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Validity and Reliability of the Omron HJ-303 Tri-Axial Accelerometer-Based Pedometer

Jeremy A. Steeves, Brian M. Tyo, Christopher P. Connolly, Douglas A. Gregory, Nyle A. Stark, and David R. Bassett

Background: This study compared the validity of a new Omron HJ-303 piezoelectric pedometer and 2 other pedometers (Sportline Traq and Yamax SW200). ***Methods:*** To examine the effect of speed, 60 subjects walked on a treadmill at 2, 3, and 4 mph. Twenty subjects also ran at 6, 7, and 8 mph. To test lifestyle activities, 60 subjects performed front-back-side-side stepping, elliptical machine and stair climbing/descending. Twenty others performed ballroom dancing. Sixty participants completed 5 100-step trials while wearing 5 different sets of the devices tested device reliability. Actual steps were determined using a hand tally counter. ***Results:*** Significant differences existed among pedometers ($P < .05$). For walking, the Omron pedometers were the most valid. The Sportline overestimated and the Yamax underestimated steps ($P < .05$). Worn on the waist or in the backpack, the Omron device and Sportline were valid for running. The Omron was valid for 3 activities (elliptical machine, ascending and descending stairs). The Sportline overestimated all of these activities, and Yamax was only valid for descending stairs. The Omron and Yamax were both valid and reliable in the 100-step trials. ***Conclusions:*** The Omron HJ-303, worn on the waist, appeared to be the most valid of the 3 pedometers.

Keywords: steps, physical activity, walking, running

Pedometers have the ability to provide a valid, objective measure of overall ambulatory activity.[1–3] In general, pedometers fall into 2 different categories: spring-levered and piezoelectric.[4] The traditional spring-levered pedometers rely on a horizontal spring-suspended pendulum arm that moves up-and-down with each step, which opens and closes an electrical circuit. In contrast, the piezoelectric pedometer measures acceleration at frequent time intervals, and the number of peaks or 0 crossings are used to count steps.

Research has shown that spring-levered pedometers are susceptible to errors in overweight/obese individuals.[4–6] With increasing BMI and tilt angle, the error increases. Our previous research, and that of other investigators, has shown that piezoelectric pedometers (eg, Omron HJ-720ITC) have superior accuracy compared with the traditional spring-levered pedometers.[4–6]

Omron Healthcare, Inc. (Bannockburn, IL) recently introduced a new triaxial piezoelectric accelerometer (model HJ-303). According to the manufacturer, the triaxial design allows the pedometer to be oriented in any direction and still validly record steps.[7] This allows it to be worn either at the traditional waist-mounted location, but also in a pocket or backpack. Thus, the purpose of this study was to examine the validity of the new Omron HJ-303 pedometer at multiple wear locations (on the waist, in a pants pocket, or in a backpack) and compare it to 2 other pedometers (Sportline Traq and Yamax SW200) under a variety of conditions.

The authors are with the Dept of Exercise, Sport, and Leisure Studies, University of Tennessee, Knoxville, TN.

Methods

Participants

Sixty individuals, 31 males (36 ± 13.37 years) and 29 females (35 ± 12.37 years) were recruited from the University of Tennessee staff, student body and surrounding community. In addition, 20 University of Tennessee students (10 males and 10 females who had participated in ballroom dance classes) were recruited for the dancing part of the study. Participants were asked to read and sign an informed consent form, which was approved by the University of Tennessee Institutional Review Board (IRB) before taking part in the study. Before exercise, participants completed a Physical Activity Readiness Questionnaire (PAR-Q), and if they reported any contraindications to exercise they were not tested.

Anthropometric Measurements

For all participants, height and weight were measured (in light clothing, without shoes) using a wall-mounted stadiometer and a Tanita bioelectrical impedance analyzer (model BC-418), respectively. Body mass index (BMI) was calculated using the formula: body mass (kg) × [height (m)]$^{-2}$. Percent body fat was determined using the

Tanita BC-418 bioelectrical impedance analyzer. Waist circumference was measured to the nearest 0.1 cm using a Gulick spring-loaded tape measure over bare skin at the narrowest portion of the torso (above the umbilicus and below the xiphoid process). Means and standard deviations for the descriptive characteristics of subjects were computed; these are displayed in Table 1.

Pedometers

The Omron HJ-303 is an electronic pedometer that responds to body movements when walking. This device uses a triaxial microelectromechanical systems (MEMS) accelerometer that measures acceleration in the X, Y, and Z planes, and this information is used to count steps. Subject information such as age, height, weight, and gender can be input into the pedometer and estimates of steps, distance, and calories are provided. A 7-day memory with clock is provided, and it can store cumulative data up to 999,999 steps.

Sportline Traq is an accelerometer-based pedometer that is designed to be worn in the pocket. Subject information (age, height, weight, gender) can be input into the pedometer. It displays steps, distance, calories, date and time, and exercise time, and it has a pacing tone and a countdown of one's daily step goal.

The Yamax digi-walker SW200 is the most widely used pedometer in research studies. This pedometer is worn on the belt or waistband, and it uses a horizontal lever arm that is suspended by a coil spring, which bobs up-and-down when walking. This movement causes an electronic circuit to open and close, and steps are accumulated using a simple circuit board.[4] The SW-200 model has a reset button to set the steps to "0"; it has no memory and no other functions.

This 3-part study examined the validity of the pedometers at different speeds and during lifestyle activities. In part I, participants performed treadmill walking (2, 3, and 4 mph) and running (6, 7, and 8 mph). In Part II, they performed other physical activities (stair-climbing, stair-descending, front-back-side-side (FBSS) stepping, exercise on an elliptical machine and ballroom dancing). In Part III, reliability was determined by having individuals complete 5 100-step trials on a track while wearing 5 different sets of devices, each containing an Omron HJ-303 (worn on the waist, in the pants pocket, and in a backpack), a Sportline Traq, and a Yamax SW200 pedometer.

Part I: Treadmill Walking and Running

This part of the study examined the effects of speed on the validity of 3 pedometers (Omron HJ-303 (worn in pants pocket, waist-mounted and in a Camelback backpack), Sportline (worn in pants pocket), and Yamax (mounted on belt/waistband). Sixty participants with BMI values in the normal (N = 20), overweight (N = 20), and obese (N = 20) range walked 100 steps on a motor-driven treadmill (Quinton model Q55XT, Seattle, WA). Treadmill speeds were calibrated using a Shimpo DT-107 tachometer (Nidec-Shimpo America Corp., Itasca, IL). The treadmill was set at 0.0% grade, and this was verified using a carpenter's level.

Five sets of pedometers (labeled A-E) were used for this part of the study, so as not to base our conclusions on a single device of each brand. Each participant wore the next succeeding set from the participant before them. Even-numbered subjects wore the Omron's (waist and pants pocket) on the right side of the body, and the Sportline and Yamax SW200 on the left, while the odd-numbered subjects did the opposite. Three walking speeds were used (2, 3, and 4 mph). To determine the actual number of steps taken, an investigator used a hand-tally counter to count the participants' steps. The Yamax pedometer was reset to "0" just before the start of each trial. The Omron and Sportline pedometers could not be reset, so beginning and ending steps were recorded for each trial and the difference were computed. Each stage lasted 100 steps, and the stages were interrupted just long enough to increase the treadmill speed and record data.

Table 1 Physical Characteristics of Subjects (N = 80)

	Treadmill, other activities, and reliability			Ballroom dancers		
	Men (N = 31)	Women (N = 29)	All participants (N = 60)	Men (N = 10)	Women (N = 10)	All participants (N = 20)
Age (yr)	36 ± 13.37	35 ± 12.37	35 ± 12.8	23 ± 4.14	21 ± 1.78	22 ± 3.15
Height (cm)	180 ± 7.52	163 ± 20.47	171 ± 17.3	179 ± 6.48	165 ± 5.65	172 ± 9.13
Weight (lbs)	203 ± 41.21	171 ± 42.89	187 ± 44.6	171 ± 18.24	133 ± 9.92	152 ± 24.33
BMI (kg m^{-2})	28 ± 5.02	28 ± 6.75	28 ± 5.9	24 ± 2.78	22 ± 1.43	23 ± 2.47
Tanita (%BF)	22 ± 7.17	34 ± 9.34	27 ± 10.3	13 ± 3.99	25 ± 5.92	19 ± 7.76
Waist circumference (cm)	95 ± 13.91	87 ± 25.48	91 ± 20.5	82 ± 3.93	68 ± 3.47	75 ± 8.03

Note. Values are mean ± SD (range).

Abbreviations: BF, body fat.

The dependent variable was number of steps recorded. Individuals in the normal weight range (n = 20) also performed treadmill running at speeds of 6, 7, and 8 mph. Step counting and recording was done in the same fashion as for walking.

Part II: Other Activities

To evaluate the validity of the pedometers during stair-climbing, stair-descending, FBSS stepping, and exercise on an elliptical machine the same set of 60 participants participated in this part of the study. These activities were performed until the subject completed the task, or until they completed 100 steps. For the stair climbing activity, participants ascended 2 flights of stairs, and for stair descending they went down 2 flights of stairs. For FBSS stepping, starting with legs together, the participants stepped forward 30 cm with 1 foot and then brought both feet together. They then stepped back to their original position and then brought both feet together. This was repeated to the right side, then backward, then to the left side until 100 steps were accumulated. For the elliptical exercise machine, the participants performed exercise on a Bally elliptical machine (resistance setting = 3) for 100 steps.

Twenty different subjects completed the ballroom dance activity; these were University of Tennessee students who had participated in ballroom dance classes. They performed the foxtrot to music in pairs, until they completed 100 steps. The investigator observed 1 partner at a time and determined actual steps using a hand-tally counter.

Part III: Reliability Study

To evaluate interdevice reliability of pedometers, the same 60 participants completed 5 100-step trials (walking on an outdoor track) while wearing 5 different sets of devices. Each set consisted of 3 Omron HJ-303 devices (waist, pants pocket, and backpack), a Sportline, and a Yamax pedometer. An investigator determined the actual number of steps using a hand tally counter. For each 100-step trial, participants stood with both feet together while the first set of pedometers was positioned on them. The Yamax digi-walker SW-200 was reset to "0," and initial readings were recorded for the other pedometers. An investigator walked behind the participant, counting steps with a hand-tally counter. The investigator counted aloud from 90 to 100 steps, which cued the participant to stop precisely at 100. The number of steps was noted for each pedometer, and for the hand-tally counter. This procedure was then repeated with the 4 additional sets of pedometers.

Data Analysis

All step data were converted to "percentage of actual steps" by dividing the pedometer values by the investigator-determined value.[8–10] For all validity testing, the percentage of actual steps recorded by each pedometer model/location was determined for each person. These numbers were averaged to determine the mean percentage of steps recorded (100% of actual steps indicates a perfect score). However, since it is theoretically possible that under and over-estimations could cancel each other out and still yield 100% of actual steps, we also reported a measure of the variability in percent of actual steps (either 95% confidence intervals or SE bars) to guard against the possibility of concluding that a pedometer was valid when it was not. For part I, we analyzed the data for treadmill walking and running separately. Three-way repeated-measures ANOVAs (device x speed x BMI) were used to test for differences in the percentage of steps recorded. In the case of significant interactions, we conducted post hoc tests consisting of pairwise comparisons with Bonferroni adjustments. In addition, 1 sample *t* tests were used to compare the percentage of actual steps at each speed to 100%, to determine which devices over- or under-estimated steps.

For part II we analyzed each lifestyle activity separately. Two-way repeated-measures ANOVAs (device x BMI) were used to test for differences in the percentage of steps recorded. In the case of significant interactions, we used pairwise comparisons with Bonferroni adjustments to determine which devices differed significantly from each other. One sample *t* tests were used to determine which devices over- or under-estimated steps, relative to the criterion.

For part III, we could not use traditional reliability measures (intraclass correlation coefficient, etc.) because there was almost no variability in steps, other than random error. Thus, we examined the intradevice validity across 5 devices of the same make and model. In addition, if all of the devices of the same make and model gave consistent step counts then we concluded that it was a reliable device.

Results

Part I: Effects of Walking and Running Speed on Pedometer Validity

There were significant differences among pedometers for steps taken at all speeds ($P < .05$) as shown in Figure 1. The Omron (worn on the waist) was the most valid. Most pedometers show greater error at slower walking speeds. At the slowest walking speed (2 mph), only the Omron on the waist and in the backpack were valid, while the Omron in the pants pocket slightly overestimated steps, the Sportline overestimated steps, and the Yamax underestimated steps. For walking at 3 and 4 mph, the validity of the Omron (at all locations) and the Yamax were high. The Sportline remained significantly different from all other devices ($P < .001$) and continued to overestimate steps. There was no effect of BMI among pedometers at any walking or running speed.

The Omron HJ-303 (worn at the waist or in the backpack) was valid at 6 and 7 mph and at 8 mph worn at the

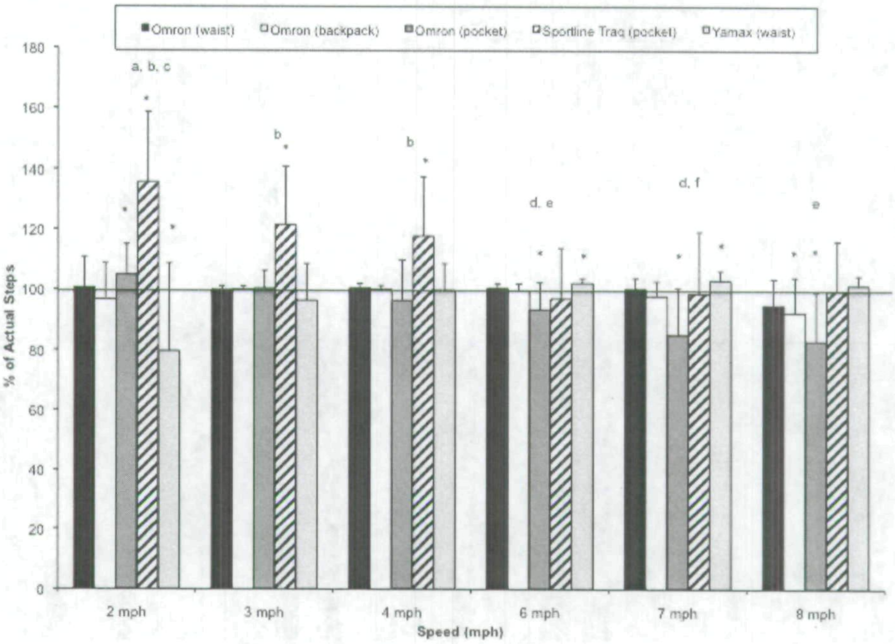

Figure 1 — Comparison of 3 brands of pedometers and different placements at different walking and running speeds (N = 60 for 2, 3, and 4 mph, mean ± SD) (N = 20 for 6, 7, and 8 mph, mean ± SD). a = significant difference between Omron pocket and Omron backpack ($P < .05$); b = significant difference between Sportline and all others ($P < .05$); c = significant difference between Yamax and all others ($P < .05$); d = Omron pocket significant different than Omron waist, Omron backpack and Yamax ($P < .05$); e = Yamax significantly different than all Omron's (waist, pocket and backpack) ($P < .05$); f = Yamax significantly different than Omron waist and Omron backpack; * = significant difference between device and percent of actual steps.

waist. The Sportline was the only other device found to be valid for all running speeds. The Omron in the pants pocket was invalid for all speeds, and it underestimated steps in every case. At 8 mph the Omron HJ-303 in the backpack underestimated steps. The Yamax SW-200 statistically overestimated steps at 6 and 7 mph ($P < .001$), but it was valid at 8 mph.

Part II: Validity of Pedometers During Various Lifestyle Activities

There were significant step count differences between devices ($P < .05$) for all lifestyle activities (Figure 2). None of the devices provided valid estimates of FBSS stepping, or ballroom dance. The 3 Omron pedometers and the Yamax all underestimated FBSS stepping and ballroom dance. The Sportline Traq overestimated steps during both of these activities.

All Omron locations were valid during stair ascending and descending. However, when ascending stairs the Omron (worn in the pants pocket) tended to underestimate steps (mean = 90.8 steps, SD = 37.0 steps), although it was not statistically different from the 100-step criterion ($P = .3$). The Yamax digi-walker was valid for descending stairs (mean = 101.3 steps, SD = 18.4 steps), but not for ascending stairs (mean = 87.8 steps, SD = 25.5 steps). Meanwhile, the Sportline Traq significantly overestimated steps during stair activities ($P < .001$).

There were significant differences in step counts between pedometers for elliptical machine exercise and a significant interaction of BMI category and device. The 3 Omron pedometers were valid for elliptical machine exercise, across all BMI categories. The validity of the Yamax digi-walker decreased, underestimating by 30 steps as BMI category increased from the normal weight category to the overweight. The Sportline Traq overestimated steps across all BMI categories, and the overestimation increased as the BMI category increased.

Part III: Interdevice Validity and Reliability of Pedometers During Walking

Table 2 shows the total number of steps recorded by each pedometer for 60 subjects over each of the 5 self-selected speed 100-step trials of walking on a rubberized track. The Omron pedometers (all locations) and Yamax digi-walker were both valid and reliable, showing no significant differences between the 5 trials. The Sportline Traq pedometers, although reliable, were not valid ($P < .001$) and they consistently overestimated steps by about 20%. There was no effect of BMI among pedometers during walking.

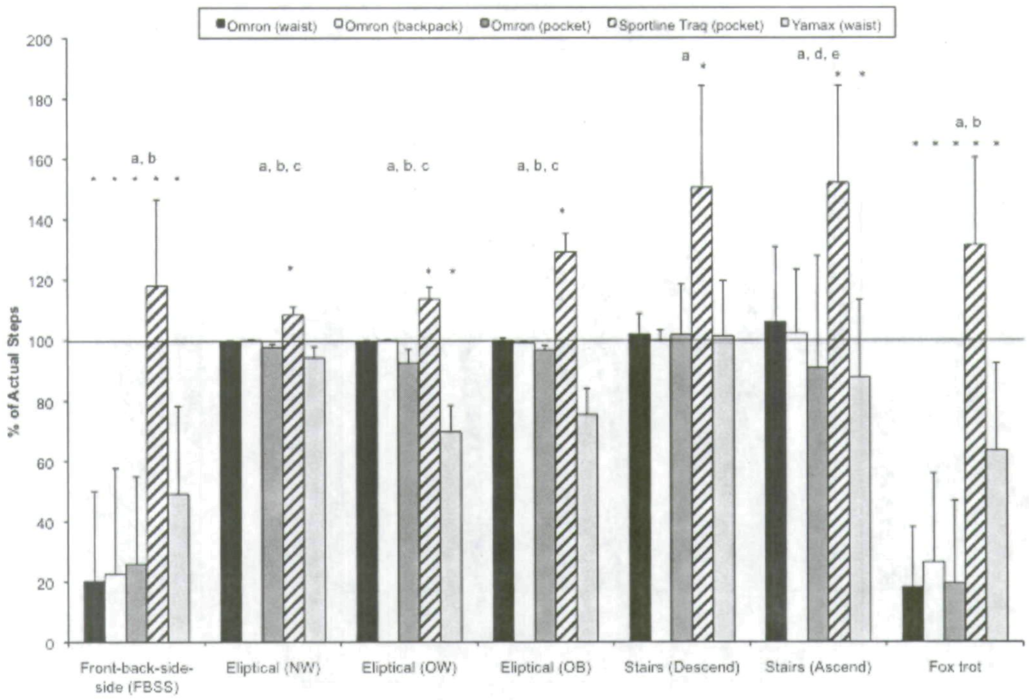

Figure 2 — Comparison of 3 brands of pedometers and different placements at different lifestyle activities (N = 60 for all but Foxtrot, mean ± SD) (N = 20 for Foxtrot, mean ± SD). a = significant difference between Sportline and all others ($P < .05$); b = significant difference between Yamax and all others ($P < .05$); c = Omron pocket significantly different than all others ($P < .05$); d = Omron pocket significantly different than Omron waist; e = Yamax significantly different from Omron waist and Omron backpack; * = significant difference between device and percent of actual steps. NW= normal weight, OW = overweight, and OB = obese.

Discussion

The Omron HJ-303 pedometer, worn on the waist, appears to be the most valid and reliable of the 3 pedometers for walking and running. By comparison, the Yamax digi-walker SW-200 had similar validity for most speeds, but it underestimated steps by about 25% at the slowest speed (2 mph), which is consistent with other studies.[4,9,10] The Sportline Traq pedometer overestimated steps at all 3 walking speeds, though it was valid for running.

The site where the Omron was worn had little effect, except that it undercounted steps during treadmill running at 6, 7, and 8 mph when worn in the pocket. Both the waist and the backpack Omron positions were valid during running, and all 3 Omron locations were valid for walking.

With regard to lifestyle activities (Part II), the Omron HJ-303 pedometer was valid for elliptical machine, stair-climbing, and stair-descending. Regardless of where the Omron HJ-303 was worn, it validly counted steps during these activities. However, the Omron underestimated steps during FBSS stepping and ballroom dancing. This indicates that, despite the presence of a triaxial accelerometer mechanism, it does not detect 100% of steps during activities that involve small, quick steps or sliding/turning movements. It is possible that these activities do not produce accelerations that exceed the threshold needed for step detection; in addition, the Omron mechanism may not count steps correctly when walking at an inconsistent pace.[7]

The Sportline Traq pedometer overestimated steps during all lifestyle activities, suggesting that the sensitivity of this device is set too high. In walking and in lifestyle activities, it over-estimated steps by approximately 15% to 60%.

The Yamax pedometer captured approximately 50% of steps during FBSS stepping, 100% of steps during stair descending, 90% of steps during stair ascending, and 70% of steps during ballroom dancing (foxtrot). The validity of the Yamax pedometer was not quite as high as that of the Omron HJ-303 during elliptical exercise (79.6% of actual steps vs 95.6% to 99.8%, depending on location). These underestimates are partially due to the fact that the Yamax SW200 requires a "threshold" vertical acceleration of 0.35 G to record a step.[11]

In Part III, all 3 of the pedometer models (Omron, Sportline, and Yamax) yielded highly consistent data for the 5 track walks. This suggests good interdevice reliability, within each pedometer model. The Omron pedometers worn at the waist, in the pocket, and in the backpack, as well as the Yamax pedometers, all recorded nearly 100% of the actual steps. The Sportline Traq, however, consistently overestimated the actual number of steps. Hence, even though this Sportline model was reliable, it did not appear to be valid.

Table 2 Results of the 5 Trials of the 100-Step Track Walk, Using a Different Set of All Devices With Each Walk (Mean and 95% CI; N = 60)

Trial	Omron (waist)	95% CI	Omron (backpack)	95% CI	Omron (pocket)	95% CI	Sportline Traq (waist)	95% CI	Yamax (waist)	95% CI
1	99.93	98.48–101.40	100.24	100.00–100.48	100.11	98.64–101.57	124.38	119.42–129.34	100.43	95.08–105.77
2	100.54	100.04–101.03	100.28	99.94–100.62	100.86	99.25–102.46	121.36	117.16–125.56	99.59	96.00–103.20
3	100.77	99.81–101.73	100.16	99.95–100.36	100.44	96.98–103.90	121.19	115.24–127.13	100.93	99.24–102.61
4	100.41	99.98–100.84	100.18	99.91–100.44	101.24	99.53–102.95	119.85	114.92–124.78	100.59	98.43–102.75
5	100.49	100.02–100.96	99.87	99.10–100.65	100.01	98.58–101.45	128.43	123.23–133.62	102.19	97.69–106.68

Weaknesses of this study should be noted. We evaluated the 3 pedometer models with specific speeds and locomotion patterns that were continuous in nature. This did not allow for comparisons between devices during intermittent activities, which may be more characteristic of daily living. The next step in research should examine the validity of these pedometers for step counting in a free-living environment, where activities may have more variable motion and be less continuous in nature.

Important strengths of this study should be noted. This laboratory-based study was well thought out and conducted in a controlled testing environment. It was a thorough validation study of 3 different pedometers, worn in a variety of locations (hip, pocket, backpack). The participants participated in a wide variety of movements and a wide range of walking and running speeds, consistent with what would be observed in free-living environments. The sample size was fairly large ($n = 60$ parts I, II and III; $n = 20$ ballroom dance), included a wide range of ages, (21–59 years) and BMIs (20–44.4 $kg \cdot m^{-2}$). We did obtain a criterion measure of steps, an investigator using a hand-tally counter to count the participants' steps.

Conclusions

The Omron HJ-303 is a valid device for step counting, when used for continuous bouts of walking and running at speeds ranging from 2 to 8 mph. The Omron device was not influenced by BMI. The location where it was worn did not matter during walking; however, only the waist and backpack positions yielded valid data during running. Due to its superior ability to count steps when compared with the Yamax SW-200 and the Sportline Traq, the Omron HJ-303 would be useful for individuals interested in a valid and reliable pedometer to monitor continuous walking or running. In general, all 3 pedometers (Omron HJ-303, Yamax and Sportline) appeared to have limitations in regard to correctly registering steps during lifestyle activities such as FBSS stepping and ballroom dancing. The Omron HJ-303 and Yamax SW-200 devices failed to record a significant percentage of low-intensity steps (ie, very short steps, or not straight ahead) that are common during these activities. The Sportline Traq, however, recorded too many steps, even at low-intensity. Future studies should examine the validity of these pedometers in a free-living environment, and compare them to other highly accurate, reliable monitors used for step counting such as accelerometers (both waist and ankle-mounted).[12–16]

Acknowledgments

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