# Estimating Physical Activity Using the CSA Accelerometer and a Physical Activity Log

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**ABSTRACT**

SCHMIDT, M. D., P. S. FREEDSON, and L. CHASAN-TABER. Estimating Physical Activity Using the CSA Accelerometer and a Physical Activity Log. *Med. Sci. Sports Exerc.*, Vol. 35, No. 9, pp. 1605–1611, 2003. **Purpose:** To compare two methods for measuring time spent in physical activity of differing absolute intensities. **Methods:** Over a 7-d period, 59 women wore Computer Science and Applications, Inc. (CSA) accelerometers and recorded their activity in physical activity logs (PAL) at 15-min intervals. Three published cut points were used to classify CSA data into resting/light, moderate, and vigorous intensity categories. Data were analyzed using descriptive statistics, Spearman rank-order correlations, and Bland-Altman plots. **Results:** The CSA estimates of total (moderate plus vigorous) physical activity using the three cut points ranged from a mean (± SD) of 38.1 (±26.8) $min \cdot d^{-1}$ to 312.6 (± 101.1) $min \cdot d^{-1}$. Using the PAL, women self-reported a mean (± SD) of 75.1 (± 51.7) $min \cdot d^{-1}$ of total activity. There was fair to modest rank-order agreement between each of the three CSA measures and the PAL measure of total activity, with correlations ranging from r = 0.15 to 0.24. Correlations between CSA and PAL estimates of total activity were higher in women with body mass index values (BMI) below 25 $kg \cdot m^{-2}$ (r = 0.23–0.38) compared with women with BMI ≥ 25 $kg \cdot m^{-2}$ (r = 0.06–0.08) but did not differ according to age. Correlations between the three CSA cut points ranged from r = 0.45 to 0.86. **Conclusions:** Three published cut points designed to classify CSA output by intensity level produced different estimates of physical activity participation. Correlations between CSA and PAL measures of activity intensity were fair overall but higher among leaner women. **Key Words:** MEASUREMENT, MOTION SENSORS, EPIDEMIOLOGIC METHODS, FEMALE

Physical activity of moderate intensity has recently been shown to decrease risk of cardiovascular disease, diabetes, and certain cancers (9,15,17,20). In light of such findings, the U.S. Surgeon General's report on physical activity and health recommended that adults obtain a minimum of 30 $min \cdot d^{-1}$ of moderate intensity activity (28). To measure adherence to these recommendations, tools that can assess the intensity of physical activity are necessary. Current methods include subjective measures such as questionnaires and physical activity logs (PAL), and objective measures such as accelerometers (3,11,25).

In comparison with objective measures, such as doubly labeled water and heart rate monitoring, PAL are more feasible for measuring adherence to physical activity recommendations for large populations (1). Unlike questionnaires, PAL involve self-report of activity intensity, frequency, and duration as they occur and are not subject to errors due to a fixed list of activities, memory, and interpretation of questions. However, PAL likely elicit socially desirable responses, and if not filled out properly, may lead to decreased precision. Although objective measures such as accelerometers are able to provide reliable and valid measures of energy expenditure (3), studies on the use of accelerometers to measure intensity-specific activity are sparse. Thus, it has become increasingly important for studies to compare accelerometer measures of intensity specific activity with self-reported measures of activity, particularly for activities of moderate or greater intensity. Additional studies are needed to determine whether accelerometer measures of intensity specific activity are comparable to estimates obtained from other measures of physical activity, such as PAL.

In order for accelerometers to provide information about time spent in absolute intensity categories, valid, intensity-specific count ranges are required to classify accelerometer output. Several different cut points have recently been proposed (8,10,26); however, they differ substantially, especially regarding the threshold for moderate intensity activity. These cut points, therefore, have the potential to result in widely discrepant estimates of the time spent in moderate and vigorous intensity activity. In the only prior study to examine the three cut points, Ainsworth and colleagues (2) reported estimates of moderate intensity activity participation that ranged from 25 to 258 $min \cdot d^{-1}$, depending upon the cut point values used.

Therefore, the overall goal of the current study was to compare various methods of assessing physical activity in a field setting. Specifically, we compared two methods (the

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Computer Science and Applications, Inc. (CSA) accelerometer and PAL) for quantifying the amount of time spent in moderate and vigorous physical activity over a 7-d period. A secondary goal was to compare CSA estimates of activity intensity based upon the three available cut points.

## METHODS

**Sample and study design.** The data for these analyses were obtained from the Alumnae Health Study, which was designed to assess the reliability and validity of a modified version of the Historical Leisure Activity Questionnaire (HLAQ) (6,22). Original study participants consisted of 134 women recruited from the alumnae rosters of two colleges in western Massachusetts. Eligibility requirements included: (a) age 39–65 yr, (b) graduating class of 1955 to 1980, and (c) currently residing in the United States. The Institutional Review Board of the University of Massachusetts, Amherst, approved all participant recruitment and data collection procedures. Each participant read and signed an approved written informed consent.

During the fall of 1998, a subgroup of 59 participants in the Alumnae Health study wore CSA accelerometers for a 1-wk period while simultaneously completing a 7-d PAL. The current analysis is based upon this subgroup.

**CSA accelerometer.** CSA model 7164 activity monitor was used to obtain objective estimates of physical activity behavior. The CSA 7164 is a uniaxial accelerometer that detects vertical accelerations ranging in magnitude from 0.05 to 2.00 *g* with frequency response from 0.25 to 2.50 Hz. The above parameters will detect normal human movement while filtering out high-frequency movements such as vibrations. The filtered acceleration signal is digitized and the magnitude is summed over a user-specified time interval (epoch). At the end of each epoch, the activity count is stored in memory and the accumulator is reset to zero (7). A 1-min epoch was used in this study.

For the current study, the CSA accelerometer was worn under clothing on the right hip fastened to an adjustable elastic belt during waking hours for the 7-d period corresponding to each subject's fall PAL. Participants were instructed to remove the monitor for bathing and swimming activities.

**Physical activity log (PAL).** The PAL was based on a modified version of the Bouchard Physical Activity Record (5). For each 15-min interval of every hour of the day, subjects were instructed to record in the PAL, on an ongoing basis, the number that corresponded to the intensity level of their activity, selecting from six intensity categories (inactive, sitting, light, moderate, vigorous, and very vigorous). Examples of activities in each intensity level were provided. Participants were not asked to record perceived intensity or the specific type of activity. For analyses, the inactive, sitting, and light PAL categories were grouped into one category labeled "resting/light activity," and the hard and very hard PAL categories were combined into a single "vigorous activity" category.

Mean energy expenditure per kilogram of body weight as measured by the Bouchard 3-d Physical Activity Record was found to be significantly and positively correlated with physical working capacity ($r = 0.31$), expressed per kilogram of body weight, and negatively correlated with body fat ($r = 0.13$) (5). In addition, Matthews and Freedson (18) reported a strong correlation ($r = 0.82$) between the Tritrac activity monitor and a 3-d PAL. Test-retest reproducibility (ICC = 0.96) of the PAL has also been established (5).

**CSA data reduction.** The CSA data for each subject were downloaded to a PC using the CSA, Inc. reader interface unit. Using the cut points developed from three prior studies (8,10,26), activity counts were used to classify each 1-min epoch into resting/light, moderate, or vigorous intensity categories. Therefore, three separate estimates of the minutes per day spent in each of the activity intensities were calculated. The specific count ranges used to classify activity as resting/light, moderate, and vigorous intensity, respectively, were as follows: 0–1951, 1952–5724, ≥5725 (Freedson et al. (8)); 0–190, 191–7525, ≥7526 (Hendelman et al. (10)); and 0–573, 574–4944, ≥4945 (Swartz et al. (26)). A custom-designed computer program written using Statistical Analysis Systems (SAS Institute, Cary, NC) version 8.0 was used to calculate the average minutes per day spent in sedentary/light (<3 METs), moderate (3–5.99 METs), and vigorous (≥6 METs) activities using the cut points above.

**Statistical analysis.** SAS version 8.0 was used to complete all analyses. To prevent significant underestimation of daily activity, only days in which the accelerometer was worn for at least 10 h were included. For these calculations, we assumed the CSA was not worn during periods where CSA output was equal to zero for ≥ 15 continuous minutes. Daily estimates from both the CSA and PAL were used to calculate mean values for each subject, which were the units of analysis for all summary statistics and analyses.

Univariate analysis included means, standard deviations, and quartile values. To compare the CSA and PAL estimates of activity, estimates of the number of minutes spent in moderate, vigorous, and total (moderate and vigorous) physical activity obtained from the three CSA cut point methods were compared with like estimates obtained from the PAL using Spearman rank-order correlations. Mean total CSA counts per day were also correlated with each intensity-specific PAL estimate. To examine whether the comparison between CSA and PAL estimates varied according to subject age or body composition, we calculated stratum specific correlations within categories of age (above and below the 50th percentile) and body mass index (BMI) (above and below 25 $kg \cdot m^{-2}$, based on the recommended cut point for overweight (19)). Bland-Altman plots (4) were constructed to illustrate the distribution of error scores (CSA − PAL estimates of total activity) across the range of physical activity levels. Solid horizontal lines on these plots indicate mean error scores, whereas dashed horizontal lines represent the 95% confidence intervals for the error scores.

To assess the concordance of CSA and PAL measures in classifying subjects into low, medium, and high categories of moderate and total activity, tertile groupings were created

TABLE 1. Estimates of daily participation in moderate and vigorous physical activity by measurement method, overall, and stratified by BMI.

| | CSA Cut Points | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Freedson et al. ($min \cdot d^{-1}$) | | Hendelman et al. ($min \cdot d^{-1}$) | | Swartz et al. ($min \cdot d^{-1}$) | | Physical Activity Log | |
| | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| Total sample ($N = 58$) | | | | | | | | |
| Total activity[a] (≥ 3 METs) | 38.1 | 26.8 | 312.6 | 101.1 | 162.7 | 69.2 | 75.1 | 51.7 |
| Moderate (3–5.99 METs) | 33.6 | 20.1 | 311.2 | 102.1 | 157.1 | 66.9 | 65.6 | 48.4 |
| Vigorous (≥ 6 METs) | 4.5 | 16.8 | 1.4 | 4.1 | 5.6 | 17.7 | 9.5 | 18.0 |
| BMI < 25 $kg \cdot m^{-2}$ ($N = 41$) | | | | | | | | |
| Total activity (≥ 3 METs) | 40.7 | 30.6 | 313.2 | 104.7 | 162.8 | 73.3 | 75.5 | 43.9 |
| Moderate (3–5.99 METs) | 35.3 | 22.6 | 311.7 | 106.0 | 156.1 | 69.9 | 65.0 | 41.2 |
| Vigorous (≥ 6 METs) | 5.4 | 19.8 | 1.4 | 4.6 | 6.8 | 20.8 | 10.5 | 20.5 |
| BMI ≥ 25 $kg \cdot m^{-2}$ ($N = 16$) | | | | | | | | |
| Total activity (≥ 3 METs) | 31.9 | 13.5 | 313.0 | 97.4 | 162.8 | 62.2 | 73.9 | 71.0 |
| Moderate (3–5.99 METs) | 29.7 | 11.8 | 311.6 | 98.0 | 159.7 | 63.0 | 66.2 | 66.0 |
| Vigorous (≥ 6 METs) | 2.2 | 3.7 | 1.3 | 2.7 | 3.1 | 4.8 | 7.8 | 10.3 |

[a] Total activity = moderate activity + vigorous activity.

based on each CSA measure and the PAL. The PAL and CSA groupings were cross-tabulated, and the percent agreement between methods, along with the corresponding Kappa statistic, were calculated.

Finally, the consistency of the three CSA cut point methods, as well as the raw CSA output, in ranking subject activity levels was assessed by calculating the Spearman rank-order correlations.

## RESULTS

From the total sample of 59 participants, one subject was excluded due to CSA monitor failure. Thirteen days of measurement were excluded from six participants because the accelerometer was not worn for at least 10 h. Complete PAL were obtained from all participants with the exception of a single subject who completed only 4 d of measurement. Therefore, to obtain comparable estimates for both the CSA and PAL, only days with complete data from both instruments were used to calculate mean subject values.

Subjects had a mean age of 49.4 yr and a mean BMI of 23.7 $kg \cdot m^{-2}$. Estimates of mean total activity levels varied considerably across assessment methods largely due to the high degree of variation in the estimation of moderate intensity activity (Table 1). For example, CSA estimates of moderate physical activity ranged from a low of 33.6 $min \cdot d^{-1}$ using the Freedson cut points (CSA_F) to a high of 311.2 $min \cdot d^{-1}$ using the Hendelman cut points (CSA_H). Mean moderate activity as measured by the self-report PAL was 65.6 $min \cdot d^{-1}$. All of the assessment methods resulted in low estimates of vigorous intensity activity ranging from a low of 1.4 $min \cdot d^{-1}$ (CSA_H) to a high of 9.5 $min \cdot d^{-1}$ (PAL). It should be noted that these estimates of vigorous activity, which are strongly and positively skewed, overestimate actual participation in vigorous intensity activity in this sample of women. Median values, which better reflect group participation in vigorous activity, varied from 0 to 1.1 $min \cdot d^{-1}$ across measurement methods.

Estimates of mean total activity derived from the Swartz (CSA_S) and CSA_H cut points were similar between women with BMI values above and below 25 $kg \cdot m^{-2}$, whereas CSA_F total activity estimates were higher in women with lower BMI values (Table 1). Although PAL estimates of mean total activity were similar across strata of BMI, women with BMI values below 25 $kg \cdot m^{-2}$ reported higher levels of vigorous intensity activity. CSA estimates of mean total activity were higher among younger women (<50 yr), whereas PAL estimates were similar in both age groups.

TABLE 2. Spearman correlation coefficients between physical activity log (PAL) and CSA accelerometer estimates of moderate and vigorous intensity physical activity, overall, and stratified by BMI.

| | PAL ($min \cdot d^{-1}$) vs CSA, by Cut Point Method | | | |
|---|---|---|---|---|
| | Freedson et al. ($min \cdot d^{-1}$) | Hendelman et al. ($min \cdot d^{-1}$) | Swartz et al. ($min \cdot d^{-1}$) | PAL ($min \cdot d^{-1}$) vs CSA ($counts \cdot d^{-1}$) |
| Total Sample ($N = 58$) | | | | |
| Total activity[a] (≥ 3 METs) | 0.24 | 0.15 | 0.24 | 0.23 |
| Moderate (3–5.99 METs) | 0.25 | 0.23 | 0.28[b] | 0.28[b] |
| Vigorous (≥ 6 METs) | 0.16 | 0.17 | 0.08 | 0.03 |
| BMI < 25 $kg \cdot m^{-2}$ ($N = 41$) | | | | |
| Total activity[a] (≥ 3 METs) | 0.26 | 0.23 | 0.33[b] | 0.38[b] |
| Moderate (3–5.99 METs) | 0.29 | 0.34[b] | 0.40[c] | −0.02 |
| Vigorous (≥ 6 METs) | 0.36[b] | 0.32[b] | 0.24 | 0.28 |
| BMI ≥ 25 $kg \cdot m^{-2}$ ($N = 16$) | | | | |
| Total activity[a] (≥ 3 METs) | 0.06 | 0.08 | 0.06 | 0.16 |
| Moderate (3–5.99 METs) | 0.08 | 0.10 | 0.20 | 0.16 |
| Vigorous (≥ 6 METs) | −0.29 | −0.09 | −0.34 | 0.12 |

[a] Total activity = moderate activity + vigorous activity.
[b] $P < 0.05$.
[c] $P < 0.01$.

Rank-order agreement between the self-reported PAL and CSA measures were quite modest, with correlations ranging from r = 0.15 to 0.24 for total activity (Table 2). Correlations were higher between the PAL and CSA estimates of moderate activity (ranging from r = 0.23 to 0.28) as compared with CSA estimates of vigorous intensity activity (ranging from r = 0.08 to 0.17). Raw CSA output (counts$\cdot$d$^{-1}$) was found to be associated with total and moderate physical activity to the same degree as any of the cut point methods but had lower correlations for vigorous activity. Observed correlations were higher (ranging from r = 0.23 to 0.38 for total activity) when the analysis was restricted to women with BMI values less than 25 kg$\cdot$m$^{-2}$, based upon the National Heart, Lung, and Blood Institute cut point for overweight (19). In particular, correlations between CSA and PAL estimates of vigorous intensity were substantially higher among women with BMI values below 25 kg$\cdot$m$^{-2}$ compared with women with higher BMI values. Correlations between CSA and PAL estimates were similar across age strata.

Bland-Altman plots were used to examine differences between the PAL and each of the three CSA cut point estimates across the range of total activity in minutes per day. There was reasonable absolute agreement between the PAL and CSA_F estimates for women whose average total activity was less than approximately 50 min$\cdot$d$^{-1}$ (Fig. 1A). Among women with higher average values of total activity, CSA_F estimates were progressively lower than PAL estimates. For most participants, both the CSA_H and CSA_S cut points substantially overestimated total physical activity compared with the PAL (Fig. 1, B and C). The magnitude of this overestimation tended to increase with increasing average total activity.

Rank-order correlations between estimates of total physical activity derived from the three cut point methods ranged from r = 0.45 (for CSA_F vs CSA_H) to r = 0.86 (for CSA_H vs CSA_S) (Table 3). These results indicate that the differences in physical activity estimates between the cut point methods were not uniform across subjects and result in discrepant rankings of subjects by activity level. The correlation between the three CSA cut point methods and count output ranged from 0.67 to 0.92 for total activity and were highest for the CSA_F estimates.

Rather than use continuous measures, epidemiological studies frequently categorize subjects according to quantiles of physical activity. We evaluated the ability of each cut point method to group subjects into tertiles of physical activity using the self-report PAL for the comparison (Table 4). For the classification of total activity, the Swartz cut points had the highest level of agreement with the PAL, correctly classifying 48.3% of subjects. However, as 33.3% agreement would be expected by chance, the CSA cut points, at best, demonstrate only "poor to fair" predictive ability (23).

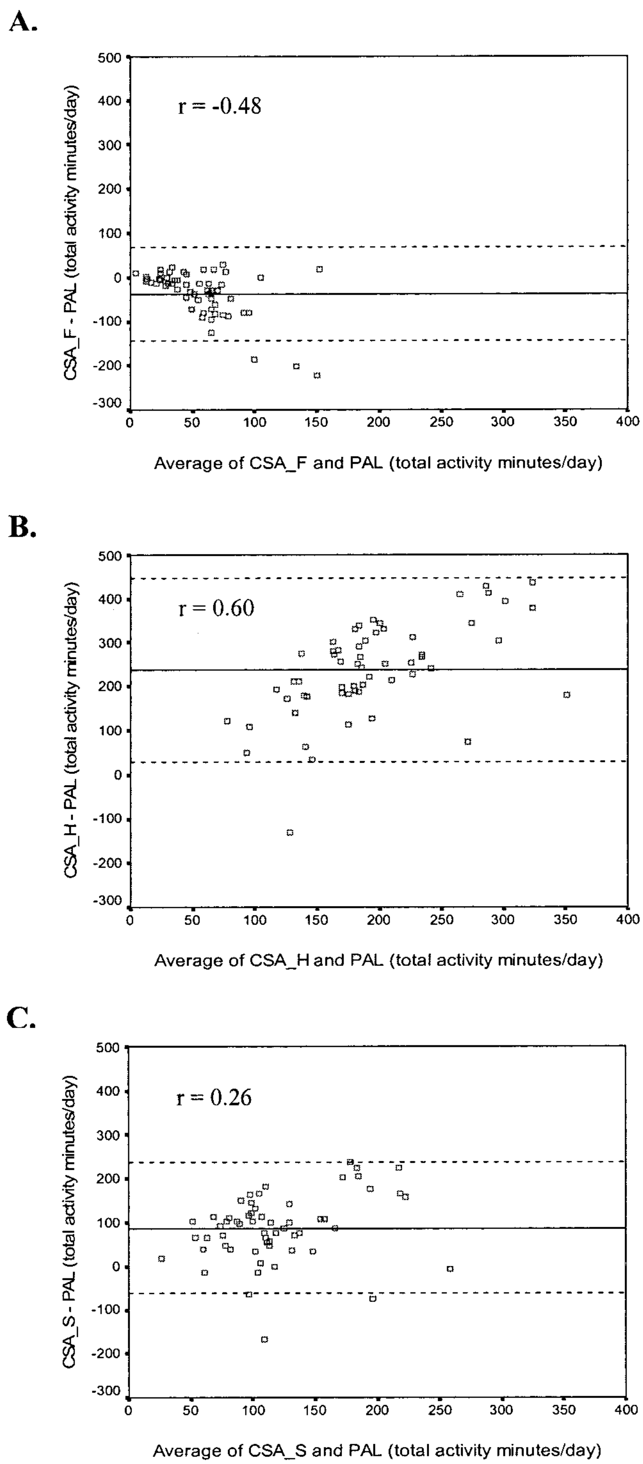


**FIGURE 1—Bland-Altman plots showing error scores (CSA − PAL estimates of total physical activity) plotted against the average of CSA and PAL estimates. The *lines* represent the mean error scores (*solid*) and the 95% confidence intervals of the observations (*dashed*). CSA_F, Freedson et al. cut points; CSA_H, Hendelman et al. cut points; CSA_S, Swartz et al. cut points.**

## DISCUSSION

The current study compared estimates of the time spent in intensity-specific physical activity using CSA accelerometers and PAL in a free-living population of women. There was fair to modest rank-order agreement between each of the three CSA measures and the PAL measure of total activity, with correlations ranging from r = 0.15 to 0.24. Correlations were higher for moderate intensity activity (r = 0.23 to 0.28) and among women with lower BMI values (r

= 0.23 to 0.38) but did not differ according to age. Correlations between the cut points ranged from r = 0.45 to 0.86.

The Hendelman-derived cut points and, to a lesser extent the Swartz, produced estimates of total physical activity that were higher than the Freedson as well as the PAL estimates. As participation in vigorous activity was minimal, these differences may be attributed to differential classification of moderate intensity activity. Specifically, both Hendelman and Swartz cut points classified all but one study participant as exceeding 30 min of moderate intensity activity a day—the minimum amount recommended by current public health guidelines (28). This is in sharp contrast to results from the most recent Behavioral Risk Factor Surveillance Survey (16), in which only 26% of women met this guideline. Although women participating in this analysis were volunteers and likely to be more active than the general population of women, these CSA estimates are much higher than would be expected based on the self-report PAL and national survey data.

The CSA and PAL measures are subject to limitations that may have resulted in misclassification of physical activity. For example, when the CSA is worn on the hip, error results from the inability of the accelerometer to accurately measure activities involving upper body movement, pushing or carrying a load, stationary exercise (e.g., cycling), weight-lifting, and water activities (e.g., swimming) (3). In contrast, errors in the PAL may result from subject inaccuracy in self-reporting physical activity (13,14). For example, the PAL may be subject to errors due to memory if it is not updated on an on-going basis. In addition, several activities listed as moderate intensity on the PAL (i.e., sweeping, dusting, vacuuming, childcare, gardening, walking) could have been performed at different levels of intensity but were uniformly recorded as moderate intensity. The magnitude of inaccuracy in self-reported activity may be higher in certain subgroups, such as overweight populations (12). This may, in part, explain our observed higher correlations between the CSA and PAL among women with BMI values in the normal range compared with overweight women. Given that neither method is perfect, it is crucial that the errors of both methods be as independent (uncorrelated) as possible, as correlated errors will result in spuriously high correlation coefficients. Therefore, because errors associated with the CSA and PAL are largely independent, our correlation coefficients are likely not overstated (29).

The current study did not include a true "gold standard" criterion measure of physical activity participation. Although doubly labeled water is the preferred criterion method for measuring total energy expenditure, it does not allow estimation of the duration or intensity of activity. Although direct observation would be a valid criterion measure, cost and logistic considerations prohibited its use in this study.

TABLE 4. Percent agreement between the CSA accelerometer and PAL in grouping subjects by duration of moderate, vigorous, and total physical activity ($N$ = 58).

| CSA Cut Point Method | % Agreement with PAL | Kappa |
|---|---|---|
| Total activity[a,b] | | |
| Freedson et al. | | 0.02 |
| Hendelman et al. | 41.4 | 0.12 |
| Swartz et al. | 48.3 | 0.22[e] |
| Moderate[c] | | |
| Freedson et al. | 41.4 | 0.12 |
| Hendelman et al. | 39.7 | 0.10 |
| Swartz et al. | 43.1 | 0.15 |
| Vigorous[d] | | |
| Freedson et al. | 58.6 | 0.17 |
| Hendelman et al. | 60.3 | 0.21 |
| Swartz et al. | 48.3 | −0.03 |

[a] Total activity = moderate activity + vigorous activity.
[b] Percent agreement between CSA and PAL tertiles of total physical activity.
[c] Percent agreement between CSA and PAL tertiles of moderate physical activity.
[d] Percent agreement between CSA and PAL in categorizing women into yes/no categories of vigorous activity.
[e] $P < 0.05$.

Our observed CSA estimates of moderate intensity activity were similar in relative magnitude to those reported from a prior study by Ainsworth et al. (2) among 83 middle-aged men and women. Using the PAL, participants in the Ainsworth study reported 120 min·d$^{-1}$ of moderate activity, almost twice as high as 65.6 min·d$^{-1}$ of moderate activity observed in the current study. Ainsworth et al. observed somewhat higher correlations between CSA and PAL measures than those reported in the current study, especially for vigorous intensity activity (r = 0.24–0.35 and r = 0.31–0.36 for moderate and vigorous intensity activity, respectively). The greater intersubject variability that would be expected in their sample of both men and women may have, in part, contributed to the higher correlation coefficients observed in the Ainsworth study.

As noted previously, very few women participated in vigorous intensity activity. The relative absence of vigorous intensity activity in the current study also effectively limits between-subject variation in total activity. Assuming a constant degree of measurement error, this decreased between-subject variation would result in reduced correlation coefficients between CSA and PAL estimates of total activity.

The disagreement between the three CSA estimates of physical activity largely reflects differences in cut point values, especially regarding the threshold for moderate activity. These differences may be due, in part, to variation in the methods and populations used to generate each of the cut

TABLE 3. Spearman rank-order correlation coefficients between CSA accelerometer cut point estimates of total[a] physical activity and with CSA counts ($N$ = 58).

| | Total Activity | | | |
|---|---|---|---|---|
| | Freedson et al. (min·d$^{-1}$) | Hendelman et al. (min·d$^{-1}$) | Swartz et al. (min·d$^{-1}$) | CSA (counts·d$^{-1}$) |
| Total activity | | | | |
| Freedson et al. (min·d$^{-1}$) | 1.00 | 0.45 | 0.67 | 0.92 |
| Hendelman et al. (min·d$^{-1}$) | — | 1.00 | 0.86 | 0.67 |
| Swartz et al. (min·d$^{-1}$) | — | — | 1.00 | 0.81 |

[a] Total activity = moderate activity + vigorous activity.

points. The Freedson cut points were derived from laboratory based locomotor activities that, for a given intensity, will generate higher count values than other activities (8,26). In contrast, both the Hendelman and Swartz cut points were based on field activities including indoor and outdoor household tasks, recreational activities, and walking. As compared with the Hendelman study, the Swartz study also included family care and a greater variety of conditioning and recreational activities. All three studies were performed among both men and women; however, subjects in the Freedson study were younger and leaner on average than subjects in the Hendelman and Swartz studies.

The disparate estimates of time spent in physical activity obtained from the three cut point methods underscores the difficulty of creating one set of cut points that can accurately classify a wide variety of activity types in diverse populations. As suggested by Hendelman et al. (10), the CSA count to energy expenditure relationship appears to be activity specific. Thus, the counts generated during brisk walking will be quite different from the counts generated by stacking boxes, even though both activities may be of identical intensity (26). One potential way to improve estimates of activity duration may be to create cut points that are weighted averages of the most common activities for specific age and gender groups. Nonetheless, because factors such as body type (27), locomotor characteristics (i.e., stride frequency) (21), and interinstrument variability (21) are significant sources of intersubject variation, substantial misclassification of activity is likely to remain.

A more promising alternative may be to use accelerometers in conjunction with heart rate monitors. In a recent study by Rennie and colleagues (24), a simple motion sensor was effectively used to help distinguish activity patterns at low heart rates and to identify heart rate elevations due to factors other than activity. Further innovations in combining these two measures may eventually yield a much needed field measure of absolute physical activity that is both objective and valid.

The cut points assessed in the current study were developed and validated for use only with the CSA accelerometer. Other accelerometers, such as the Caltrac and Kenz, do not provide minute-by-minute output data and therefore do not have the potential to estimate the duration of activity at different intensity levels. Newer accelerometers that are capable of collecting minute-by-minute information, such as the Biotrainer and RT-3 monitors, differ in certain characteristics (e.g., gain, filters) such that the CSA cut points cannot be applied to these accelerometers.

In summary, the current study observed fair to modest rank-order agreement between each of the three CSA cut points and PAL measures of total activity. Correlations were higher for moderate intensity activity and among women with lower BMI values but did not differ according to age. The three published CSA cut points, designed to classify physical activity by intensity level, produced different estimates of physical activity participation.

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## REFERENCES


1. Ainsworth, B. E. Practical assessment of physical activity. In: *Barrow & McGee's Practical Measurement and Assessment*, 5th Ed., K. Tritschler (Ed.). Baltimore: Lippincott Williams & Wilkins, 2000, pp. 475–492.
2. Ainsworth, B. E., D. R. Bassett, Jr., S. J. Strath, et al. Comparison of three methods for measuring the time spent in physical activity. *Med. Sci. Sports Exerc.* 32(Suppl.):S457–S464, 2000.
3. Bassett, D. R. Validity and reliability issues in objective monitoring of physical activity. *Res. Q. Exerc. Sport* 71:30–36, 2000.
4. Bland, J. M., and D. G. Altman. Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet* 8:307–310, 1986.
5. Bouchard, C., A. Tremblay, C. Leblanc, et al. A method to assess energy expenditure in children and adults. *Am. J. Clin. Nutr.* 37:461–467, 1983.
6. Chasan-Taber, L., J. B. Erickson, P. C. Nasca, et al. Validity and reproducibility of a physical activity questionnaire in women. *Med. Sci. Sports Exerc.* 34:987–992, 2002.
7. Computer Science and Applications, Inc. *Activity Monitor Operators Manual.* Model 7164, Release 1.04, Shalimar, FL, 1995, pp. 1–11.
8. Freedson, P. F., E. Melanson, and J. Sirard. Calibration of the Computer Science and Applications, Inc. accelerometer. *Med. Sci. Sports Exerc.* 30:777–781, 1998.
9. Friedenreich, C. M., and T. E. Rohan. A review of physical activity and breast cancer. *Epidemiology* 6:311–317, 1995.
10. Hendelman, D., K. Miller, C. Baggett, et al. Validity of accelerometry for the assessment of moderate intensity physical activity in the field. *Med. Sci. Sports Exerc.* 32(Suppl.):S442–S449, 2000.
11. Jacobs, D. R., B. E. Ainsworth, T. J. Hartman, and A. S. Leon. A simultaneous evaluation of 10 commonly used physical activity questionnaires. *Med. Sci. Sports Exerc.* 25:81–91, 1993.
12. Jakicic, J. M., B. A. Polley, and R. R. Wing. Accuracy of self-reported exercise and the relationship with weight loss in overweight women. *Med. Sci. Sports Exerc.* 30:634–638, 1998.
13. Lamonte, M. J., and B. E. Ainsworth. Quantifying energy expenditure and physical activity in the context of dose response. *Med. Sci. Sports Exerc.* 33(Suppl.):S370–S378, 2001.
14. Laporte, R. E., H. J. Montoye, and C. J. Casperson. Assessment of physical activity in epidemiologic research: problems and prospects. *Public Health Rep.* 100:131–146, 1985.
15. Lee, I. M., R. S. Paffenbarger, and C. C. Hsieh. Physical activity and risk of prostatic cancer among college alumni. *Am. J. Epidemiol.* 135:169–179, 1992.
16. Macera, C. A., and M. Pratt. Public health surveillance of physical activity. *Res. Q. Exerc. Sport* 71:97–103, 2000.
17. Manson, J. E., E. B. Rimm, M. J. Stampfer, et al. Physical activity and incidence of non-insulin-dependent diabetes mellitus in women. *Lancet* 338:774–778, 1991.
18. Matthews, C. E., and P. S. Freedson. Field trial of a three dimensional activity monitor: comparison with self-report. *Med. Sci. Sports Exerc* 27:1071–1078.
19. National Heart, Lung, and Blood Institute. *Clinical Guidelines on the Identification, Evaluation, and Treatment of Overweight and Obesity in Adults: The Evidence Report.* Washington, DC: National Institutes of Health, Publication 98-4083, 1998, pp. 60.
20. National Institutes of Health. NIH consensus statement: physical activity and cardiovascular health. Hyattsville, MD: National Institutes of Health, Publication 13(3), 1995, pp. 1–183.

21. Nichols, J. F., C. G. Morgan, L. E. Chabot, J. F. Sallis, and K. J. Calfas. Assessment of physical activity with the Computer Science and Applications, Inc., accelerometer: laboratory versus field validation. *Res. Q. Exerc. Sport* 71:36–43.
22. Pereira, M. A., S. J. Fitzgerald, E. W. Gregg, et al. A collection of physical activity questionnaires for health related research. *Med. Sci. Sports Exerc.* 29:S43–S45, 1997.
23. Portney, L. G., and M. P. Watkins. *Foundations of Clinical Research: Applications to Practice*. East Norwalk, CT: Appleton and Lange, 1993, pp. 516–523.
24. Rennie, K., T. Rowsell, S. A. Jebb, D. Holburn, and N. J. Wareham. A combined heart rate and movement sensor: proof of concept and preliminary testing study. *Eur. J. Clin. Nutr.* 54:409–414, 2000.
25. Sallis, J. F., and B. E. Saelens. Assessment of physical activity by self-report: status, limitations, and future directions. *Res. Q. Exerc. Sport* 71:1–14, 2000.
26. Swartz, A. M., S. J. Strath, D. R. Bassett, Jr., et al. Estimation of energy expenditure using CSA accelerometers at hip and wrist sites. *Med. Sci. Sports Exerc.* 2(Suppl.):S450–S456, 2000.
27. Tryon, W. W., and R. Williams. Fully proportional actigraphy: a new instrument. *Behav. Res. Methods Instrum. Comput.* 28:392–403, 1996.
28. U.S. Department of Health and Human Services. Physical activity and health: a report of the surgeon general. Atlanta, GA: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Center for Chronic Disease Prevention and Health Promotion, Publication 017-023-00196-5, 1996, pp. 4.
29. Willett, W. C. *Nutritional Epidemiology*. New York: Oxford University Press, 1998, pp. 97–110.