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ScienceDirect

Journal of Exercise Science & Fitness 12 (2014) 31—37

www.elsevier.com/locate/jesf

Original article

Effect of walking speed and placement position interactions in determining the accuracy of various newer pedometers

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Received 16 August 2013; revised 1 January 2014; accepted 27 January 2014
Available online 3 April 2014

Abstract

Older types of pedometers had varied levels of accuracy, which ranged from 0% to 45%. In addition, to obtain accurate results, it was also necessary to position them in a certain way. By contrast, newer models can be placed anywhere on the body; however, their accuracy is unknown when they are placed at different body sites. We determined the accuracy of various newer pedometers under controlled laboratory and free walking conditions. A total of 40 participants, who varied widely in age and body mass index, were recruited for the study. The numbers of steps recorded using five different pedometers placed at the waist, the chest, in a pocket, and on an armband were compared against those counted with a hand tally counter. With the exception of one, all the pedometers were accurate at moderate walking speeds, irrespective of their placement on the body. However, the accuracy tended to decrease at slower and faster walking speeds, especially when the pedometers were worn in the pockets or kept in the purse ($p < 0.05$). In conclusion, most pedometers examined were accurate when they were placed at the waist, chest, and armband irrespective of the walking speed or terrain. However, some pedometers had reduced accuracy when they were kept in a pocket or placed in a purse, especially at a slower and faster walking speeds.

Keywords: Aerobic exercise; Energy expenditure; Physical activity; Walking steps

Introduction

Regular physical activity (PA) is critical in maintaining and enhancing physical fitness and cardiovascular and metabolic health.[1] Despite this fact, more than half of US adults do not accumulate enough PA.[2] Pedometers are increasingly used as a convenient way to quantify PA levels because they provide an accurate and objective method of monitoring and recording walking and other ambulatory activities.[3—5] Some pedometers also provide comprehensive feedback that can estimate distance traveled and calorie expenditure.[6] Interestingly, wearing a pedometer and setting a step goal motivates individuals to increase their PA,[4] and indeed pedometers have been shown to be effective in increasing PA in previously sedentary adults.[2] The Japanese Industrial Standards recommend that adults should walk at least 10,000 steps a day for maintaining optimal health.[7] However, the goal of achieving and sustaining 10,000 steps/day may not be possible for some groups including the elderly people and patients with chronic diseases.[8] Accordingly, some alternatives such as <5000 steps/day as a sedentary lifestyle index and >10,000 steps/day to classify individuals as active have been proposed.[8]

There are a number of different types of pedometers with regard to internal mechanism. Spring-suspended horizontal lever-arm pedometers move the lever up and down in response to trunk vertical displacement. A glass-enclosed magnetic reed proximity switch uses a spring lever arm, but uses a magnetic field to count a step. Pedometers with a piezoelectric crystal use mechanical force from body movement to generate electrical charge for counting steps.[6,9] A previous study[10] reported that a piezoelectric pedometer counts steps more accurately

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http://dx.doi.org/10.1016/j.jesf.2014.01.003

than a spring-levered pedometer for overweight and obese individuals, particularly at slower walking speeds. Since then, a wide variety of newer pedometers have been emerging in the market and a number of options, including three-dimensional accelerometers and smart phone interfaces, have been incorporated. However, the accuracy of these newer pedometers is not clear. In addition, technological advances allowed users to place the pedometers in many convenient locations (e.g., in a pocket, on a lanyard), but it is not known whether the placement of pedometers in various locations would cause any differences in their accuracy.

Accordingly, the primary aim of this study was to determine the accuracy of various newer pedometers in the market worn at different locations of the body and at different walking speeds. We hypothesized that step rates recorded on the pedometers would deviate from those recorded manually on the hand tally counter at some locations as well as at slower and faster walking speeds. To address this issue as comprehensively as possible, the accuracy of pedometers was assessed at a variety of walking speeds in controlled laboratory conditions and in self-selected free walking conditions on paved ground. In addition, to make the study findings more applicable to a wider population, participants widely varying in age and body mass index were recruited and studied.

Methods

Participants

A total of 40 volunteers (20 males and 20 females) varying widely in age (18−61 years) were recruited from the city of Austin, Texas, USA and the surrounding community using online advertisements. Participants with cardiovascular and other chronic degenerative diseases were excluded from the study. In addition, we recruited only those who were able to walk without any difficulty. Before participation in the study, the nature of the study was explained to the participants, and they were asked to read and sign an informed consent form that was previously reviewed and approved by the Institutional Review Board of the University of Texas at Austin. Body mass was measured to the nearest 0.1 kg with a physician's balance scale (SECA, Hamburg, Germany). Percent body fat was estimated using the skinfold thickness method. Body mass index was calculated according to the following formula: body mass (kg) divided by height squared (m^2). Selected physical characteristics of the participants are presented in Table 1.

Table 1
Selected characteristics of the participants.

Characteristics	Men	Women
N	20	20
Age (y)	38.1 ± 13.4	39.1 ± 14.0
Height (cm)	175 ± 7	162 ± 7
Body mass (kg)	83.4 ± 14.9	70.4 ± 14.8
BMI (kg/m^2)	27.4 ± 4.8	26.9 ± 5.5
Body fat (%)	23 ± 8	35 ± 8

Data are presented as mean ± standard error of the mean.
BMI = body mass index.

Protocol

Five models of commercially available electronic pedometers were evaluated (Fig. 1): Fitbit Ultra Activity Plus Sleep Tracker (FB), Lifesource XI-25ant Ehealth Wireless Activity monitor (XI), Omron HJ-320 (OB), Omron HJ-324U (OU), and Virgin HealthMiles GoZone pedometer (VG). The selection of these pedometers was based on midlevel pedometers that had been used in corporate fitness settings. Five pedometers were worn, at three different locations, namely, in the front pants' pocket, on the waist (belts or upper elastic part of the pants), or on a lanyard in front of the chest. Four pedometers (FB, XI, OB, and OU) were also worn on an armband placed on the upper arm at the insertion of deltoid. Only a limited number of VG pedometers were available for the study because subscription to the Virgin health and fitness plan was required for the acquisition of VG pedometers and was cost prohibitive. Two of the pedometers (OB and OU) were also positioned in a handbag (purse) that was carried by the participants in their hand. The pedometers were randomly assigned to a specific location (e.g., medial to lateral locations on the waist) for every test by an investigator. Before the first trial, the participants received instructions for the test and walked or jogged on a motor-driven treadmill (Full Vision, Newton, KS, USA) at speeds of 54, 80, 107, 134, and 161 m/minute for 6 minutes at each speed. These walking speeds correspond to 2, 3, 4, 5, and 6 miles/hour. During the test, an investigator counted actual steps using a hand tally counter. There were 5−10-minute rests between the treadmill trials to record the step counts from each pedometer and to reset the pedometers. In addition to the laboratory testing session, the participants performed self-selected speed walking tests outside on paved ground for approximately 10 minutes (around the football stadium of the University of Texas at Austin). One investigator guided the participants, and another investigator followed behind them to count the steps taken using a hand tally counter.

Statistical analyses

Absolute values of step counts obtained with each pedometer were compared with those recorded with hand counts (criterion) using *t* tests. A percent difference score [(comparison − criterion)/criterion × 100] was calculated and used as an outcome measure. The smaller the percent difference score, the better the accuracy. Three-way (pedometers × locations × walking speed) analysis of variance was used to evaluate mean difference in step counts obtained with various pedometers against the hand tally counter. If a significant difference was shown, a follow-up Bonferroni adjustment was performed to locate the significant difference. For all analyses, $p < 0.05$ was used to denote statistical significance. The data were processed using SPSS version 18 (SPSS Inc., Chicago, IL, USA).

Fig. 1. Pedometers examined in this study.

Results

All the pedometers at all the positions provided step counts to be used in the analyses. Table 2 displays the actual steps counted during walking or jogging on the treadmill and self-selected speed walking on the paved ground outside. Fig. 2 shows the mean difference scores as a percentage of the steps counted by the hand tally counter at different wearing locations, and Table 3 lists individual numbers of percent errors. Percent difference scores were within ±5% of the criterion measure[11] when pedometers were placed on the waist (3.7% ± 7.9%), chest (3.6% ± 9.0%), and arm (3.4% ± 8.1%). However, the score was significantly ($p < 0.05$) greater when they were placed in a purse (7.3% ± 14.4%) or in a pocket (7.7% ± 12.2%). With some exceptions, most pedometers were accurate at moderate walking speeds (80–134 m/minute). However, the accuracy decreased at the slowest and fastest walking speeds (7.8% ± 14.2% at 54 m/minute and 6.2% ± 11.1% at 161 m/minute; $p < 0.05$). The results were similar no matter where the walking was performed (on the treadmill in the laboratory and outside on the pavement). The VG and FB had significantly ($p < 0.05$) greater percent difference scores than the other three pedometers (7.2 ± 11.8 and 6.1 ± 12.5% vs. 4.0%). Overall, pedometers tended to underestimate actual steps at all speeds as reflected in the downward bars in Fig. 2. There were no significant associations between mean error scores and age or body fatness ($p > 0.05$).

Discussion

In this study, the accuracy of five newer commercially available triaxial piezoelectric pedometers placed on various sites on the body was examined while participants walked at different speeds. With the exception of one model, all the pedometers examined performed well irrespective of the wearing locations when the walking was performed at moderate or normal speeds. However, the deviation from the criterion measures increased at the slower and faster walking speeds. This trend was particularly evident when the pedometers were placed in a pocket or in a purse. Our present findings are consistent with the notion that the accuracy of the pedometers is influenced by walking speed as well as by the location of placement.

In a landmark study in this area, Bassett et al[3] examined the accuracy of five electronic pedometers and found an inaccuracy at slower walking speeds. However, none of the spring lever-arm pedometers are currently available, as piezoelectric pedometers took over the market as the internal mechanisms of choice. Indeed, a number of investigators[10,12,13] have reported that piezoelectric pedometers are more accurate than spring lever-arm pedometers, especially at slower walking speeds. All the pedometers examined in our study used piezoelectric internal mechanisms, but still the deviations from the criterion measure of hand counts increased at slower walking speeds. It is plausible that the vertical movement of slow walking speed may not generate sufficient acceleration to exceed the threshold[14] (e.g., 0.30 g for piezoelectric accelerometers) needed for triggering steps.

In recent years, pedometers are increasingly used by a variety of populations, including healthy, fit individuals who occasionally perform jogging and/or running. As such, it is important to determine the accuracy of pedometers at fast treadmill speeds. The highest treadmill speed (161 m/minute or 6 miles/hour) examined in this study necessitated most participants to either jog or run on the treadmill. To the best of our knowledge, the present investigation is the only study that examined the accuracy of various pedometers at such a faster speed. Step counts measured on most pedometers tended to deviate from the criterion measures as the treadmill speed was increased. Vigorous bodily movement during running may have contributed to the deviation of the step counts. Thus, additional studies are needed to determine the efficacy of pedometers at various running speeds so that these pedometers can be applicable to healthy, fit individuals.

Throughout the tests, pedometers worn in the pants pocket showed most errors compared with pedometers worn in other locations at all speeds. However, this trend was particularly

Table 2
Step counts per minute during walking or jogging on the treadmill and self-selected outside walking.

	Hand count	OU	OB	XI	FB	VG
54 m/min						
Pocket	101.7 ± 1.8	105.5 ± 2.0	104.1 ± 2.3	106.2 ± 2.6	100.1 ± 1.8	106.7 ± 2.3
Waist		100.2 ± 2.2	102.0 ± 2.5	102.1 ± 1.7	101.4 ± 1.8	90.6 ± 2.4*
Chest		99.6 ± 2.2	101.7 ± 2.6	96.0 ± 2.1*	100.9 ± 1.7	80.8 ± 4.4*
Arm		96.5 ± 2.7	92.0 ± 3.8*	98.7 ± 2.4	101.5 ± 1.8	—
Purse		86.0 ± 5.3*	92.0 ± 4.9	—	—	—
80 m/min						
Pocket	115.6 ± 1.8	118.5 ± 1.9	118.0 ± 1.9	118.7 ± 1.6	115.1 ± 1.5	127.1 ± 2.3*
Waist		115.3 ± 1.5	113.6 ± 2.3	115.0 ± 1.2	114.8 ± 1.9	115.2 ± 1.5
Chest		115.6 ± 1.4	115.7 ± 1.5	115.5 ± 1.4	115.9 ± 1.4	114.3 ± 1.4
Arm		114.4 ± 1.9	115.3 ± 1.4	115.7 ± 1.6	115.6 ± 1.5	—
Purse		114.4 ± 1.5	114.5 ± 1.6	—	—	—
107 m/min						
Pocket	133.9 ± 1.8	134.8 ± 2.2	134.1 ± 1.9	130.4 ± 1.6	126.2 ± 1.6*	144.0 ± 2.3*
Waist		132.9 ± 1.7	132.8 ± 1.7	132.1 ± 1.5	133.7 ± 1.9	129.0 ± 3.3
Chest		132.8 ± 1.7	133.0 ± 1.7	132.1 ± 1.1	130.0 ± 3.3	130.8 ± 2.1
Arm		133.8 ± 1.9	134.1 ± 1.7	131.1 ± 1.7	132.8 ± 1.7	—
Purse		130.0 ± 2.8	130.5 ± 2.9	—	—	—
134 m/min						
Pocket	163.6 ± 2.4	157.6 ± 3.6	160.0 ± 2.6	152.8 ± 3.1*	113.2 ± 3.8*	168.2 ± 2.9
Waist		158.8 ± 2.9	160.1 ± 2.4	158.1 ± 2.4	155.6 ± 3.3	163.0 ± 3.8
Chest		161.7 ± 2.5	162.2 ± 2.5	161.1 ± 2.6	159.6 ± 2.6	156.4 ± 3.6
Arm		160.4 ± 2.8	159.1 ± 2.2	161.5 ± 2.7	157.5 ± 3.3	—
Purse		160.1 ± 4.0	160.0 ± 3.8	—	—	—
161 m/min						
Pocket	171.4 ± 2.5	167.0 ± 2.4	166.7 ± 2.3	156.7 ± 3.0*	99.0 ± 4.5*	163.6 ± 4.3
Waist		167.0 ± 2.2	166.3 ± 2.5	163.1 ± 2.0*	155.4 ± 2.9*	163.7 ± 3.7
Chest		169.5 ± 2.4	172.0 ± 4.3	166.0 ± 2.0	164.8 ± 3.0	167.9 ± 2.5
Arm		170.5 ± 2.7	169.0 ± 2.5	163.8 ± 2.4*	163.0 ± 2.7*	—
Purse		160.4 ± 2.3*	160.0 ± 2.2*	—	—	—
Outside						
Pocket	147.1 ± 2.6	148.7 ± 2.6	149.1 ± 2.5	144.7 ± 2.2	143.5 ± 2.3	158.1 ± 2.8*
Waist		143.9 ± 2.3	143.5 ± 2.2	144.2 ± 1.9	144.3 ± 2.1	144.2 ± 2.2
Chest		142.9 ± 2.1	142.7 ± 2.2	142.0 ± 2.0	143.9 ± 2.0	145.5 ± 3.5
Arm		142.5 ± 2.0	143.0 ± 2.3	142.2 ± 2.0	142.9 ± 2.0	—
Purse		140.6 ± 2.1	140.0 ± 2.2*	—	—	—

Data are presented as mean ± standard error of the mean.
* $p < 0.05$ versus hand count.
FB = Fitbit Ultra Activity Plus Sleep Tracker; OB = Omron HJ-320; OU = Omron HJ-324U; VG = Virgin HealthMiles GoZone pedometer; XI = Lifesource XI-25ant Ehealth Wireless Activity monitor.

evident at slower and faster treadmill speeds. The reason for the inaccuracy is not clear. However, it is possible that lifting the thigh when stepping might cause a tilt on the pedometers, resulting in their inability to maintain the perpendicular position,[15] which is recommended by the manufacturers when worn in the pocket for accurate measurements. Although this study was the first to examine the accuracy of various pedometers placed at different sites, a few investigators[16–18] have evaluated the validity of a single pedometer model. Zhu et al[18] examined the Omron HJ-720 pedometer worn at 10 different locations, and found that its accuracy was slightly decreased in the pants pocket location when the participant walked on a flat sidewalk. Hasson et al[16] investigated the validity of the Omron HJ-112 pedometer worn at four different locations (hip, neck, shirt pocket, and pants pocket) and found that the error of a pedometer worn in the pants pocket increased by fivefold. In the present study, Omron HJ-324U was the most accurate pedometer examined even when they were worn in the pants pocket.

In the modern lifestyle, it is common to place pedometers in the backpack and the purse. Zhu et al[18] found that the accuracy of pedometers was worse when they were placed in the backpack as the individuals walked up and down the stairs. Holbrook et al[17] also found that pedometers in the backpack produced more errors than pedometers in the pocket. In the present study, we determined the accuracy of pedometers when they were placed in a handheld purse. Because the number of pedometers was limited, this question was addressed only using the two best performed pedometers (OB and OU). These pedometers were accurate (within ± 5% of the criterion measure[11]) in most walking speeds but at the slowest and fastest speeds, the accuracy was decreased substantially. These results suggest that the walking speed and wearing location interactions determine the accuracy of pedometers.

Most pedometers in this study underestimated the step counts at most walking speeds as reflected by the downward directions of mean error scores (i.e., bars). The

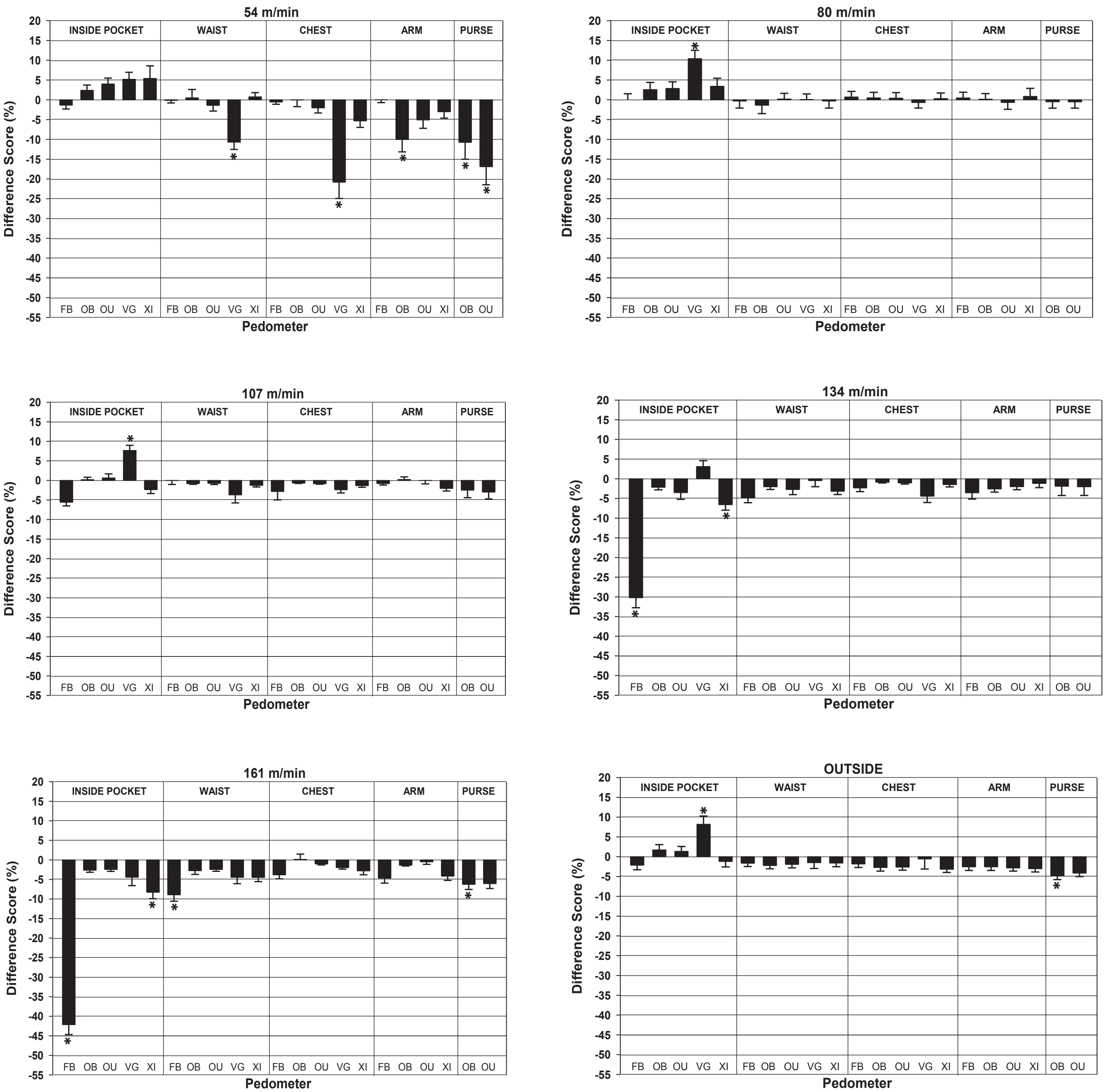

Fig. 2. Mean error score [(comparison − criterion)/criterion × 100] ± standard error of the mean as a percentage of the criterion-estimated steps. * $p < 0.05$ vs. hand counts (criterion). FB = Fitbit Ultra Activity Plus Sleep Tracker; OB = Omron HJ-320; OU = Omron HJ-324U; VG = Virgin HealthMiles GoZone pedometer; XI = Lifesource XI-25ant Ehealth Wireless Activity monitor.

underestimation may be attributed to a random-movement filter function that is built into pedometers. This function is incorporated into the device to avoid counting irregular movement. In addition, some pedometers (e.g., Omron) have a 4-second filter that does not start counting steps unless the walking lasts for only 3 consecutive seconds.[19] In a free-living condition, the most common walking bout is four steps in a row and the second most common bout is six steps in a row, accounting for 17% and 10% of total bout of walking, respectively.[20] At the beginning and at the end of each walking trial, participants commonly took a few steps that pedometers might not have counted as steps. The filter would be beneficial for step counting during continuous walking. However, it might be a cause of underestimation of the total steps in this study. Overall, the VG was the least accurate pedometer among all the pedometers examined in this study. This can be attributed to the fact that the VG does not have a random-movement filter function like other pedometers have.

Table 3
Absolute percent error [(comparison/criterion) × 100] ± standard error of the mean (>100% indicates overestimation and <100% indicates underestimation).

	OU	OB	XI	FB	VG
54 m/min					
Pocket	104.0 ± 1.5	102.4 ± 1.3	105.4 ± 3.2	98.7 ± 1.0	105.2 ± 1.8
Waist	98.6 ± 1.4	100.5 ± 2.1	100.7 ± 1.1	99.8 ± 0.6	89.3 ± 1.8
Chest	98.0 ± 1.3	99.9 ± 1.7	94.7 ± 1.7	99.4 ± 0.6	80.8 ± 4.5
Arm	94.9 ± 2.1	90.0 ± 3.1	97.0 ± 1.6	100.0 ± 0.7	—
Purse	83.1 ± 4.6	89.2 ± 4.3	—	—	—
80 m/min					
Pocket	102.9 ± 1.7	102.6 ± 1.8	103.4 ± 2.0	100.0 ± 1.5	110.4 ± 2.1
Waist	100.2 ± 1.5	98.6 ± 2.1	100.2 ± 1.6	99.7 ± 1.8	100.1 ± 1.4
Chest	100.4 ± 1.4	100.5 ± 1.4	100.3 ± 1.4	100.7 ± 1.4	99.3 ± 1.4
Arm	99.3 ± 1.7	100.2 ± 1.4	100.9 ± 2.0	100.5 ± 1.4	—
Purse	99.5 ± 1.6	99.5 ± 1.6	—	—	—
107 m/min					
Pocket	100.6 ± 1.0	100.2 ± 0.6	97.6 ± 1.0	94.4 ± 1.0	107.7 ± 1.3
Waist	99.3 ± 0.3	99.2 ± 0.2	98.7 ± 0.4	100.0 ± 1.0	96.3 ± 2.1
Chest	99.2 ± 0.1	99.3 ± 0.1	98.7 ± 0.4	97.2 ± 2.1	97.6 ± 0.8
Arm	100.0 ± 0.9	100.2 ± 0.7	98.0 ± 0.7	99.2 ± 0.4	—
Purse	97.0 ± 1.8	97.5 ± 1.9	—	—	—
134 m/min					
Pocket	96.5 ± 1.7	97.9 ± 0.7	93.4 ± 1.4	69.8 ± 2.5	103.1 ± 1.5
Waist	97.3 ± 1.3	98.0 ± 0.7	96.8 ± 0.8	95.2 ± 1.2	99.5 ± 1.6
Chest	99.0 ± 0.3	99.2 ± 0.2	98.5 ± 0.6	97.7 ± 0.9	95.6 ± 1.6
Arm	98.0 ± 0.8	97.4 ± 0.8	98.8 ± 1.1	96.5 ± 1.6	—
Purse	98.0 ± 2.2	98.1 ± 2.4	—	—	—
161 m/min					
Pocket	97.5 ± 0.5	97.4 ± 0.5	91.7 ± 1.6	57.9 ± 2.5	95.6 ± 2.1
Waist	97.6 ± 0.5	97.3 ± 0.9	95.5 ± 1.1	91.1 ± 1.7	95.5 ± 1.6
Chest	98.9 ± 0.2	100.1 ± 1.4	97.2 ± 1.0	96.2 ± 1.0	98.0 ± 0.4
Arm	99.5 ± 0.7	98.6 ± 0.2	95.8 ± 1.1	95.3 ± 1.3	—
Purse	93.9 ± 1.3	93.8 ± 1.3	—	—	—
Outside					
Pocket	101.4 ± 1.2	101.7 ± 1.3	98.8 ± 1.4	97.9 ± 1.2	108.2 ± 2.1
Waist	98.1 ± 0.9	97.8 ± 0.8	98.4 ± 0.9	98.4 ± 0.8	98.5 ± 1.5
Chest	97.4 ± 0.8	97.3 ± 0.9	96.8 ± 0.8	98.2 ± 0.9	99.4 ± 2.5
Arm	97.2 ± 0.8	97.4 ± 0.9	97.4 ± 0.9	97.5 ± 0.9	—
Purse	95.9 ± 0.9	95.2 ± 1.0	—	—	—

Data are presented as mean ± standard error of the mean.
FB = Fitbit Ultra Activity Plus Sleep Tracker; OB = Omron HJ-320; OU = Omron HJ-324U; VG = Virgin HealthMiles GoZone pedometer; XI = Lifesource XI-25ant Ehealth Wireless Activity monitor.

The present study has several limitations. First, participants with overweight, obesity, and elderly age were often unable to jog comfortably on a treadmill at fast speeds. The test had to be minimized from 6 to 3, 2, or 1 minute for these participants at the fastest speeds. Second, the slowest walking speed examined in this study was 54 m/minute. This was based on the observation that an average walking speed for community dwelling older adults aged ≥65 years was approximately 55 m/minute.[21] However, as the errors increased at slower walking speeds, it is possible and likely that the errors could have become greater if we had included a slower walking speed. Third, we were not able to examine the accuracy of the pedometers under free-living conditions. Therefore, further research is needed to investigate the accuracy of these pedometers under free-living conditions.

Two types of electronic motion sensors are increasingly used in the market today as tools to assess PA. Although accelerometers may provide more accurate and diverse information regarding PA, pedometers remain as more convenient and practical sensors that can be applied to a variety of populations. A pedometer is versatile and can be used for a number of functions including activity feedback (through step counts), reminders to stay active, and activity tracking. A lower cost of pedometers makes this option more attractive. However, pedometers must be demonstrated to be accurate. In this study, we found that most of the pedometers examined were accurate when they were worn at the waist, chest, and armband, irrespective of the walking speed or the terrain on which the participants exercised. However, some pedometers did not register accuracy when they were placed in a pocket or in a purse, especially at slow and fast walking speeds.

Conflicts of interest

All contributing authors declare no conflicts of interest.

Acknowledgments

This research was supported by a grant from Omron Healthcare Inc. and they provided the pedometers tested in the

study. The results of the study do not constitute endorsement of the products by the authors.

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