Pedometer Measures of Free-Living Physical Activity: Comparison of 13 Models

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ABSTRACT

PATRICK L. SCHNEIDER, SCOTT E. CROUTER, and DAVID R. BASSETT, JR. Pedometer Measures of Free-Living Physical Activity: Comparison of 13 Models. *Med. Sci. Sports Exerc.*, Vol. 36, No. 2, pp. 331–335, 2004. **Purpose:** The purpose of this study was to compare the step values of multiple brands of pedometers over a 24-h period. The following 13 electronic pedometers were assessed in the study: Accusplit Alliance 1510 (AC), Freestyle Pacer Pro (FR), Colorado on the Move (CO), Kenz Lifecorder (KZ), New-Lifestyles NL-2000 (NL), Omron HJ-105 (OM), Oregon Scientific PE316CA (OR), Sportline 330 (SL330) and 345 (SL345), Walk4Life LS 2525 (WL), Yamax Skeletone EM-180 (SK), Yamax Digi-Walker SW-200 (YX200), and the Yamax Digi-Walker SW-701 (YX701). **Methods:** Ten males (39.5 ± 16.6 yr, mean ± SD) and 10 females (43.3 ± 16.6 yr) ranging in BMI from 19.8 to 35.4 $kg \cdot m^{-2}$ wore two pedometers for a 24-h period. The criterion pedometer (YX200) was worn on the left side of the body, and a comparison pedometer was worn on the right. Steps counted by each device were recorded at the end of the day for each of the thirteen pedometers. **Results:** Subjects took an average of 9244 $steps \cdot d^{-1}$. The KZ, YX200, NL, YX701, and SL330 yielded mean values that were not significantly different from the criterion. The FR, AC, SK, CO, and SL345 significantly underestimated steps ($P < 0.05$) and the WL, OM, and OR significantly overestimated steps ($P < 0.05$) when compared with the criterion. In addition, some pedometers underestimated by 25% whereas others overestimated by 45%. **Conclusion:** The KZ, YX200, NL, and YX701 appear to be suitable for most research purposes. Given the potential for pedometers in physical activity research, it is necessary that there be consistency across studies in the measurement of "steps per day." **Key Words:** STEPS, STEP COUNTER, MOTION SENSOR, WALKING

The objective quantification of physical activity is a challenge to those involved in research and practice. Traditionally, physical activity has been assessed using questionnaires, but there are limitations in subjects' recall ability, especially for ubiquitous, light-, or moderate-intensity activities (8). Thus, there has been interest in using objective monitors to record physical activity.

Pedometers are a type of motion sensor that are low-cost, unobtrusive, accurate (1,4,11), and their output (steps or distance) is easily comprehendible. Pedometers are typically worn on the belt or waistband and respond to vertical accelerations of the hip during gait cycles. They provide data on steps and some models estimate distance traveled and energy expenditure. Although pedometers measure ambulatory activity, they do not capture all types of physical activity (swimming, weight lifting, bicycling, etc.). Nevertheless, walking is one of the most common forms of activity and is readily captured by a pedometer. These devices are becoming increasingly popular in physical activity research on clinical interventions, community-wide interventions, surveillance, and international comparisons. A recent *PubMed* search revealed that the number of studies using pedometers nearly doubled (32 vs 60) from 1993–1997 to 1998–2002.

Pedometers have several practical applications. They can be used to: 1) distinguish between individuals who vary based on steps per day, 2) measure increases in physical activity with interventions, 3) conduct cross-study comparisons of different populations, and 4) compare time trends in physical activity. In addition, members of the general public are interested in using pedometers to determine whether they are meeting step recommendations. However, if the differences in steps between pedometer brands are large and a variety of brands are being used, then it becomes impossible to use pedometers for these purposes.

Pedometer models differ in regard to cost ($10–$200) and internal mechanisms. There are at least three basic types of mechanisms, including the spring-suspended lever arm with metal-on-metal contact, a magnetic reed proximity switch, and an accelerometer type (4,11). The first mechanism uses a spring-suspended horizontal lever that moves up and down in response to the hip's vertical accelerations. This movement opens and closes an electrical circuit; the lever arm makes an electrical contact (metal-on-metal contact), and a step is registered. The second type of mechanism is a magnetic reed proximity switch. This type also uses a spring-suspended horizontal lever arm; however, with this mechanism, a magnet is attached to the lever arm, and it is the magnetic field that causes two overlapping pieces of metal encased in a glass cylinder (magnetic reed proximity switch) to touch, resulting in a step being counted. The third

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type uses an accelerometer-type mechanism consisting of a horizontal beam and a piezo-electric crystal. The walking motion generates a sinusoidal curve when vertical acceleration is plotted against time. This mechanism uses zero crossings of the acceleration vs time curve to detect steps.

A second issue is sensitivity, which is related to the internal mechanism, and is a function of the vertical acceleration "threshold" needed to trigger a step. Previous studies (1,4,11) have shown that these differences may translate into variations in accuracy among pedometer models. Some models have been shown to be accurate over a fixed distance (1,11) or at a variety of treadmill speeds (1,4) compared with direct observation of steps. However, no study has compared pedometer models under free-living conditions over 24 h. This is an important issue because pedometer output is often reported as "steps per day."

One of the difficulties in assessing pedometer accuracy under free-living conditions is the lack of a "gold standard." Although pedometer accuracy can be assessed by counting steps in controlled laboratory experiments, it is not be feasible to assess pedometer accuracy in this manner over 24 h. Therefore, it was decided to use a single pedometer (Yamax SW-200) as the criterion. In controlled laboratory settings, the Yamax SW series pedometers have consistently been shown to be among the most accurate (4,11). In addition, the Yamax pedometer is commonly used in applied research (7,9,13,16). The purpose of this study was to compare the step values of multiple brands of pedometers over the course of a 24-h period.

METHODS

Pedometers. The criterion pedometer selected for this study was the Yamax SW-200 (YX200). The SW series pedometer has performed very well in previous validation studies. The SW-701 (which has the same mechanism as the SW-200) consistently gave values within 3% of actual steps taken during a self-paced walk, on an individual basis (10). Moreover, this pedometer gave mean step counts that were within 1% of actual steps. At walking speeds ranging from 54 to 107 $m \cdot min^{-1}$, the SW-701 was the only one out of 10 models that did not differ significantly from actual steps taken (4). Finally the SW-200 pedometer was found to have similar accuracy in normal weight, overweight, and moderately obese individuals (12).

Thirteen models of commercially available electronic pedometers were assessed in this study: Accusplit Alliance 1510 (AC), Freestyle Pacer Pro (FR), Colorado on the Move (CO), Kenz Lifecorder (KZ), New-Lifestyles NL-2000 (NL), Omron HJ-105 (OM), Oregon Scientific PE316CA (OR), Sportline 330 (SL330) and 345 (SL345), Walk4Life LS 2525 (WL), Yamax Skeletone EM-180 (SK), Yamax Digi-Walker SW-200 (YX200), and the Yamax Digi-Walker SW-701 (YX701).

Subjects. Ten male (39.5 ± 16.6 yr) and 10 female adults (43.3 ± 16.6 yr) ranging in BMI from 19.8 to 35.4 $kg \cdot m^{-2}$ volunteered to participate in the study. The procedures were reviewed and approved by the Institutional Review Board (IRB) at the University of Tennessee. Each subject completed a Physical Activity Readiness Questionnaire (PAR-Q) and signed a written informed consent before participating in the study. Height was measured without shoes using a stadiometer and weight was also assessed without shoes in light clothing using a calibrated physician's scale. Physical characteristics of the subjects are presented in Table 1.

TABLE 1. Physical characteristics of subjects.

	Men (N = 10)	Women (N = 10)	All Subjects (N = 20)
Age (yr)	39.5 ± 16.6	43.3 ± 16.6	41.4 ± 16.3
Height (cm)	181.6 ± 5.6	164.6 ± 7.3	173.1 ± 10.8
Weight (kg)	89.2 ± 17.3	66.6 ± 8.6	77.9 ± 17.7
BMI ($kg \cdot m^{-2}$)	26.9 ± 4.6	24.6 ± 3.2	25.8 ± 4.1
Steps · d^{-1}	9525 ± 2349	8963 ± 2466	9244 ± 3727

Values are Mean ± standard deviation; BMI, body mass index.

Protocol. All participants wore the Yamax SW-200 (criterion) on the left side of the body and a comparison model on the right side for a 24-h period, except when sleeping or showering. Each subject was tested over 13 d, and the order of testing was randomized for the various pedometer models. (On one of these days the YX200 model was compared with a YX200 on the opposite side of the body to test for left vs right side differences.) Previous studies using the same brand of pedometer have shown that there is no statistically significant difference between pedometers worn on the right and left sides of the body (1,4,11). Among the 20 participants, five devices of each model were tested to provide a more representative sample.

Pedometer placement was standardized by placing it on the belt or waistband, in the midline of the thigh, consistent with the manufacturers' recommendations. Pedometers with a variable sensitivity switch (OM and OR) were always placed in the middle setting. Subjects were instructed to put the pedometers on each morning and reset each device to zero, with the exception of two models (KZ and NL), which have internal clocks and reset on their own at midnight. Subjects then wore the pedometers over the course of the entire day and wrote the values down on a log sheet before going to bed each night. This procedure was repeated until all 13 pedometers were compared with the criterion. The subjects were instructed not to wear the pedometers on Sundays due to the fact that significantly fewer steps are usually taken on Sundays compared with all other days of the week (2).

Statistical analysis. All analyses were performed using SPSS 11.0.1 for Windows (SPSS, Inc., Chicago, IL). For all analyses, an alpha of 0.05 was used to denote statistical significance. A difference score (comparison − criterion) was computed and compared with zero. Difference scores of zero would indicate that there was no difference between the criterion pedometer and the comparison pedometer. Positive difference scores represent overestimations and negative scores represent underestimations. A two-way repeated measures ANOVA was used to determine whether there was a significant difference between the mean difference scores of various pedometers and to determine whether there was

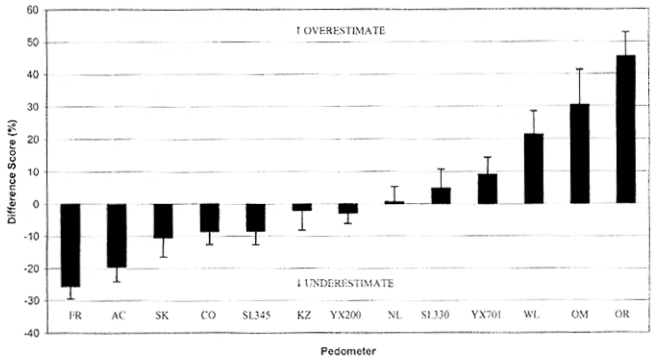

FIGURE 1—Mean difference scores [(comparison − criterion pedometer)/criterion] ± SE as a percentage of the criterion estimated steps over a 24-h period. Positive difference scores represent overestimations, and negative difference scores indicate underestimations of steps compared with the criterion pedometer.

TABLE 2. Difference scores (comparison − criterion pedometer) in number of steps over a 24-hr period.

Pedometer	Mean	SD	95% CI	95% PI
FR*	−2445	2157	−3454, −1436	−6672, 1782
AC*	−2189	2697	−3451, −926	−7475, 3098
SK*	−1161	2279	−2228, −94	−5629, 3307
CO*	−1042	2146	−2407, −38	−5249, 3164
SL345*	−997	1872	−1873, −121	−4666, 2673
KZ	−703	1537	−1422, 17	−3716, 2311
YX200#	−372	1685	−1161, 417	−3675, 2931
NL	206	1539	−514, 926	−2809, 3222
YX701	426	1547	−298, 1149	−2606, 3457
SL330	443	1885	−439, 1325	−3251, 4137
WL†	1099	1833	241, 1957	−2493, 4691
OM†	2266	3019	853, 3679	−3652, 8183
OR†	3636	2662	2390, 4882	−1583, 8854

SD, standard deviation; CI, confidence interval; PI, prediction interval.
* Significantly lower than the criterion ($P < 0.05$).
† Significantly higher than the criterion ($P < 0.05$).
\# This pedometer is also sold under the names Accusplit AE120 and Walk4Life LS2000.

a significant difference in the mean difference scores between genders. Independent *t*-tests were used to determine if the comparison models were significantly different from the criterion.

Bland-Altman (3) plots were constructed to show the distribution of the individual (criterion − comparison) scores around zero. This is a standard method to show the accuracy of biomedical devices (18). In this manner, the mean difference (criterion − comparison) can be illustrated and the 95% prediction interval (i.e., 95% confidence interval for the individual observations) can also be shown. Pedometers that have a tight prediction interval around zero are more accurate.

RESULTS

Subjects took an average of 9244 steps·d^{-1} according to the criterion pedometer. There was no significant interaction between pedometer model and gender, and there were no significant gender differences ($P > 0.05$). However, there were significant differences ($P < 0.05$) among the 13 pedometer models. Figure 1 displays the mean difference scores expressed as a percentage of the steps counted by the criterion pedometer. Table 2 displays mean difference scores, standard deviations, and 95% confidence intervals for each pedometer model. The FR, AC, SK, CO, and SL345 significantly underestimated steps whereas the WL, OM, and OR significantly overestimated ($P < 0.05$). Figure 2 shows the Bland-Altman plots for various pedometer models. The Oregon Scientific pedometer appeared to overestimate steps to a greater extent at higher step counts. However, this was an isolated case as other models did not show this type of systematic error.

DISCUSSION

In the current study, 5 (KZ, YX200, NL, YX701, and SL330) of the 13 pedometers tested yielded mean values that were not significantly different from the criterion. Five (FR, AC, SK, CO, and SL345) pedometers significantly underestimated steps and three (WL, OM, and OR) significantly overestimated steps, compared with the criterion (YX200).

The statistical power in the present study was adequate to detect a 10% difference among pedometer brands. This roughly coincided with what we considered to be a meaningful difference. For research purposes, we suggest using one of the models that did not significantly differ from the criterion. The pedometers that met this standard are the KZ, YX200, NL, YX701, and SL330. However, given the fact that statistical significance is a function of sample size (15), some emphasis should be placed on practical significance. Thus, we suggest that the CO and SL345, which were significantly different from the criterion but had mean values within 10% of the criterion would be suitable choices for physical activity promotion purposes.

The following pedometer determined steps per day activity classifications have been proposed: <5000 sedentary, 5000–7499 inactive, 7500–9999 somewhat active, and ≥10,000 active (17). Having standardization among pedometer brands is necessary to ensure that such a classification scheme for activity status is meaningful. If a pedometer yields mean scores that are not within ± 10% of the criterion, the risk of misclassification increases, making it difficult to compare results across studies. In addition, given that the same pedometer model on the right and left hip can differ by 5%, this suggests that an acceptable difference of less than 10% may be too strict. It is important to note that an acceptable difference of 10% applies only to free-living conditions. Laboratory type validations must be held to a higher standard as suggested in previous publications (4,11).

Schneider et al. (11) previously showed that the KZ, NL, and YX701 were the most accurate pedometers at counting steps during a 400-m track walk at a self-selected pace. These three pedometers are all made in Japan and they all met the Japanese Industrial Standard set by the Ministry of Industry and Trading regulations (5), which requires less than a 3% margin of error (3 steps out of 100). Interestingly, these same three devices (KZ, NL, and YX701) were among the five pedometers that were not significantly different from the criterion (YX200) in the present study.

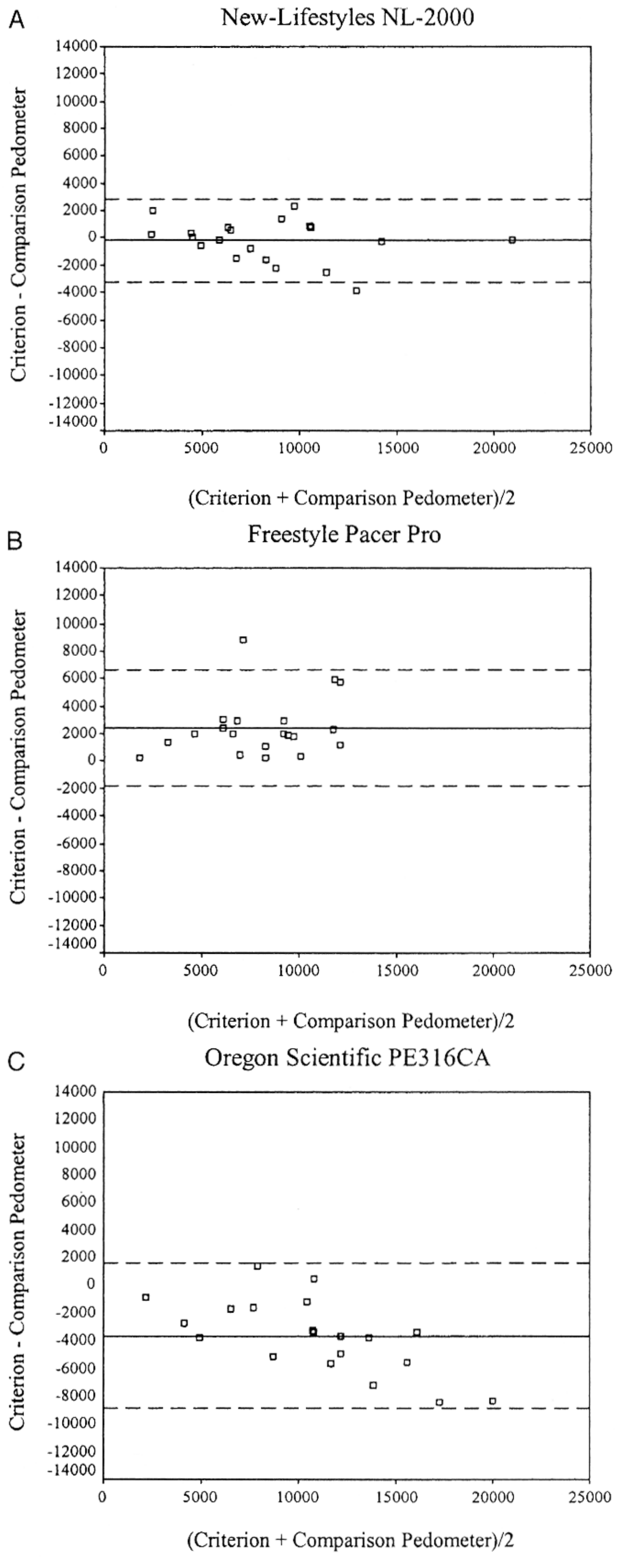

FIGURE 2—Representative Bland-Altman plots for three pedometers with varying accuracy. The New Lifestyles NL-2000 (NL) was one of the five most accurate pedometers, the Freestyle Pacer Pro (FR) was among the five pedometers that significantly underestimated steps ($P < 0.05$) compared with the criterion, and the Oregon Scientific PE316CA (OR) was one of three pedometers that significantly overestimated steps ($P < 0.05$). ***Solid horizontal line*** **= mean error score,** ***dashed lines*** **= 95% prediction intervals (i.e., 95% confidence intervals of the individual observations).**

Crouter et al. (4) also showed that the KZ, NL, and YX701 were among the most accurate pedometers at counting steps on the treadmill at speeds ranging from 54 to 107 m·min^{-1}. These three pedometers, along with the WL, showed acceptable accuracy (recording at least 88% of actual steps) at a slow speed (54 m·min^{-1}) and thus were considered a good choice for research studies. In that study, these same three pedometers were among six that gave mean values within ± 1% of the actual steps taken at 80 m·min^{-1} and above.

There are four plausible explanations for the step counting discrepancy that exists among pedometer models. First, models may differ in their vertical acceleration threshold required to trigger a step. This feature is related to the internal mechanism of the device, which has been described in a previous publication (11). Those devices that are highly sensitive compared with the criterion model are prone to overestimate steps while those that are less sensitive would likely underestimate steps. The Yamax SW-200 requires an acceleration ≥ 0.35 *g* to register a step (16). Tudor-Locke et al. (16) compared a pedometer (YX200) and the CSA model 7164 accelerometer/step counter over a 24-h period and found a significant difference in mean step counts with the YX200 counting 1845 fewer steps per day than the CSA. This difference was attributed to the CSA's lower vertical acceleration threshold required to record a step compared with the YX200 (0.30 *g* vs 0.35 *g*). Although the lower threshold of the CSA makes it more likely to capture steps at slower walking speeds, it is also apt to detect nonambulatory activity such as twisting, fidgeting, and bending as well as mechanical vibration (e.g., motor vehicle travel) (7). Second, some pedometers (FR, AC, and SL345) are programmed to only begin recording steps after four consecutive steps have been taken. For example, if an individual took just four steps and then stopped, the steps would not be counted. However, if he took five or more consecutive steps, each step would be counted (the first four steps do not appear on the output screen but the fifth step registers as a five and every step is counted individually thereafter). This feature would logically result in an underestimation in steps when compared with a device that counts every step regardless of whether or not they were taken in succession. Third, some devices may be more accurate than others in overweight or obese subjects. In an individual with a significant amount of abdominal obesity, the pedometer may not be vertically aligned resulting in decreased accuracy (11). Finally, one device (OR) has been shown to frequently double-count steps (11), which explains the overestimation in this study.

Previous studies have shown that waist-mounted pedometers gave mean values within ± 12% at speeds ≥ 80 m·min^{-1} (1,4) although they tend to underestimate steps taken at slower walking speeds. A gait laboratory study found that the self-selected walking speed of 200 healthy adults averaged 84 m·min^{-1} (14). Taken together, this might lead one to conclude that most pedometers would yield fairly similar values (steps per day) in free-living adults. However, the present study found large mean error scores between pedometers, ranging from an underestimation of 25% to an overestimation of 45%, for 24-h data. This suggests that a large percentage of steps taken throughout the day might be accumulated at slower speeds or in light activity. For future studies, we recommend the selection of a pedometer model that compares closely with the criterion model used in the current study. This would help to ensure standardization of free-living pedometer data.

Hatano (5) has proposed that taking 10,000 steps per day would be effective for cardiovascular disease prevention. He estimates that a 60-kg Japanese male would expend at least 333 $kcal \cdot d^{-1}$ in walking 10,000 steps. Earlier research indicates that this amount (>2000 $kcal \cdot wk^{-1}$) appears to be protective against heart attacks (8). Alternatively, Hill has proposed that weight gain could be eliminated by some combination of increasing energy expenditure and decreasing energy intake by 100 $kcal \cdot d^{-1}$ (6). He notes that energy expenditure can be increased by 100 $kcal \cdot d^{-1}$ by walking an extra mile each day. Hill et al. (6) state that "Walking a mile, whether done all at once or divided up across the day, burns about 100 kcal, which would theoretically completely abolish the energy gap and hence weight gain for most of the population. A mile of walking for most people is only about 2000 to 2500 extra steps . . .." Whether one's goal is to take 10,000 steps per day or to increase normal daily walking by 2000 steps per day, it is essential that the pedometer counts are standardized. In this study, there were several individual occasions where the comparison pedometer gave values that under or overestimated steps by 35–60%, respectively. These inconsistencies in pedometer-estimated steps would make it difficult to measure progress toward meeting various daily step goals.

In conclusion, the present study shows that there are differences between models in pedometer measures of free-living physical activity. Five pedometers appear to give similar values for steps per day compared with the criterion (YX200). However, one of these (SL330) was shown to be unreliable in a previous study (11) and therefore cannot be recommended. The remaining four pedometers (KZ, YX200, NL, and YX701) seem to be suitable for applied physical activity research. To standardize results across studies, researchers should use one of these pedometers or demonstrate the equivalence of a different pedometer using a similar research design. Given the increasing use of pedometers in physical activity research, it is imperative that there be consistency across studies in the measurement of "steps per day."

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REFERENCES

1. Bassett, D. R., B. E. Ainsworth, S. R. Leggett, et al. Accuracy of five electronic pedometers for measuring distance walked. *Med. Sci. Sports Exerc.* 28:1071–1077, 1996.
2. Bassett, D. R., A. L. Cureton, and B. E. Ainsworth. Measurement of daily walking distance-questionnaire versus pedometer. *Med. Sci. Sports Exerc.* 32:1018–1023, 2000.
3. Bland, J. M., and D. G. Altman. Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet* 1:301–310, 1986.
4. Crouter, S. E., P. L. Schneider, M. Karabulut, and D. R. Bassett. Validity of ten electronic pedometers for measuring steps, distance, and energy cost. *Med. Sci. Sports Exerc.* 35:1455–1460, 2003.
5. Hatano, Y. Use of the pedometer for promoting daily walking exercise. *ICHPER J.* 29:4–8, 1993.
6. Hill, J. O., H. R. Wyatt, G. W. Reed, and J. C. Peters. Obesity and the environment: where do we go from here? *Science* 299:853–855, 2003.
7. Le Masurier, G., and C. Tudor-Locke. Comparison of pedometer and accelerometer accuracy under controlled conditions. *Med. Sci. Sports Exerc.* 35:867–871, 2003.
8. Montoye, H. J., H. C. G. Kemper, W. H. M. Saris, and R. A. Washburn. *Measuring Physical Activity and Energy Expenditure.* Champaign, IL: Human Kinetics, 1996, pp. 3–102.
9. Moreau, K. L., R. Degarmo, J. Langley, et al. Increasing daily walking lowers blood pressure in postmenopausal women with borderline to stage 1 hypertension. *Med. Sci. Sports Exerc.* 33:1825–1831, 2001.
10. Paffenbarger, R. S., A. L. Wing, and R. T. Hyde. Physical activity as an index of heart attack risk in college alumni. *Am. J. Epidemiol.* 108:161–175, 1978.
11. Schneider, P. L., S. E. Crouter, O. Lukajic, and D. R. Bassett. Accuracy and reliability of ten pedometers for measuring steps over a 400-m walk. *Med. Sci. Sports Exerc.* 35:1779–1784, 2003.
12. Swartz, A. M., D. R. Bassett, J. B. Moore, D. L. Thompson, and S. J. Strath. Effects of body mass index on the accuracy of an electronic pedometer. *Int. J. Sports Med.* 24:588–592, 2003.
13. Swartz, A. M., and D. L. Thompson. Increasing daily walking improves glucose tolerance in overweight women. *Prev. Med.* 37:356–362, 2003.
14. Temes, W. C. Cardiac Rehabilitation. In: *Essentials of Cardiopulmonary Physical Therapy*. E. A. Hillegass and H. S. Sadowsky (Eds.). Philadelphia: W.B. Saunders, 1994, p. 641.
15. Thomas, J. R., and J. K. Nelson. *Research Methods in Physical Activity*. Champaign, IL: Human Kinetics, 1996. p. 110.
16. Tudor-Locke, C., B. E. Ainsworth, R. W. Thompson, and C. E. Matthews. Comparison of pedometer and accelerometer measures of free-living physical activity. *Med. Sci. Sports Exerc.* 34:2045–2051, 2002.
17. Tudor-Locke, C., and D. R. Bassett. How many steps/day are enough? Preliminary pedometer indices for public health. *Sports Med.* (in press).
18. White, W. B., P. Lund-Johansen, and P. Omvik. Assessment of four ambulatory blood pressure monitors and measurements by clinicians versus intraarterial blood pressure at rest and during exercise. *Am. J. Cardiol.* 65:60–66, 1990.