due to the positioning itself than the change of positioning. Most study participants were normal weight which reduces the risk of an effect due to the angle. Other sources of variation between subjects for treadmill walking could be ascribed to differences in step frequency (Brage et al., 2003), however, this was not assessed in this study.

Limitations of the study are that the results were found under laboratory conditions and may not be generalizable to field-based activities. Furthermore, the Actigraph used was purchased new a few months before the study and was calibrated by the manufacturer. However, not calibrating the Actigraph before the tests can be considered as a limitation of our study.

In conclusion, the correspondence between the PAM and the Actigraph results suggests that both devices produces similar estimates of bodily movement in fit, normal weight young adults. The PAM is a valid device to rank subjects in EE, but it underestimates EE by 36% during treadmill walking and 66% during stair walking. Both the PAM accelerometer as well as the Actigraph underestimate EE of treadmill walking and stair walking. The test–retest reliability of the PAM was high and comparable with the Actigraph. Therefore, the PAM will most likely underestimate physical activity over a 24-h period in field measurements by a substantial amount, like the Actigraph accelerometer. The PAM, however, can be useful in collecting objective data to monitor habitual physical activity and to discriminate between individuals who differ in activity levels. Further research is needed to assess the reliability and validity of the PAM accelerometer in field-based assessments of physical activity.

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Perspectives

Substantial improvement in public health is possible through encouragement of physical activity in inactive groups. To achieve public health benefits, we are faced with the task to establish awareness of physical (in)activity and encourage, but also enable people to include more physical activity in their daily life. The PAM concept combines the objective measurement of physical activity by means of an accelerometer with a web-based tailored physical activity advice. By providing physical activity feedback on the physical activity level, this device may increase awareness and hence stimulate the recommended physical activity. In this study, the PAM accelerometer shows a high test–retest reliability and the correlation between the PAM and indirect calorimetry was at least as good as the correlation between the MTI Actigraph and indirect calorimetry. Hence, this study indicates that the PAM can be used for monitoring purposes as well as a tool to stimulate physical activity. A combined tool could benefit health promotion professionals in providing inactive subjects with immediate feedback about their physical activity level in their present situation.

Key words: physical activity, energy expenditure, reliability measurement, treadmill walking, stair walking.

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Sloutmaker et al.

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