# Estimation of energy expenditure using CSA accelerometers at hip and wrist sites

ANN M. SWARTZ, SCOTT J. STRATH, DAVID R. BASSETT, JR., WILLIAM L. O'BRIEN, GEORGE A. KING, and BARBARA E. AINSWORTH

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**ABSTRACT**

SWARTZ, A. M., S. J. STRATH, D. R. BASSETT, JR., W. L. O'BRIEN, G. A. KING, and B. E. AINSWORTH. Estimation of energy expenditure using CSA accelerometers at hip and wrist sites. *Med. Sci. Sports Exerc.,* Vol. 32, No. 9, Suppl., pp. S450–S456, 2000. **Purpose:** This study was designed to establish prediction models that relate hip and wrist accelerometer data to energy expenditure (EE) in field and laboratory settings. We also sought to determine whether the addition of a wrist accelerometer would significantly improve the prediction of EE (METs), compared with a model that used a hip accelerometer alone. **Methods:** Seventy participants completed one to six activities within the categories of yardwork, housework, family care, occupation, recreation, and conditioning, for a total of 5 to12 participants tested per activity. EE was measured using the Cosmed $K4b^2$ portable metabolic system. Simultaneously, two Computer Science and Applications, Inc. (CSA) accelerometers (model 7164), one worn on the wrist and one worn on the hip, recorded body movement. Correlations between EE measured by the Cosmed and the counts recorded by the CSA accelerometers were calculated, and regression equations were developed to predict EE from the CSA data. **Results:** The wrist, hip, and combined hip and wrist regression equations accounted for 3.3%, 31.7%, and 34.3% of the variation in EE, respectively. The addition of the wrist accelerometer data to the hip accelerometer data to form a bivariate regression equation, although statistically significant ($P = 0.002$), resulted in only a minor improvement in prediction of EE. Cut points for 3 METs (574 hip counts), 6 METs (4945 hip counts), and 9 METs (9317 hip counts) were also established. **Conclusion:** The small amount of additional accuracy gained from the wrist accelerometer is offset by the extra time required to analyze the data and the cost of the accelerometer. **Key Words:** EXERCISE, PHYSICAL ACTIVITY, OXYGEN UPTAKE, MOTION SENSOR

The estimation of energy expenditure (EE) is of interest in epidemiologic research. Many epidemiologic studies have relied on the use of self-report data to arrive at an estimate of EE. However, the use of self-report data has inherent limitations and sources of error, such as recall bias (7). Consequently, investigators continue to seek improved methods of estimating EE in epidemiologic studies.

The small size, ease of use, and objectivity of accelerometers make them a promising tool to assess EE. The Computer Science and Applications, Inc. (CSA; Shalimar, FL) accelerometer (model 7164) is a lightweight (42 g) and small (5.08 × 4.06 × 1.52 cm) lithium battery-powered accelerometer designed to recognize and record acceleration and deceleration of human movement (4). This uniaxial accelerometer records accelerations of magnitudes ranging from 0.05 to 2 G and frequencies of 0.25 to 2.5 Hz, thereby filtering out movements not made by the subject, such as vibrations. All acceleration data are stored in memory according to the user-specified time interval (epoch), and the count data in each epoch represents the intensity of the activity performed. The internal real-time clock of the CSA allows data to be analyzed over intervals as short as 1 s. In addition, the CSA has the ability to store 22 consecutive days of data at 60-s intervals. A complete technical description of CSA model 7164 accelerometer has been published elsewhere (15).

The CSA accelerometer has been shown to be a valid tool in assessing EE in college-aged men and women walking and running on a treadmill (9) and middle-aged adults walking outdoors (17). In addition, the CSA accelerometer has shown reasonable agreement with heart rate in assessing physical activity of children in both laboratory (5,14) and field settings (4,6).

Regression equations have been developed to predict the metabolic cost of physical activities from CSA counts. One such equation was developed to predict the metabolic cost of walking and jogging on a flat surface from CSA model 7164 hip counts (2). Other regression equations were developed to predict the energy cost of walking and jogging based on CSA model 5032 counts from the wrist, hip, and ankle (9). Furthermore, a regression equation has been developed to estimate the cost of moderate intensity lifestyle activities including walking, golfing, washing windows, dusting, vacuuming, lawn mowing, and planting shrubs from CSA hip counts (3). However, tasks involving upper body movement such as ironing, washing dishes, and raking leaves may require a gross EE of 2–4 METs (1 MET = 3.5 mL $O_2 \cdot kg^{-1} \cdot min^{-1}$), even though the hip accelerometer may

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TABLE 1. Physical characteristics of participants (mean ± SD).

| Physical Characteristic | All Participants ($N$ = 70) | Men ($N$ = 31) | Women ($N$ = 39) |
|---|---|---|---|
| Age (yr) | 41 ± 15 | 41 ± 17 | 42 ± 14 |
| Height (cm) | 171.1 ± 9.4 | 178.9 ± 6.5 | 164.8 ± 6.0 |
| Weight (kg) | 76.2 ± 18.2 | 83.0 ± 18.0 | 70.7 ± 16.6 |
| BMI (kg·m$^{-2}$) | 26.0 ± 5.4 | 26.0 ± 5.9 | 26.0 ± 3.4 |

detect almost no movement. Consequently, an accelerometer worn on the wrist may be able to account for the EE associated with upper body movement involved in these types of tasks.

The purpose of this study was to establish a prediction model that relates CSA counts to EE using a combination of data from two CSA accelerometers, one worn on the wrist and one worn on the hip, in field and laboratory settings. An additional goal of this study was to determine whether the addition of an accelerometer worn on the wrist would improve the accuracy of estimating EE compared with a single accelerometer worn on the hip.

## METHODS

**Participants.** Participants were qualified to enroll in this study if they were between the ages of 19 and 74 yr, were apparently healthy, and were able to complete the assigned tasks. Eighty-one participants volunteered for this study, of which 11 were excluded from analysis owing to electronic malfunctioning of the CSA accelerometer. Therefore, 70 participants (16% African American, 1% Hispanic, 3% Asian, and 80% Caucasian), including 31 apparently healthy men (ages 41 ± 17 yr, mean ± SD) and 39 apparently healthy women (ages 42 ± 14 yr, mean ± SD), completed one to six activities. All participants were recruited from within the university and surrounding community through public postings. Each participant was informed of potential risks and benefits and signed an informed consent form approved by the University of Tennessee Institutional Review Board. Participants also completed the physical activity readiness questionnaire (PAR-Q) (13). Participants who answered yes to any of the PAR-Q questions or who were not physically able to complete the tasks were excluded from the study.

Before testing, height and weight (one layer of clothes, no shoes) were measured via a stadiometer and a standard physician's scale, respectively. The physical characteristics of the participants included in this study are listed in Table 1.

**Procedures.** Each participant performed one to six activities within one or more categories for a total of 5–12 participants tested per activity. The activities included:

- Yardwork: mowing the lawn (manual and power mowers); raking; trimming (power trimmer or "weed-eater"); gardening (pulling weeds, planting flowers).
- Occupation: walking at 67 m·min$^{-1}$ and carrying items weighing 6.8 kg; walking at 93.8 m·min$^{-1}$ and carrying items weighing 6.8 kg; loading and unloading boxes weighing 6.8 kg.
- Housework: vacuuming; sweeping and mopping; laundry; ironing; washing dishes; cooking; light cleaning (dusting, general picking up); grocery shopping with a cart.
- Family care: feeding and grooming animals; caring for small children; playing with children in the yard; playing with animals in the yard.
- Conditioning: stretching; light calisthenics; slow walking (average speed 78 m·min$^{-1}$); brisk walking (average speed 100 m·min$^{-1}$).
- Recreation: doubles tennis; golf in a two-some or four-some (carrying clubs); golf in a two-some or four-some (pulling clubs); softball.

A more complete description of all activities is available elsewhere (12).

Each activity was performed for 15 min. Before each activity, the participant was asked to sit quietly for five min as a control period. The activities were performed in the exercise physiology laboratory (occupation, conditioning), within the university grounds (recreation), at the participant's home (yardwork, housework, family care), and at a local golf course (golf) and tennis club (doubles tennis).

**Indirect calorimetry.** Each participant wore the Cosmed K4b$^2$ (Cosmed S.r.I, Rome, Italy), a portable indirect calorimetry system, while performing each activity and throughout the rest periods. The Cosmed K4b$^2$ has been shown to be a valid instrument to measure oxygen consumption for a wide range of work rates on a cycle ergometer (0–250 W) (8). The portable indirect calorimetry unit was mounted on the participant via a chest harness. A flexible face mask (Hans-Rudolph, Kansas City, MO) that covered the participant's mouth and nose was attached to a flowmeter. The face mask and adjoining flowmeter was secured to the participant via a head strap. The flowmeter is a bidirectional digital turbine and uses an opto-electric reader. A disposable gel seal (Hans-Rudolph) was placed between the face mask and the participant to provide an airtight seal to capture all expired air. The Cosmed K4b$^2$ portable metabolic system was calibrated immediately before each test session in accordance with the manufacturer's guidelines. The calibration procedure is specified elsewhere (1). After the calibration process was completed, participant characteristics (gender, age, height, and weight) were entered into the Cosmed K4b$^2$ portable system.

The Cosmed K4b$^2$ was synchronized to an external timepiece. All data from the portable Cosmed K4b$^2$ were stored in memory and directly downloaded to a Windows-based personal computer after the test was completed. Mean $\dot{V}O_2$ was calculated from the last 10 min of every activity each participant performed. The mean $\dot{V}O_2$ values (mL·kg$^{-1}$·min$^{-1}$) derived from the Cosmed K4b$^2$ were transformed into gross METs for each activity by dividing by 3.5. One kilogram was added to measured body weight for each participant to compensate for the added weight of the Cosmed unit and accelerometers worn by the individual.

**Motion sensors.** Calibration of the CSA accelerometers took place at the beginning, midpoint, and end of the study. The two CSA accelerometers were found to produce a response that met the manufacturer's standards (within ±

TABLE 2. Actual Computer Science and Applications (CSA) accelerometer counts per minute for all activities (mean ± SD).

| Activity | *N* | CSA Hip Counts | CSA Wrist Counts |
|---|---|---|---|
| Gardening | 8 | 1869 ± 490 | 4244 ± 2677 |
| Trimming | 8 | 930 ± 416 | 1297 ± 1267 |
| Raking | 8 | 1194 ± 347 | 6482 ± 1694 |
| Power mowing | 8 | 1939 ± 618 | 1699 ± 1242 |
| Manual mowing | 8 | 2097 ± 764 | 1277 ± 721 |
| Vacuuming | 9 | 1115 ± 912 | 2520 ± 797 |
| Sweeping and mopping | 9 | 1026 ± 327 | 3762 ± 1191 |
| Laundry | 10 | 480 ± 309 | 2925 ± 1066 |
| Ironing | 9 | 236 ± 302 | 2306 ± 543 |
| Washing dishes | 6 | 275 ± 158 | 2700 ± 1684 |
| Cooking | 5 | 174 ± 249 | 1765 ± 932 |
| Light cleaning | 10 | 553 ± 385 | 2624 ± 1030 |
| Grocery shopping (with a cart) | 6 | 529 ± 199 | 1158 ± 422 |
| Feeding and grooming animals | 8 | 483 ± 316 | 2534 ± 1158 |
| Playing with animals in the yard | 7 | 1075 ± 764 | 3522 ± 1980 |
| Caring for children | 10 | 968 ± 727 | 2464 ± 960 |
| Playing with children in the yard | 10 | 1304 ± 539 | 4961 ± 2302 |
| Slow walking (78 $m \cdot min^{-1}$) | 12 | 2479 ± 820 | 2124 ± 1035 |
| Brisk walking (100 $m \cdot min^{-1}$) | 12 | 4311 ± 1222 | 3013 ± 1204 |
| Conditioning | 10 | 398 ± 347 | 1564 ± 678 |
| Calisthenics | 10 | 767 ± 356 | 6093 ± 1741 |
| Golf—pulling clubs | 9 | 1716 ± 184 | 3219 ± 1018 |
| Golf—carrying clubs | 9 | 1888 ± 370 | 2995 ± 1050 |
| Doubles tennis | 11 | 1449 ± 334 | 5484 ± 1581 |
| Softball | 12 | 1864 ± 252 | 3995 ± 1248 |
| Walking at 67 $m \cdot min^{-1}$ with 6.8-kg box | 12 | 1846 ± 606 | 1594 ± 658 |
| Walking at 93.8 $m \cdot min^{-1}$ with 6.8-kg box | 12 | 3597 ± 944 | 2950 ± 828 |
| Loading and unloading 6.8-kg boxes | 12 | 1476 ± 555 | 5488 ± 1744 |

5% of the reference value) both before and after the study. The midpoint calibration was also satisfactory for the CSA accelerometer worn on the hip. However, the midpoint calibration revealed a broken beam, or sensory unit, within the CSA accelerometer worn on the wrist. The broken beam resulted in lower count values than should have been recorded (66.7% of the reference value). Consequently, the malfunctioning CSA resulted in the exclusion of 11 participants from the data analysis.

Each participant wore two CSA accelerometers (model 7164, Shalimar, FL) while performing the activities. One CSA accelerometer was placed on the right anterior axillary line at waist level, and the other was placed on the dominant wrist; both were secured in nylon pouches with Velcro closures supplied by the manufacturer. The CSA accelerometers were initialized according to the manufacturer's specifications before each activity session. The accelerometer worn on the hip was secured tightly to the waist via a belt supplied by the manufacturer. The accelerometer worn on the wrist was secured tightly by a Velcro wrist strap. Data from the CSA accelerometers were downloaded to a personal computer and subsequently imported to an Excel file, where minute-by-minute data could be compared with oxygen consumption data from the Cosmed K4b$^2$.

The two CSA accelerometers were also synchronized to the same external timepiece to ensure that data from the Cosmed K4b$^2$ and the accelerometers were collected over simultaneous time periods. The CSA accelerometers were set to a 60-s epoch time interval. Once the test was completed, the CSA data were downloaded according to the manufacturer's specifications. Mean CSA counts for the hip and the wrist accelerometers were calculated for each participant from the last 10 min of every activity.

**Data analysis.** SPSS 9.0 for Windows (Chicago, IL) was used to perform linear regression analyses to predict METs from 1) only CSA hip counts 2), only CSA wrist counts, and 3) CSA hip and wrist counts for all activities performed. The overall significance level was set at $\alpha = 0.05$. Difference scores were calculated as the measured MET values from the Cosmed K4b$^2$ minus the predicted MET values from the CSA. Multiple *t*-tests with Bonferroni's adjustment were performed to determine whether each error score varied significantly from zero. The adjusted alpha level was set at $\alpha = 0.002$ to maintain an $\alpha = 0.05$ across all comparisons. Multiple paired *t*-tests with Bonferroni's adjustment were performed to compare differences between predicted MET levels between the hip only and the

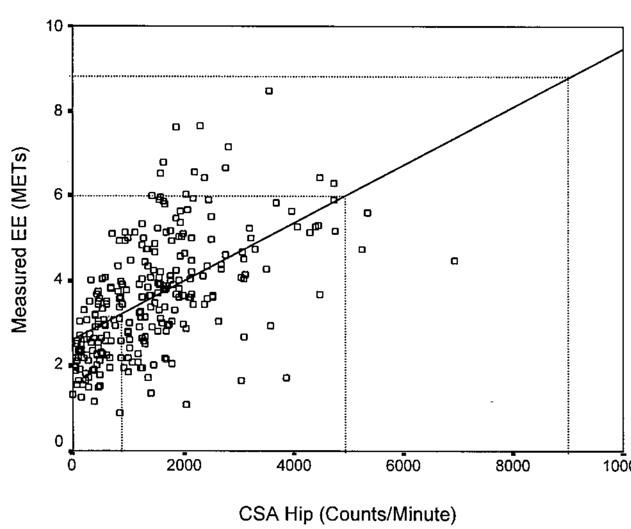


**Figure 1—Regression line for measured energy expenditure (METs) versus CSA hip counts for all activities (3).**

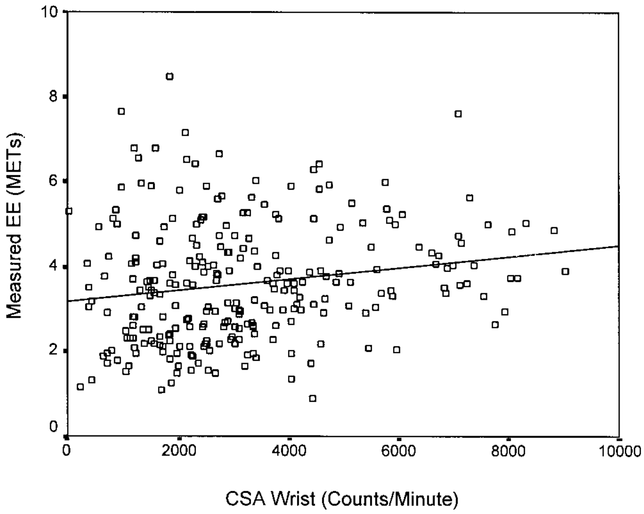


**Figure 2—Regression line for measured energy expenditure (METs) versus CSA wrist counts for all activities.**

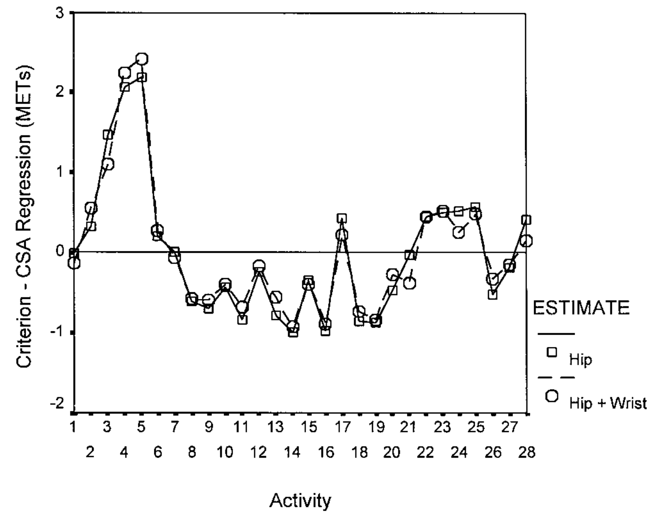


**Figure 3—Difference scores for the criterion value (Cosmed K4b[2]) and predicted value (CSA regression) for individual activities. Data points represent mean values for 5–12 participants; 1, gardening; 2, trimming; 3, raking; 4, mowing the lawn (power mower); 5, mowing the lawn (manual mower); 6, vacuuming; 7, sweeping and mopping; 8, laundry; 9, ironing; 10, washing dishes; 11, cooking; 12, light cleaning; 13, grocery shopping (with a cart); 14, feeding and grooming animals; 15, playing with animals in the yard; 16, caring for small children; 17, playing with children in the yard; 18, slow walking; 19, brisk walking; 20, stretching; 21, light calisthenics; 22, golf (pulling clubs); 23, golf (carrying clubs); 24, doubles tennis; 25, softball; 26, walking at 67m·min$^{-1}$ and carrying items weighing 6.8 kg; 27, walking at 93.8 m·min$^{-1}$ and carrying items weighing 6.8 kg; and 28, loading and unloading boxes weighing 6.8 kg.**

hip and wrist regression equations for selected activities. The adjusted significance level was set at $\alpha = 0.008$ to maintain an $\alpha = 0.05$ across all comparisons.

## RESULTS

Mean and standard deviation values for the CSA model 7164 accelerometers worn on the wrist and hip are shown in Table 2 for each activity. Brisk overground walking and treadmill walking at 93.8 m·min$^{-1}$ while carrying a 6.8-kg box produced the highest hip counts. The highest wrist counts were observed during raking and calisthenics.

The relationship between EE (METs) and CSA hip counts, shown in Figure 1, yielded a statistically significant correlation (r = 0.563, $P < 0.001$). The relationship between EE (METs) and CSA wrist counts, shown in Figure 2, also produced a statistically significant correlation (r = 0.181, $P = 0.003$). Accounting for the wrist in addition to the hip counts significantly improved the correlation (r = 0.586, $P < 0.001$) compared with the hip alone. The regression equations developed from the CSA wrist counts, CSA hip counts, and the combination of the CSA hip and wrist are displayed in Table 3. The variance in METs explained by the wrist is less than 5%, whereas the hip counts explained 31.7% of the variance. Furthermore, the hip and wrist equation accounted for only an additional 2.6% of the variance in METs compared with the hip alone.

Figure 3 illustrates the difference scores (measured METs minus CSA regression estimated METs) for the hip and the hip and wrist regression equations in each activity. The difference scores demonstrate an over- or under-estimation of the CSA regression for individual activities. Both regression equations significantly underpredicted the actual measured energy cost of mowing with a power mower ($P <$ 0.001) and a manual mower ($P = 0.001$). Both regression equations significantly overpredicted the energy cost of ironing ($P < 0.001$), caring for children ($P = 0.001$), and slow walking (78 m·min$^{-1}$) ($P = 0.001$).

TABLE 3. CSA regression equations to predict gross energy expenditure from wrist and hip accelerometer counts for all activities.

| Prediction Model | Equation | $R^2$ | SEE[a] |
|---|---|---|---|
| Wrist | METs = 3.195 + 0.0001314* CSA counts | 0.033 | 1.3809 |
| Hip | METs = 2.606 + 0.0006863* CSA counts | 0.317 | 1.1602 |
| Hip and wrist | METs = 2.245 + 0.000679* CSA hip counts) + (0.0001165* CSA wrist counts) | 0.343 | 1.1404 |

[a] SEE, standard error of the estimate.

The hip and the hip and wrist regression equations provided significantly different estimates of METs for only five activities: trimming ($P = 0.004$), raking ($P = 0.001$), manual mowing ($P < 0.001$), calisthenics ($P < 0.001$), and doubles tennis ($P < 0.001$). However, the magnitude of the difference was quite small in each case. The regression equations gave similar estimates of METs for all other activities.

## DISCUSSION

Researchers have been interested in the relationship between physical activity and health outcomes for many years. The new recommendations by the Centers for Disease Control and Prevention and the American College of Sports Medicine (11), along with the Surgeon General's report on *Physical Activity and Health* (16), have spurred interest in epidemiologic research to quantify how much physical activity Americans are currently performing. Traditionally, epidemiologic studies have relied on questionnaires to quantify the amount and intensity of physical activity that participants perform (10). These methods have served epidemiology well, but they are subject to limitations (7). Surveys are subjective and usually require recall on the respondent's part, which leads to a potential source of error (7). Therefore, the challenge remains to develop accurate, objective methods of measuring physical activity within large populations.

Accelerometers have the potential to provide accurate and objective estimates of EE in epidemiologic studies. The CSA accelerometer model 7164 can provide concurrent information on the frequency, duration, and intensity of physical activity. Many studies have developed prediction models to estimate metabolic cost in a laboratory setting using a CSA accelerometer (2,3,9). These studies have focused on one activity or a variety of activities and have constructed regression equations to estimate EE using a single accelerometer mounted on the hip or a combination of accelerometers on the hip, wrist, and ankle (2,3,9). The fundamental goals of this study were 1) to develop a prediction model that incorporates CSA counts from accelerometers worn on the hip and wrist and 2) to determine whether the addition of an accelerometer worn on the wrist, while performing common daily activities, would improve the accuracy of estimating EE (METs) compared with a prediction model based on a single accelerometer worn on the hip. Regression equations were developed from accelerometer counts and measured energy cost (METs) during a variety of activities performed in field and laboratory settings (Table 3). The equations developed from the CSA wrist, hip, and hip and wrist accelerometer counts accounted for 3.3% ($P = 0.003$), 31.7% ($P < 0\ 0.001$), and 34.3% ($P < 0.001$) of the variability in EE (METs) of the activities performed, respectively. The regression equation derived from the hip and wrist accelerometer counts explained significantly more of the variability in EE (METs) of the activities than the hip alone, although only an additional 2.6% ($P = 0.002$).

The results from this study differ from those of Melanson and Freedson (9), who looked at the relationship between CSA model 5032 accelerometer counts from the hip, wrist, and ankle and the measured EE for three different speeds of walking and jogging. They found that counts were significantly correlated with EE (r = 0.66–0.81) regardless of the location of the accelerometer (wrist, hip, ankle). Contrary to the results in the present study, the best single accelerometer regression equation used data from the CSA accelerometer worn on the wrist to predict EE, accounting for 86% of the variance in EE for walking and jogging. Melanson and Freedson (9) also found that the addition of CSA count data from other anatomical sites (hip, ankle) improved the prediction of EE compared with the wrist alone. A combination of hip and wrist or wrist and ankle yielded an $R^2 = 0.89$. In the present study, the hip and wrist CSA counts predicted EE (METs) with an $R^2$ of 0.343. The large discrepancy between the amount of variation explained by the equations developed in this study and the equations developed by Melanson and Freedson could be due to the activity modes. Melanson and Freedson (9) examined treadmill locomotion (two different walking speeds and one jogging speed) in a laboratory setting, whereas the equation developed in this study was based on a wide variety of tasks, both indoors and outdoors, in field and laboratory settings.

TABLE 4. "Cut points" for gross energy expenditures values of 3, 6, and 9 METs determined from two prediction models using the CSA model 7164 accelerometer worn on the hip.

| MET Value | Hip Counts (Present Study) | Hip Counts (Hendelman et al. [3]) |
|---|---|---|
| 3 | 574 | 190.7 |
| 6 | 4945 | 7525.7 |
| 9 | 9317 | 14,860.6 |

Hendelman et al. (3) developed a regression equation for a variety of activities, including walking at four speeds, golf (pulling cart), washing windows, dusting, vacuuming, lawn mowing, and planting shrubs. They showed a moderate to strong correlation between hip CSA model 7164 accelerometer counts and the metabolic cost of walking (r = 0.77), accounting for 58.9% of the variance in EE. However, the correlation was reduced when all activities were used to develop the regression equation (r = 0.59), accounting for 35.2% of the variance in EE, a finding similar to our observations.

The hip and wrist regression equation developed in this study accounted for 34.3% of the variability in the metabolic cost of the activities, a 2.6% improvement over the hip-alone regression. Although 2.6% more of the variability could be explained with the addition of another accelerometer, one needs to consider whether the increased time, cost, and effort required are worth the small improvement in accuracy. Figure 3 shows a graph of difference scores computed as the measured METs minus CSA regression estimated METs for both regression equations (hip, hip and wrist) developed in this study. We recognize the limitations of using the same data from which the regression equations were derived to evaluate how well the regression equation estimates EE. However, the purpose of Figure 3 was to graphically represent the marginal benefit of the hip and wrist equation over the hip equation. In addition, Figure 3 demonstrates which activities were over- and under-estimated in our study. The difference scores for most activities were similar for each of the two regression equations, highlighting the quantitatively small advantage of the hip and wrist combination regression equation over the hip alone. Generally, for those activities in which external work is involved (carrying, lifting, and pushing), both regression equations (hip, hip and wrist) tended to underpredict the metabolic cost of the activities. However, the hip and the hip and wrist regression equations did provide significantly different estimates of METs for activities involving upper body movement such as trimming, raking, manual mowing, calisthenics, and doubles tennis.

Further examination of the data allowed for calculation of count values, or "cut points," which corresponded to 3, 6, and 9 METs (Table 4, Fig. 1). The "cut point" method of determining light (1.1–3 METs), moderate (3–5.9 METs), hard (6–8.9 METs), and very hard (≥9 METs) activities from actual counts could be useful to researchers interested in quantifying the amount of time spent at various intensities (2). Considering the quantitatively minor advantage of the hip and wrist regression equation, the hip-only regression equation was used to determine the “cut points.” Hendelman et al. (3) also determined “cut points” for 3, 6, and 9 METs based on the regression equation for all activities using hip accelerometer counts. As seen in Table 4, their values were very different from those developed in this study. For example, in the moderate intensity category of 3–6 METs, Hendelman et al. (3) reported a range of 190.7–7525.7 counts, whereas in this study, the range was 574-4945 counts. Some of the discrepancy is attributable to the type and number of activities performed. In the study of Hendelman et al (3)., 4 of the 10 activities examined consisted of walking. In the present study, only 2 of the 28 activities consisted of walking. Because walking yields higher counts for a given level of EE than other activities, this had an impact on the regression equations developed in the two studies.

In the past, regression equations were developed for walking or jogging (2,3,9). Although these regression equations are very accurate for these specific activities (r = 0.80–0.90), they tend to underestimate the energy cost of most other activities (1,3,18). The regression analyses in this paper (hip, hip and wrist) were based on a wide variety of activities. Therefore, although they cannot be expected to estimate the EE of a specific activity (e.g., walking) as accurately, the regression equations based on all activities have a broader application.

The discrepancies between the present study and that of Hendelman et al. (3) show the difficulty of developing consistent cut points and regression equations to predict the metabolic cost of all activities. A number of things must be considered when comparing the counts per minute for activities in the Hendelmen et al. (3) paper and the counts per minute developed in this paper. First, the activities measured need to be considered.

As seen in Figure 4, slow walking (78–79 m·min$^{-1}$), brisk walking (95–100 m·min$^{-1}$), golf (pulling a cart), dusting/light cleaning, vacuuming, and mowing the lawn with a power mower were the only activities performed in both studies (3). The CSA hip counts and measured MET values for the activities that are common to both studies show a similar pattern. The CSA scores were generally within 1000 counts per minute of each other, and the EE values were within 0.8 METs. Possible reasons for the differences in counts per min and measured MET values could be attributed to the pace at which activities were performed, or the way in which these activities were carried out (e.g., how much walking was done during vacuuming, power mowing, and golf). For instance, in the present study, golf was played in either a two-some or four-some, whereas in the paper of Hendelman et al. (3), golf was played individually. Furthermore, the terrain of the golf course or lawn, and the weight of the golf clubs, lawn mower, or vacuum can play a role in the measured MET value of each activity. Therefore, the discrepancies in counts per minute and METs for similar activities are small and can be accounted for by external

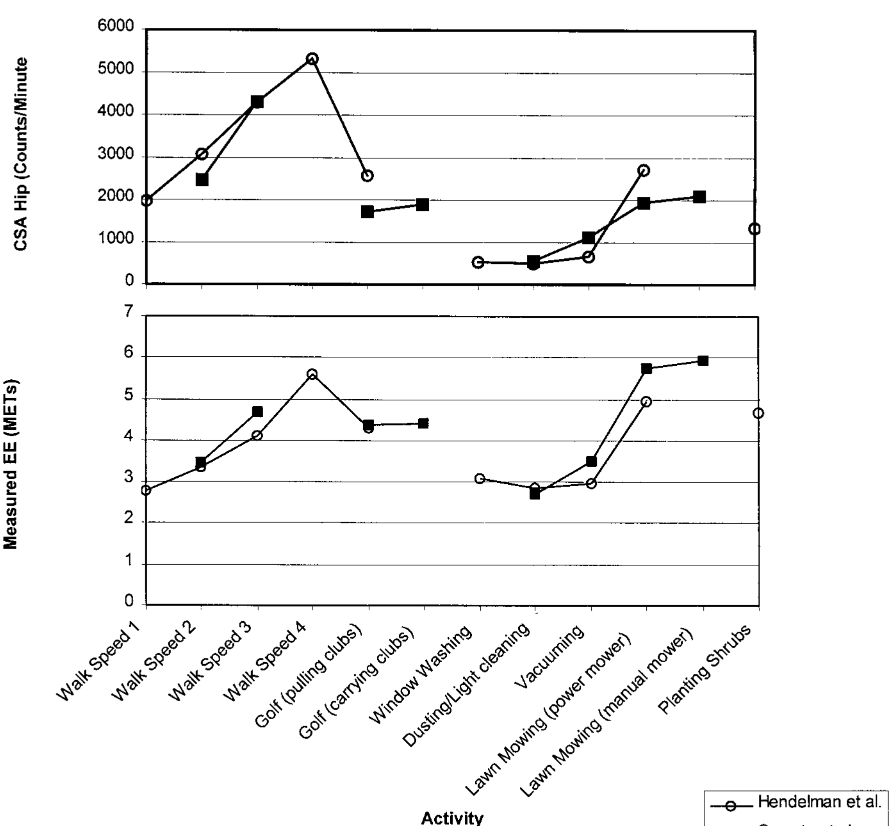


**Figure 4—Comparison of counts per minute and MET values derived from Hendelman et al. (3) and the current paper for similar activities. Walk Speed 1, 63.2 m·min$^{-1}$ for Hendelman et al.; Walk Speed 2, 79.2 m·min$^{-1}$ for Hendelman et al. and 78 m·min$^{-1}$ for Swartz et al.; Walk Speed 3, 94.7 m·min$^{-1}$ for Hendelman et al. and 100 m·min$^{-1}$ for Swartz et al.; and Walk Speed 4, 111.2 m·min$^{-1}$ for Hendelman et al.**

variability. Additional studies are needed to determine the validity of the regression equations and cut points observed in both studies.

There are limitations to the use of accelerometers for measuring EE. Motion sensors are unable to distinguish between different types of walking surfaces and changes in percent grade (3,10) and are not able to detect when a person is carrying a load, pushing an object, or ascending stairs. In addition, motion sensors cannot accurately track EE while swimming, stationary cycling, rowing, or resistance training (10).

In conclusion, it was hypothesized that an accelerometer worn on the wrist would increase the accuracy of predicting the EE of various activities compared with an accelerometer worn only on the hip. The combination of hip and wrist accelerometers did prove to be more accurate at predicting EE; however, it was only a minor improvement. The small amount of additional accuracy gained from the wrist accelerometer is offset by the extra time required to analyze the data and the cost of the accelerometer.

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