Validity of 10 Electronic Pedometers for Measuring Steps, Distance, and Energy Cost

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ABSTRACT

CROUTER, S. E., P. L. SCHNEIDER, M. KARABULUT, and D. R. BASSETT, JR. Validity of 10 Electronic Pedometers for Measuring Steps, Distance, and Energy Cost. *Med. Sci. Sports Exerc.*, Vol. 35, No. 8, pp. 1455–1460, 2003. **Purpose:** This study examined the effects of walking speed on the accuracy and reliability of 10 pedometers: Yamasa Skeletone (SK), Sportline 330 (SL330) and 345 (SL345), Omron (OM), Yamax Digiwalker SW-701 (DW), Kenz Lifecorder (KZ), New Lifestyles 2000 (NL), Oregon Scientific (OR), Freestyle Pacer Pro (FR), and Walk4Life LS 2525 (WL). **Methods:** Ten subjects (33 ± 12 yr) walked on a treadmill at various speeds (54, 67, 80, 94, and 107 $m \cdot min^{-1}$) for 5-min stages. Simultaneously, an investigator determined steps by a hand counter and energy expenditure (kcal) by indirect calorimetry. Each brand was measured on the right and left sides. **Results:** Correlation coefficients between right and left sides exceeded 0.81 for all pedometers except OR (0.76) and SL345 (0.57). Most pedometers underestimated steps at 54 $m \cdot min^{-1}$, but accuracy for step counting improved at faster speeds. At 80 $m \cdot min^{-1}$ and above, six models (SK, OM, DW, KZ, NL, and WL) gave mean values that were within ± 1% of actual steps. Six pedometers displayed the distance traveled. Most of them estimated mean distance to within ± 10% at 80 $m \cdot min^{-1}$ but overestimated distance at slower speeds and underestimated distance at faster speeds. Eight pedometers displayed kilocalories, but except for KZ and NL, it is unclear whether this should reflect net or gross kilocalories. If one assumes they display net kilocalories, the general trend was an overestimation of kilocalories at every speed. If one assumes they display gross kilocalorie, then seven of the eight pedometers were accurate to within ±30% at all speeds. **Conclusion:** In general, pedometers are most accurate for assessing steps, less accurate for assessing distance, and even less accurate for assessing kilocalories. **Key Words:** ENERGY EXPENDITURE, PHYSICAL ACTIVITY, LOCOMOTION, AND EXERCISE

The electronic pedometer is a simple device that can be used to assess physical activity. In recent years, a wide variety of new electronic pedometers have been introduced, which makes it necessary to test these new devices for accuracy and reliability. With the phasing out of older analog models, the pedometer has evolved into a device that can also estimate distance traveled and energy expenditure (kcal). Some models have internal clocks and can store information for viewing or downloading to a computer. Concerning principles of operation, electronic pedometers use three basic mechanisms for recording steps. The original and most basic is a spring-suspended horizontal lever arm that moves up and down in response to vertical displacement of the waist. The lever arm opens and closes an electrical circuit with each step, and the number of steps are counted (e.g., Yamax Digiwalker SW-701 and Sportline 345). Some newer models have incorporated a glass-enclosed magnetic reed proximity switch (e.g., Omron and Oregon Scientific). The third type has an accelerometer consisting of a horizontal beam and a piezoelectric crystal (e.g., New Lifestyles and Lifecorder); steps are determined from the number of zero-crossings of the instantaneous acceleration versus time curve.

In 1996, Bassett et al. (1) assessed the accuracy of five electronic pedometers. To date, it is the only multi-brand comparison study of electronic pedometers, and none of the pedometers they examined are currently available. Bassett et al. found that at a walking speed of 2.0 mph, pedometers underestimated steps by 50–75%, but they became more accurate as the walking speed increased. At self-selected walking speeds of 80–107 $m \cdot min^{-1}$, the Yamax Digiwalker DW-500 recorded average values for steps and distance that were within 1% of actual. Nelson et al. (9) looked at the validity of the Yamax Digiwalker DW-500 in reporting gross kilocalories. Nelson et al. showed that at walking speeds of 3–4 mph on the treadmill, it provides valid results, but it significantly underestimates gross kilocalories at 2 mph and below. However, it is possible that the kilocalorie values displayed by pedometers are supposed to reflect net kilocalories (i.e., physical activity energy expenditure, above resting).

In recent years, new recommendations have been issued concerning the amount of physical activity that one should perform on a regular basis. The current recommendation from the U.S. Surgeon General is to accumulate at least 30 min of moderate-intensity physical activity on most days of the week (16). This is also supported by the Centers for

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Submitted for publication January 2003.
Accepted for publication April 2003.

0195-9131/03/3508-1455
MEDICINE & SCIENCE IN SPORTS & EXERCISE®

DOI: 10.1249/01.MSS.0000078932.61440.A2

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

	Men (N = 5)	Women (N = 5)	All Subjects (N = 10)
Age (yr)	34 ± 13	31 ± 13	32 ± 12
Height (cm)	180.9 ± 4.2	162.8 ± 7.3	171.9 ± 11.08
Weight (kg)	84.7 ± 32.6	68.1 ± 10.6	76.4 ± 24.49
BMI ($kg \cdot m^{-2}$)	25.7 ± 8.8	25.7 ± 3.2	25.7 ± 6.25
Stride length (m)	0.81 ± 0.07	0.78 ± 0.08	0.80 ± 0.07
RMR ($kcal \cdot d^{-1}$)*	2080 ± 502	1659 ± 307	1869 ± 451

* RMR measured by indirect calorimetry.

Disease Control and Prevention and the American College of Sports Medicine, which notes that the recommendation can be met by walking 2 miles briskly (10). Studies have shown that 30 min of brisk walking is equal to 3100–4000 steps, depending on the age of the population (13,17,19), which allows one to quantify a time recommendation in terms of steps taken. Others recommend a different approach to daily physical activity. Hatano (6) advocates taking a total of 10,000 steps per day for cardiovascular disease prevention. At the University of Colorado Health Sciences Center, Hill had developed a program called "Colorado On The Move" and recommends a 2000-step increase above one's normal step count for prevention of weight gain (8).

Taking into consideration these pedometer recommendations, the increasing use of pedometers in intervention studies, and their potential for surveillance of physical activity, it is important to have valid devices for measurement. Therefore, the purpose of this study was to examine the accuracy and reliability of 10 electronic pedometers for measuring steps taken, distance traveled, and kilocalories at various treadmill walking speeds.

METHODS

Subjects. Five males and five females from the University of Tennessee volunteered to participate in the study. The average (± SD) age and body mass index (BMI) were 33 ± 12 yr and 25.7 ± 6.3, respectively. The testing protocol was approved by the University of Tennessee Institutional Review Board before the start. Written informed consent was obtained from all subjects before testing. Age was recorded, and height and weight were measured in street clothes (without shoes) with a stadiometer and calibrated physician's scale, respectively. Stride length was measured by having the subjects take 20 strides down an indoor hallway at their normal walking speed. The total distance was divided by 20 to compute stride length. This was repeated three times and an average was programmed into the pedometers. Descriptive data of the subjects is presented in Table 1.

Protocol. Ten pedometers were examined to determine the effects of walking speed on steps taken, distance traveled, and energy expenditure (kcal): Yamasa Skeletone EM-180 (SK), Sportline 330 (SL330) and 345 (SL345), Omron HJ-105 (OM), Yamax Digiwalker SW-701 (DW), New Lifestyles NL-2000 (NL), Kenz Lifecorder (KZ), Oregon Scientific PE316CA (OR), Freestyle Pacer Pro (FR), and Walk4Life LS 2525 (WL). Before the first trial, the subjects received instructions for walking on the treadmill and were allowed time to adapt to walking at the various speeds. The subjects walked at speeds of 54, 67, 80, 94, and 107 $m \cdot min^{-1}$ on a motor driven treadmill (Quinton model Q55XT, Seattle, WA). The treadmill speed and grade were calibrated before testing according to the manufacturer's instructions. Energy expenditure was measured by indirect calorimetry for all trials, except for devices that were solely step counters (SK and SL330). Measurements were made using a TrueMax 2400 computerized metabolic system (ParvoMedics, Salt Lake City, UT), which has been validated against the Douglas bag method in our laboratory (3). Before each test, the O_2 and CO_2 analyzers were calibrated using gases of known concentrations, and the flowmeter was calibrated using a 3.00-L syringe.

One electronic pedometer of each brand was worn on the right and left sides of the body, in the midline of the thigh. For the electronic pedometers that had a variable sensitivity switch (OR and OM), it was placed in the middle setting. Each trial consisted of 5 min of walking at the given speed to allow the subject to reach steady state. An average of the last 2 min was used for calculation of actual gross kilocalories. An investigator tallied actual steps with a hand counter. Between trials, the subject stepped off the treadmill for 1 min so that values from the electronic pedometers could be recorded.

Resting metabolic rate (RMR) was measured by a TrueMax 2400 metabolic system. The subjects came in early in the morning after an overnight fast, with the exception of water. They were also asked to refrain from the use of stimulants (including caffeine, tobacco, and medication) and intense physical activity. Once the subject arrived, they were allowed to relax in a reclining position while the test was explained. Gas exchange measurements were made for 40 min. The first 20-min period allowed the individual to return to resting levels and adapt to the mouthpiece, and the second 20 min-period was used for the determination of RMR. The measured RMR was then subtracted from the measured gross kilocalories, during treadmill walking, to obtain net kilocalories.

Statistical treatment. Statistical analyses were carried out using SPSS version 11.0.1 for windows (SPSS Inc., Chicago, IL). Initially, two-way repeated measures ANOVA (side of body × speed) were carried out on each pedometer brand, but because the results showed no effects of placement site (L vs R), the two sides were averaged. Intraclass correlation coefficients were used to report comparison between right and left side measures of the same electronic pedometer. Subsequently, two-way ANOVA (speed × pedometer brand) were used to compare mean difference scores (pedometer minus actual) for steps taken, distance traveled, and net and gross kilocalories. An alpha of $P < 0.05$ was used to denote statistical significance. Although mean difference scores were used for statistical analysis, they do not give a good representation of how accurate the pedometer is when presented in a graph, because the total amount of steps are not known. Therefore, all graphs are presented with percent difference scores, which allow for easier illustration of how accurate the pedometers were.

TABLE 2. Intraclass correlation coefficients for pedometers worn on the right and left sides of the body.

Pedometer	ICC (95% CI)
SL330	0.91 (0.85, 0.95)
SK	0.83 (0.89, 0.96)
OM	0.83 (0.71, 0.90)
DW	0.98 (0.94, 0.98)
KZ	0.94 (0.90, 0.97)
NL	0.99 (0.98, 0.99)
OR	0.76 (0.61, 0.86)
SL345	0.57 (0.35, 0.73)
FR	0.95 (0.92, 0.97)
WL	0.81 (0.68, 0.89)

RESULTS

All trials were completed without problems, except that one of the NL pedometers had to be replaced by a new device because of a broken mechanism. Correlation coefficients between the right and left sides exceeded 0.81 for all pedometers except OR (0.76) and SL345 (0.57) (Table 2).

Table 3 shows significant differences from actual steps, and Figure 1 shows percentage of actual steps at each speed. In general, pedometers tended to underestimate actual steps at 54 and 67 m·min^{-1}. Several pedometers were accurate at speeds of 80 m·min^{-1} and above, with six models (SK, OM, DW, NL, KZ, and WL) providing mean values that were within ± 1% of actual steps. Only one pedometer (DW) did not significantly differ from actual steps at any speed ($P > 0.05$), whereas the OR was significantly different from actual steps at all speeds ($P < 0.05$).

Six pedometers displayed the distance traveled (OM, DW, OR, SL345, FR, and WL). Table 4 shows significant differences from actual steps, and Figure 2 shows percentage of actual distance traveled at each speed. In general, the pedometers tended to overestimate distance traveled at slower speeds and underestimate distance traveled at higher speeds, with 80 m·min^{-1} being the most accurate speed for most pedometers. All electronic pedometers were significantly different ($P < 0.05$) for at least two speeds, except for FR, which was significantly different ($P < 0.05$) at only one speed (107 m·min^{-1}).

Eight pedometers displayed estimates of energy expenditure (OM, DW, NL, KZ, OR, SL345, FR, and WL). With the exception of NL and KZ, it is unclear whether they are displaying net or gross kilocalories. New Lifestyles NL-2000 and KZ estimate gross kilocalories by taking into account the subject's RMR (based on input of age, gender, weight, and height). Table 5 shows significant differences from actual gross and net kilocalories. Figure 3 shows the

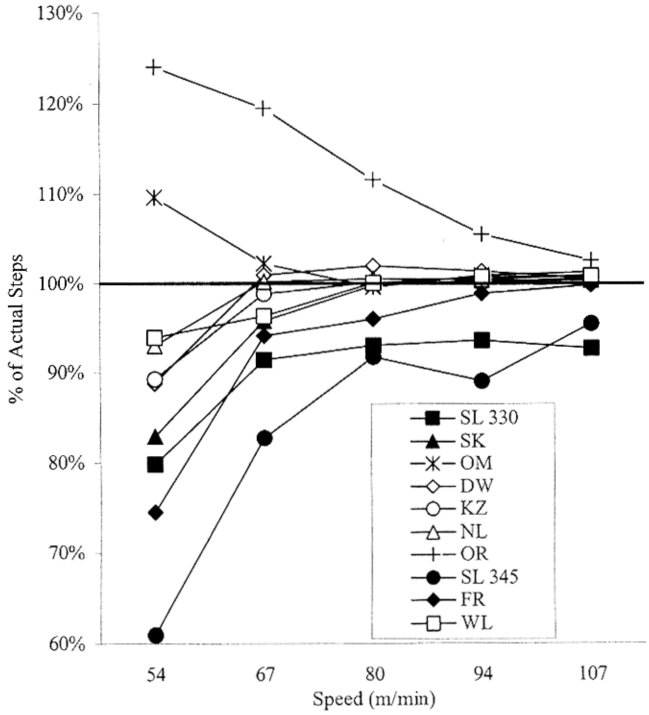

FIGURE 1—Effect of speed on pedometer accuracy (percentage of actual steps) during treadmill walking.

percent difference from actual gross kilocalories at all speeds, and Figure 4 shows the percent differences from actual net kilocalories at all speeds. Only one electronic pedometer (FR) was not significantly different ($P > 0.05$) from gross kilocalories at any speed. For net kilocalories, all electronic pedometers were significantly different ($P < 0.05$) for at least four speeds, except for KZ, which was significantly different ($P < 0.05$) at only one speed (94 m·min^{-1}).

DISCUSSION

The use of pedometers in both research and practice is rapidly growing, as these devices provide an inexpensive, objective means of assessing physical activity, and they are generally believed to be accurate and reliable. Researchers usually prefer to express pedometer data as "steps," because that is the most direct expression of what the pedometer measures (11,14,15). Six pedometers (SK, OM, DW, NL, KZ, and WL) out of the 10 gave mean values that were within ± 1% of actual values at speeds of 80 m·min^{-1} and above. The Japanese industrial standards have set the max-

TABLE 3. Pedometer accuracy for measuring steps during horizontal treadmill walking at five different speeds.

Speed (m·min^{-1})	SL330	SK	OM	DW	KZ	NL	OR	SL345	FR	WL
54	−	−					+	−	−	
67		−					+	−		
80						+	+			
94						+	+			+
107		+	+		+	+	+			+

+, Significant overestimation of actual steps ($P < 0.05$).
−, Significant underestimation of actual steps ($P < 0.05$).

TABLE 4. Pedometer accuracy for measuring distance traveled during horizontal treadmill walking at five different speeds.

Speed (m·min^{-1})	OM	DW	OR	SL345	FR	WL
54	+		+			+
67	+	+	+			+
80	+					
94			−	−		
107		−	−	−	−	−

+, Significant overestimation of actual distance traveled ($P < 0.05$).
−, Significant underestimation of actual distance traveled ($P < 0.05$).

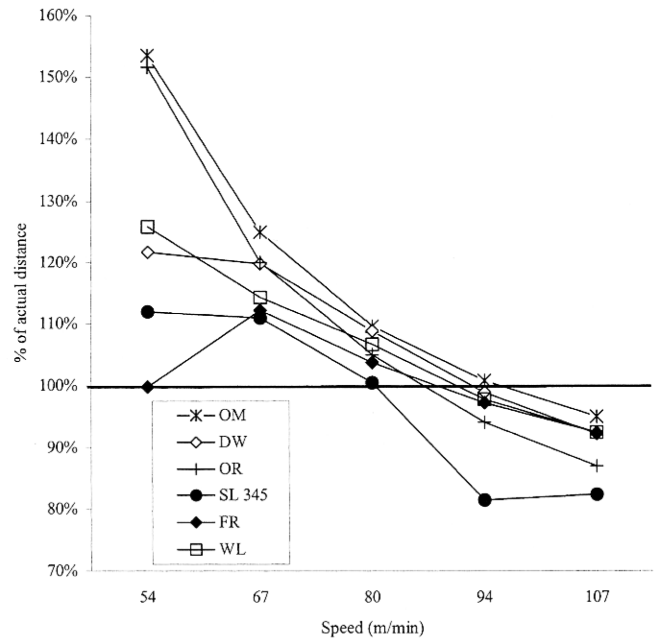

FIGURE 2—Effect of speed on pedometer estimates of percentage of actual distance traveled during treadmill walking.

imum permissible error of miscounting steps at 3%, or 3 steps out of 100 (7). It is interesting that all five of the pedometers made by Japanese companies met this recommendation, whereas only one of the non-Japanese pedometers (WL, made in Taiwan) was as accurate.

At slower speeds, the pedometers were not as accurate in step counting. This results from the fact that vertical accelerations of the waist are less pronounced at slow walking speeds, so it is less likely that the threshold value to record a step (e.g., 0.35 *g* for DW) will be exceeded. Four pedometers (WL, KZ, NL, and DW) showed acceptable accuracy at speeds 54 $m \cdot min^{-1}$ (or 2 mph), indicating that these pedometers are a good choice for use in research studies. However, it should be noted that in the frail elderly or others with a slow, shuffling gait, even these brands of pedometers are probably inadequate to obtain a true assessment of walking (4,13,18).

Most pedometers were fairly accurate for measuring distance at a speed of 80 $m \cdot min^{-1}$, providing mean estimates

TABLE 5. Pedometer accuracy for measuring gross and net kilocalories during horizontal treadmill walking at five different speeds.

Speed ($m \cdot min^{-1}$)	OM	DW	KZ	NL	OR	SL345	FR	WL
Gross kcals								
54				+	+			+
67				+	+			+
80		+	+	+	+			+
94	−		+	+	+			+
107	−			+	+	−		−
Net kcal								
54	+	+		+	+			+
67	+	+		+	+	+	+	+
80	+	+		+	+	+	+	+
94	+	+	+	+	+	+	+	+
107		+			+	+	+	+

+, Significant overestimation of actual gross or net kcal ($P < 0.05$).
−, Significant underestimation of actual gross or net kcal ($P < 0.05$).

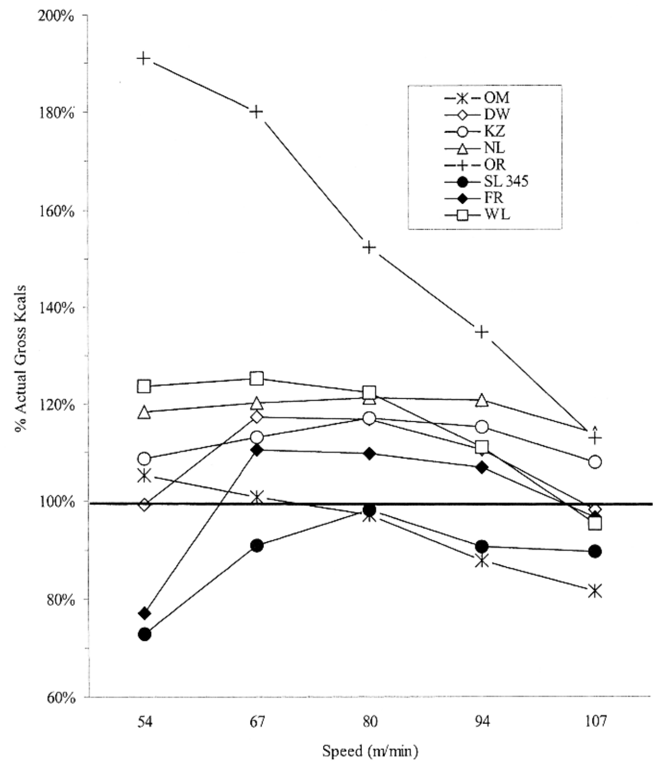

FIGURE 3—Effects of speed on pedometer estimates of percent of actual gross kilocalories during treadmill walking.

that were within ± 10% of the actual values. The stride length that was programmed into the pedometer was determined at self-selected walking speeds, which approximate 84 $m \cdot min^{-1}$ in healthy adults (12). At slower speeds, the actual stride length was shorter than the value pro-

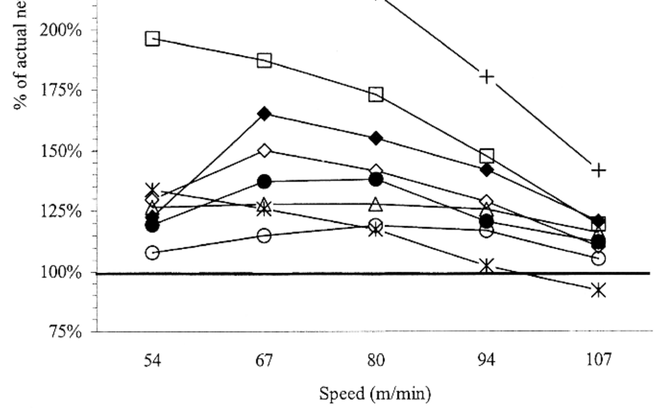

FIGURE 4—Effects of walking speed on pedometer estimates of percentage of actual net kilocalories during treadmill walking.

grammed into the pedometer, causing an overestimation of distance. At faster speeds, the actual stride length was longer than the programmed value, causing the distance to be underestimated.

The distance traveled was not only affected by stride length but also by the sensitivity of the pedometers (and accuracy in counting steps). Two of the pedometers FR and SL345 appeared to be the most accurate for measuring distance at slower speeds (<80 $m \cdot min^{-1}$), but when other factors are taken into consideration, it can be seen that they grossly undercounted steps. This is a case of "compensating errors" where overestimation of stride length and underestimation of steps offset each other and make these two models appear accurate for assessing distance.

In most cases, it is not clear whether pedometers measure gross or net kilocalories. Previous investigators have reached different conclusions on what the measured kilocalories value given by the pedometer actually represents. Nelson et al. (9) assumed that the values displayed by the Yamax Digiwalker 500 were gross kilocalories and found that at normal walking speeds (80–107 $m \cdot min^{-1}$) it gave a close estimate of gross kilocalories. Bassett et al. (2), in a study of lifestyle activities (yard work, housework, childcare, occupational tasks, and recreation) assumed that they displayed net kilocalories (above RMR) and found that at walking speeds between 78 and 100 $m \cdot min^{-1}$ the Yamax SW-701 overestimates net kilocalories. During most other lifestyle activities, however, they saw an underestimation of net kilocalories. In looking at the kilocalories data from the present study, it appears that it should be assumed that electronic pedometers are estimating gross kilocalories if the activity mode is walking. This invariably means that pedometers will underestimate the cost of most other types of "lifestyle" activities, especially those involving arm activity, pushing or carrying objects, walking uphill, or stair climbing. This is a limitation when attempting to use pedometers to quantify daily physical activity energy expenditure (2). Nevertheless, pedometers are useful in that they provide a valid, reliable measure of ambulatory activity, which is one of the most prevalent forms of activity in today's society (5,14). We believe that expressing pedometer data as "$steps \cdot d^{-1}$" provides an extremely useful index of an individual's overall ambulatory activity level. Expressing the data in this manner eliminates the need to make adjustments for height or body weight when comparing individuals, which is advantageous.

The NL and KZ provide estimates of both net and gross kilocalories, made possible because they predict the user's RMR based on age, height, weight, and gender. It should be noted that while although devices can be called "pedometers" because they measure steps, they are actually accelerometers in terms of principles of operation. Thus, activity energy expenditure is computed by integrating the acceleration versus time curve, and activities like jogging (where there is a greater amplitude of the acceleration curve) will be credited with more kilocaloriess per step than activities like walking. These two models are also unique in that they have internal memory chips that allow them to store data. The NL can store up to 7 d of data, whereas the KZ can store up to 42 d of data in 1-d epochs. This data storage feature may be useful for researchers who do not wish to rely on subjects "logging" their own steps.

Overall, it appears that DW is the most accurate at predicting steps, distance, and gross kilocalories for walking. The WL is close in terms of accuracy, although the reliability coefficient was only 0.84. The NL and KZ do not have the ability to measure distance, but they were among the most accurate at measuring steps. In addition, they have the ability to: (a) store multiple days of data, (b) distinguish between the kilocalories expended per step in walking and running, and (c) provide rough estimates of net and gross energy expenditure. The KZ can store 42 d of data, which can be downloaded to a computer for subsequent analysis. The drawback to KZ is that it has a higher cost, around $200, plus $250 for the computer interface and software.

In conclusion, it is not our intention to endorse any one pedometer for all purposes. Our objective is to make researchers aware of the validity of these devices and allow them to make the judgment of which pedometer to use. Whether the objective outcome is steps, distance, or kilocalories, consideration should be given as to which variable is the most important when determining which electronic pedometer to use.

The authors would like to thank Cary Springer (UTK Statistical Consulting Services) for performing the statistical analyses.

No financial support was received from any of the pedometer companies, importers, or retailers. The results of the present study do not constitute endorsement of the products by the authors or ACSM.

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