

JEPonline
Journal of Exercise Physiologyonline

Official Journal of The American
Society of Exercise Physiologists (ASEP)

ISSN 1097-9751

An International Electronic Journal
Volume 7 Number 3 June 2004

Equipment Testing and Validation

COMPARISON OF TWO PHYSICAL ACTIVITY MONITORS DURING A 1-MILE WALKING FIELD TEST.

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ABSTRACT

COMPARISON OF TWO PHYSICAL ACTIVITY MONITORS DURING A 1-MILE WALKING FIELD TEST. **Patricia A. Hageman, Joseph F. Norman, Kurt L. Pfefferkorn, Nicholas J. Reiss and Kimberly A. Riesberg.** JEPonline 2004;7(3):102-110. This study assessed the relationship of two different accelerometer devices to oxygen consumption (VO_2) during the performance of the Rockport Fitness Walking Test under field conditions. Forty-three healthy subjects (28 female, 15 male) aged 40-59 years (mean = 52 ± 7.7 years) participated in the study. Energy expenditure was measured simultaneously using the Caltrac and BioTrainer accelerometers and VO_2 measured with the AeroSport KB-1 system. Pearson r correlations were calculated to determine the relationships between the measures. Accuracy of the accelerometers to VO_2 was determined using one-way repeated measures ANOVA, Bland-Altman plots and the SEE. Significant correlations ($p < 0.004$) were found between the energy expenditure measures obtained by 1) VO_2 and the Caltrac ($r = 0.67$), 2) VO_2 and the BioTrainer ($r = 0.43$) and 3) Caltrac and BioTrainer accelerometers ($r = 0.70$). However, both accelerometers overestimated caloric expenditure by about 50% with a large SEE noted; 14.0 Kcals and 16.9 Kcals for the Caltrac and BioTrainer accelerometers respectively. Though our results show fair to moderate correlations ($r = 0.43 - 0.67$) between the accelerometers and VO_2 during level walking under field conditions, the accuracy of the accelerometers in predicting energy expenditure was poor. Accelerometers may prove to be an inexpensive and reliable means of tracking client progress, however until better activity specific regression equations are established, practitioners must be aware that accelerometers may not be accurate in estimating energy expenditure.

Key Words: Oxygen consumption, Biotrainer, Caltrac, Accelerometry, Field testing

INTRODUCTION

With the incidence of obesity and a sedentary lifestyle increasing among the United States population, the need for an accurate yet inexpensive assessment of energy expenditure has become a primary research priority for determining the effectiveness of physical activity interventions (1). As current public health guidelines focus on

walking and other related forms of lifestyle physical activity as a means of promoting health, accelerometers seem attractive as a means of monitoring physical activity and tracking client progress (2). Accelerometers use advanced motion sensing technologies to record movement. They are small in size, inexpensive, and do not interfere with normal movements. Several of these devices offer options of producing detailed reports of the estimated caloric expenditure occurring over extended periods of time that can be downloaded easily to a personal computer.

Researchers have attempted to validate various accelerometer units in a laboratory setting, using concurrent measures of energy expenditure obtained from the accelerometers as compared to oxygen consumption. Most validity studies of various models of accelerometers have investigated treadmill walking. The findings suggest that the relationship between accelerometers and energy expenditure during treadmill walking using a level grade at various speeds is linear ($r = 0.78 - 0.92$) (3,4,5). However, depending on the type and intensity of the physical activity being measured, the laboratory studies demonstrate that accelerometer units typically overestimate energy expenditure during walking, but underestimate energy expenditure during activities such as stepping, cycling or arm ergometry (3,4,5).

Currently, research comparing energy expenditure obtained by accelerometers with indirect calorimetry in a field setting is limited. Of the studies using this type of comparison, correlations found of various field measures of physical activity energy expenditure by accelerometers as compared with indirect calorimetry were lower. For example, Bassett et al. (6) reported correlations of $r = 0.33-0.62$ between two motion sensors and indirect calorimetry during lifestyle activities such as yardwork, housework, conditioning and recreational events. Campbell et al. (7) reported Tritrac accelerometer to energy expenditure correlations of $r = 0.57$ for walking and $r = 0.67$ for jogging completed in the field by young women, but lower correlations for arm ergometry ($r = 0.29$). Welk et al. (8) also reported a correlation of $r = 0.55$ between three accelerometers and energy expenditure during outdoor and indoor household activities.

In these field studies, accelerometers were also found to overestimate the energy expenditure of walking when compared to indirect calorimetry measures (6,7,8). Campbell et al. (7) suggested that activity specific linear regression equations may be needed to improve the measurement on energy expenditure in the field.

The purpose of this study was to assess the relationship of two different accelerometer devices to oxygen consumption obtained during the performance of the Rockport Fitness Walking Test under field conditions. Walking was selected as the physical activity because it is most frequently prescribed for promoting cardiovascular and pulmonary fitness. Walking is also the most common activity performed by adults for a variety of reasons including ease of performance, opportunity, and no expensive equipment is required (9). We hypothesized that the use of accelerometry-based physical activity monitors would be a valid method for estimating energy expenditure in the field during the performance of the Rockport Fitness Walking Test.

METHODS

Subjects

Middle aged or older adults were the population of interest because individuals in that age category are likely to demonstrate declines in fitness and/or symptoms of chronic diseases. Additionally, many individuals in this age category are referred for exercise prescriptions which include walking as part of a fitness or rehabilitation program. Forty-three healthy subjects (28 female, 15 male) aged 40-69 years from the university campus and surrounding community voluntarily consented to participate in this study. This study was approved by the University's Institutional Review Board, and written informed consent was obtained from each subject prior to participation. Subjects were eligible to participate provided they answered "no" to all questions on the physical activity readiness questionnaire (PAR-Q), or if they obtained physician clearance (10,11).

Procedures

Measurements of height and weight were obtained on each subject using a Detecto[®] Beam Medical Scale with height rod (Cardinal Scale Mfg. Co., Webb City, MO). Subjects wore light clothing and removed their shoes prior to weighing and having their heights measured. The percentage of body fat of each subject was obtained by the bioelectrical impedance method using the Biodynamics[®] Model 310e Body Composition Analyzer (Biodynamics Corp., Seattle, WA). To reduce the measurement errors associated with assessing body composition by the bioelectrical impedance method subjects were advised to a) abstain from eating or drinking within four hours of the assessment, b) avoid moderate to vigorous physical activity within 12 hours of the assessment, c) void completely before the assessment, d) abstain from alcohol consumption within 48 hours of the assessment, and e) ingest no diuretic prior to the assessment unless prescribed by their physician. Manufacturer's testing guidelines and protocol were followed for all testing procedures.

Subjects were familiarized with the study protocol and allowed to acclimate to the monitoring equipment prior to testing. Subjects were fitted with a Polar heart rate monitor (Polar Electro Inc. Woodbury, NY) for surveillance of heart rate responses at rest and during testing. Oxygen consumption (VO_2) was measured by indirect calorimetry with an AeroSport Model KB1-C portable metabolic system (AeroSport Inc., Ann Arbor, MI). The Caltrac (Muscle Dynamics, Torrance, CA) and BioTrainer (IM Systems, Baltimore, MD) accelerometers were clipped to a waist belt and worn simultaneously during testing. The Caltrac was positioned at the anterior axillary line on the subject's right side and the BioTrainer was positioned just medial to the Caltrac (Figure 1) as the BioTrainer had previously been found to be less sensitive to body positioning (8).

The testing procedure began with a seven-minute rest period in a sitting position after which baseline measures of each subject's heart rate and VO_2 were obtained and recorded. Following the initial rest period subjects performed a 1-mile walk, around a level indoor track, according to the Rockport Fitness Walking Test guidelines. The subjects were instructed to walk as fast as they comfortably could over the 1-mile distance. Prior to the start of the test the timer and both accelerometers were zeroed and the AeroSport KB1-C data were recorded. At the completion of the walk, the walk time and a 15-s pulse were taken according to the Rockport Fitness Walking Test protocol. Values from the accelerometers and AeroSport KB1-C were also recorded.

Indirect Calorimetry

Oxygen consumption (L/min) was measured by indirect calorimetry with an AeroSport Model KB1-C portable metabolic system. The AeroSport KB1-C has been validated for measurements of VO_2 during moderate exercise in a previous study (12). The AeroSport KB1-C also contains a heart rate receiver that simultaneously records heart rate from the Polar heart rate monitor transmitter worn by the subjects. Subjects were fitted with a nasal and mouth facemask (Hans-Rudolph Inc., Kansas City, MO), which was connected to the AeroSport KB1-C. A medium flow pneumotach setting was used for all testing. Prior to testing each subject the AeroSport KB1-C was gas and flow calibrated according to manufacturer's specifications. The AeroSport KB1-C unit was secured by a harness to the back of the subjects as to not interfere with their walking.

Physical Activity Monitors

The Caltrac is a uni-axial (senses one axis) accelerometer that uses a piezoceramic cantilevered beam to



Figure 1. Photograph of a subject performing the walk test wearing the AeroSport KB1-C unit harnessed to his back and with the Caltrac and BioTrainer accelerometers clipped to a belt around the subject's waist.

produces a voltage in response to vertical accelerations and decelerations. This voltage is then “scaled” to estimate the energy expenditure of the activity (13). The acceleration measurement is converted into electrical signals and displayed as a digital readout representing a measurement of energy expenditure. Before use, the subjects’ weight, height, age, and sex were entered into the Caltrac accelerometer according to the product manual. The Caltrac uses this data to formulate kilocalories expended during activity.

The Caltrac was selected for study because it is a relatively inexpensive accelerometer that has been studied previously. Laboratory studies demonstrate that the Caltrac offers excellent inter-instrument and inter-session reliability (5,14). Significant correlations ($r = 0.91$) were previously found between measures obtained by the Caltrac and oxygen uptake during treadmill walking in adults (4,15). Researchers have reported the Caltrac to be sensitive to changes in speed during treadmill walking, but not changes in grade (4). Gretebeck et al. (16) compared the energy expenditure as concurrently obtained with the Caltrac and with the gold standard, “doubly labeled water”, in adult male subjects over a 7-day period and found no significant differences between the two.

The BioTrainer accelerometer contains a piezoelectric sensor that is positioned at a 45-degree angle from vertical, allowing the unit to detect a portion of both vertical and horizontal acceleration of the body during physical activity. A high-speed sampling method allows immediate real-time readouts. The data obtained from the BioTrainer is reported as activity “counts”. The activity counts were converted into kilocalories (Kcal) expended using the equation provided by the manufacturer: divide the subject’s body weight (in pounds) by 150 and multiply by the number of counts ($Kcal = [weight/150] \times counts$). The BioTrainer was selected for study because it offers features of data storage for prolonged periods of time and permits downloading of data to a personal computer.

The literature on the BioTrainer unit is limited. When energy expenditure measures were compared between the BioTrainer and VO_2 under laboratory and field conditions, the correlation was higher for treadmill activity ($r = 0.85-0.88$) than with lifestyle activity ($r = 0.59$) (8). Under laboratory conditions, the BioTrainer tended to overestimate the energy expenditure significantly whereas it underestimated the lifestyle activities performed in the field (8).

A pilot study, conducted by the investigators, found both the Caltrac and BioTrainer accelerometers demonstrated a high test-retest reliability (ICC’s > 0.96) when tested on individuals performing a 1-mile walk, using the Rockport Fitness Walking Test protocol, scheduled 1 week apart.

Statistical Analyses

Based on preliminary statistical calculations for using correlation analyses, with a power of 0.80 and an alpha of 0.05, a minimum of 39 subjects was determined to be necessary for this study.

Descriptive statistics were used to compile demographic data. Pearson product moment correlation coefficients were calculated to determine the relationships between energy expenditure as measured by the AeroSport KB1-C (VO_2) and the two accelerometers. The strength of the Pearson correlation was determined by calculating the coefficient of determination (r^2). The accuracy of the accelerometers with the VO_2 measures was assessed using one-way repeated measures ANOVA. Additionally, Bland-Altman plots (17) were used to assess agreement between the accelerometers and VO_2 estimates of energy expenditure and the standard error of the estimate (SEE) was calculated to assess the predictive accuracy of the accelerometers with VO_2 estimates of caloric expenditure. For all tests the level of significance was set at $P < 0.05$.

RESULTS

Demographic data are summarized in Table 1. Table 2 displays the correlation results. Based on the Pearson r values (18), moderate to fair

Table 1. Subject characteristics. (N=43)

<i>Characteristic</i>	<i>Mean ± SD</i>
<i>Age (yrs)</i>	52.0 ± 7.7
<i>Weight (kg)</i>	75.4 ± 14.6
<i>Height (cm)</i>	167.6 ± 9.1
<i>% Body Fat</i>	27.2 ± 6.8

correlations were found between the measures obtained by 1) VO₂ and the Caltrac, 2) VO₂ and the BioTrainer, and 3) between the Caltrac and BioTrainer. The strength of the relationship between VO₂ and the BioTrainer was noticeably less than for the Caltrac.

Table 2. Correlation Coefficients for Energy Expenditure Estimates Among Devices

Instruments	Pearson Correlation Coefficient (r)	P-value	Coefficient of Determination (r ²)
<i>AeroSport to Caltrac</i>	0.67	< 0.001	0.45
<i>AeroSport to BioTrainer</i>	0.43	< 0.004	0.18
<i>Caltrac to BioTrainer</i>	0.70	< 0.001	0.49

One-way repeated measures ANOVA demonstrated significant differences in the estimated Kcals expended between the Caltrac and VO₂ and between the BioTrainer and VO₂. No significant differences in caloric estimates were noted between the Caltrac and BioTrainer units. Both accelerometers overestimated the caloric expenditure by nearly 50% compared to VO₂ caloric estimates. For comparison of energy expenditure in Kcals with the accelerometers (Figure 2), VO₂ during ambulation was converted to Kcals by multiplying the oxygen uptake (L/min) by 5.0 Kcal/L O₂ (19).

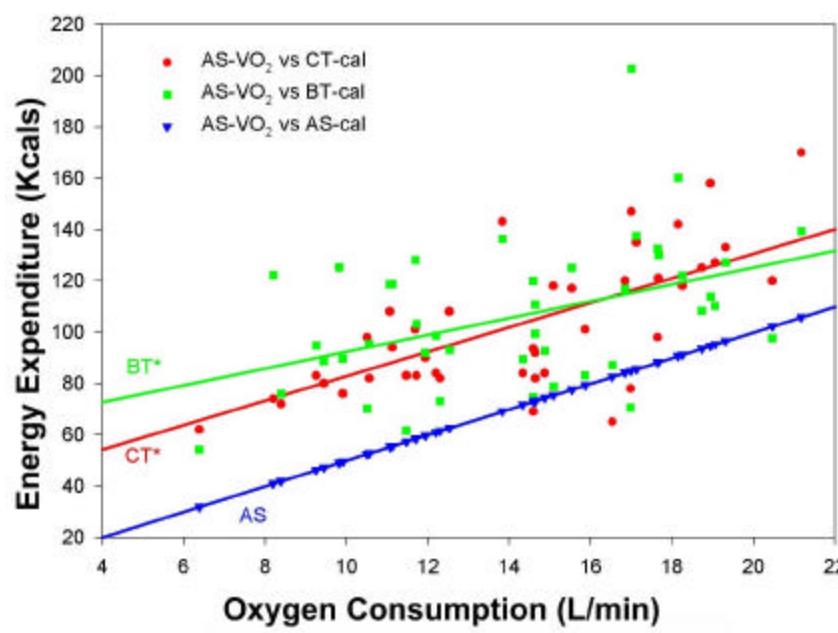


Figure 2. Scatterplot with the lines of best fit for the Caltrac (CT) and BioTrainer (BT) accelerometers compared to oxygen uptake associated with performing the Rockport Fitness Walking Test. The AeroSport (AS) data and line of best fit (blue) are plotted as a reference for comparison. (* significantly different from AS, P < 0.001)

The Bland-Altman plots for each accelerometer are illustrated in Figures 3 and 4. The average difference between the AeroSport and Caltrac measures (Figure 3) was -31.9 Kcals (solid line on the plot), with a standard deviation of 19.9 Kcals. With good agreement the average difference should be near zero, and in this case 93% of differences are below zero. A 95% confidence interval for the average difference is -37.8 to -26.0 Kcals, which does not include zero. The Bland-Altman limits of agreement (in dashed lines) are -71.7 to 7.9 Kcals. So, it is reasonable to expect the AeroSport measurement to be 71.7 Kcals less to 7.9 Kcals more than the Caltrac measurement (95% confidence interval of observations). The average difference between the AeroSport and BioTrainer measures (Figure 4) was -35.2 Kcals (solid line on the plot), with a standard deviation of 26.1 Kcals. Again, with good agreement the average difference should be near zero, but in this case 95% of

differences are below zero. A 95% confidence interval for the average difference is -43.0 to -27.4 Kcals, which does not include zero. The Bland-Altman limits of agreement (in dashed lines) are -87.4 to 16.9 Kcals. So, it is reasonable to expect the AeroSport measurement to be 87.4 Kcals less to 16.9 Kcals more than the BioTrainer measurement (95% confidence interval of observations). These Bland-Altman plots illustrate the discrepancy between the measures. In addition, the SEE values for the predictive accuracy of VO_2 to Caltrac and VO_2 to BioTrainer measures of caloric expenditure were also fairly large at 14.0 Kcals and 16.9 Kcals respectively. So, even if the average differences were not unacceptable, the range of reasonable estimates for the difference between measurements is wide given the magnitude of the measurements.

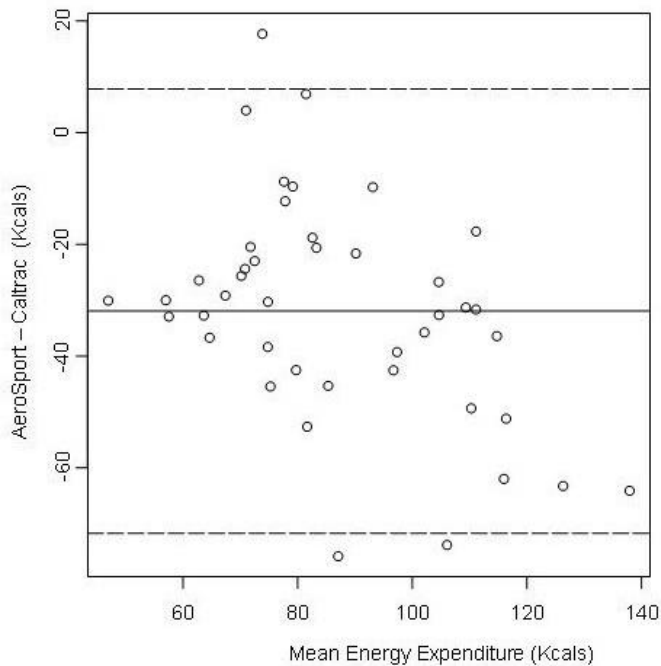


Figure 3. Bland-Altman plot depicting error scores (AeroSport - Caltrac) for the Caltrac accelerometer. The solid line represents the mean difference, and the dashed line represents the 95% confidence interval of the observations.

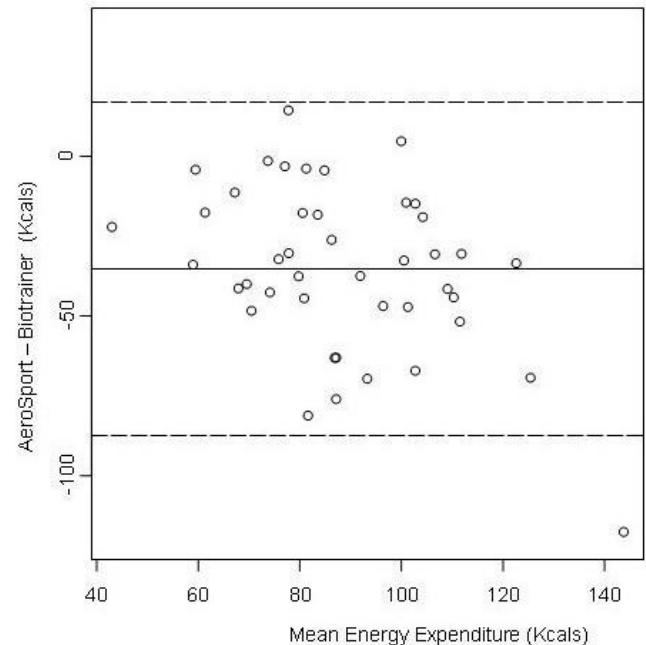


Figure 4. Bland-Altman plot depicting error scores (AeroSport - Biotrainer) for the Biotrainer accelerometer. The solid line represents the mean difference, and the dashed line represents the 95% confidence interval of the observations.

DISCUSSION

This study sought to examine the ability and accuracy of the Caltrac and BioTrainer accelerometers to measure energy expenditure, compared to indirect calorimetry, during the performance of the Rockport Fitness Walking Test conducted under field conditions. Various accelerometers have been validated under laboratory testing conditions with such activities as treadmill walking or running, cycling, or stair climbing. Under laboratory conditions the relationship between various accelerometers and VO_2 has appeared to be linear during level walking with high correlations noted between accelerometry units. However, the real value of accelerometers would be their ability to accurately estimate energy expenditure in the field.

Our results, obtained under field conditions, support a correlational relationship between accelerometry and VO_2 estimates of energy expenditure, however, the correlations we found were lower than those reported under laboratory conditions. Our correlations between the Caltrac and VO_2 , and BioTrainer and VO_2 for middle-aged and older adults during walking were $r = 0.67$ and $r = 0.43$ respectively. The correlation between the two accelerometers was $r = 0.70$, indicating they responded fairly similar to accelerations produced during walking.

Though the accelerometers tested demonstrated moderate positive correlations with VO_2 estimates of energy expenditure, we found the accuracy of these two accelerometers to be quite poor in determining energy expenditure associated with performing a one-mile walk test. Both accelerometers overestimated energy expenditure by nearly 50%, although this was consistent with previous findings reported under both laboratory and field settings with various models of accelerometers (4,8,15). The wide variations in our data as illustrated by the Bland-Altman plots and the large SEE brings into question the accuracy of these two accelerometers, based on the manufacturers' regression equations, for estimating energy expenditure of walking under field conditions.

Campbell et al. (7) reported a correlation of $r = 0.57$ between VO_2 estimates of energy expenditure and a tri-axial accelerometer, the Tritrac, during level walking on a track with young women. Their correlation was not dissimilar to our findings and though a SEE was not reported, a 31% difference in mean energy expenditure (Kcal/min) was noted with the Tritrac accelerometer overestimating energy expenditure compared to VO_2 estimates (7). In a study by Bassett et al. (6), they compared the calculated metabolic equivalents (METs) from VO_2 and Caltrac measures obtained during brisk track walking. The Caltrac overestimated energy expenditure by approximately 32% compared to the mean VO_2 estimates while still reporting a correlation between these two measures of $r = 0.58$ (6). In addition to the Caltrac accelerometer, Bassett et al. compared another uniaxial accelerometer, the CSA model 7164, during the same testing procedure as above. For comparison they evaluated the manufacturer's regression equation and a regression equation developed by Hendelman et al. (20) for the CSA accelerometer. The calculated energy expenditure from both regression equations were correlated with the calculated VO_2 MET estimates with an $r = 0.62$ for each unit (6). However, using the manufacturer's equation the CSA accelerometer overestimated MET level by approximately 26%, while using the Hendelman et al. equation there was no mean difference in calculated energy expenditure between the CSA accelerometer and VO_2 estimates. In Hendelman et al.'s study (20) they developed a regression equation for the Tritrac accelerometer in addition to the CSA accelerometer specific for walking. The calculated SEE reported for the CSA was 0.87 and for the Tritrac 0.62. Thus it appears that activity specific regression equations can significantly improve the accuracy of various accelerometers to estimate energy expenditure.

Welk et al. (21) recently reported on a regression equation they developed for predicting energy expenditure from the BioTrainer accelerometer which incorporated raw counts from the BioTrainer unit and subject's body weight. Testing was performed with adults on a treadmill at three different speeds on the level. The R^2 for the equation was 0.91 and the SEE was 1.24 (Kcal/min) (21). Their findings represent a significant improvement in the predictive value of the BioTrainer especially in comparison to our findings which were based on the manufacturer's formulas and conducted under field conditions.

Our results show that using the Caltrac and BioTrainer accelerometers to measure energy expenditure during the Rockport Fitness Walking Test has some limitations, namely the accelerometers tended to overestimate caloric expenditure and the degree of measurement error was large. This may partially be reflective of the variable intensity at which subjects walked and differences in gait patterns since the accelerometers are dependent upon movement to register energy expenditure. In addition, the proprietary equations utilized by the manufacturers of the accelerometers are not necessarily specific to walking which may contribute to the over estimations of energy expenditure during the performance of the walking tests. Our study on middle-aged individuals, though important for this age group, limits the application of our findings in evaluating those individuals younger than 40 years of age or older than 69 years of age performing the Rockport Fitness Walking Test under field conditions. The findings from this study did not support our original hypothesis that the accelerometers would be a valid method for estimating energy expenditure in the field during the performance of the Rockport Fitness Walking Test. Clearly in order to use the Caltrac or BioTrainer accelerometers to reasonably estimate energy expenditure during the Rockport Fitness Walking Test, a larger validation study specifically designed to develop an appropriate regression equation for use with the Rockport Fitness Walking Test is needed. If developed, such an equation would allow for more accurate assessments of energy

expenditure during the conduction of this field test and add an additional objective measure in tracking individuals' progress in their exercise programs.

CONCLUSIONS

Our results show a fair to moderate correlations ($r = 0.43 - 0.67$) between the Caltrac and BioTrainer accelerometers and indirect calorimetry as measured under field conditions. However, the predictive accuracy of the accelerometers was poor. Better activity specific regression equations need to be developed for these accelerometers to enhance the usefulness of these devices in estimating energy expenditure associated with the Rockport Fitness Walking Test. Physical activity accelerometers may prove to be a useful and inexpensive adjunct means for practitioners to track client progress because of their reliability; however, practitioners must be aware that accelerometers may not be accurate in estimating energy expenditure in the field setting without the development of better activity specific regression equations..

ACKNOWLEDGEMENTS

The authors would like to thank Lynette M. Smith, M.S., Statistical Coordinator in the Department of Preventive and Societal Medicine, University of Nebraska Medical Center, for her assistance with the statistical analysis.

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