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Walking Speed and Placement Position Interactions in the Accuracy of Various Newer Pedometers

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Walking Speed and Placement Position Interactions in the Accuracy of Various Newer Pedometers

by

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Abstract

Walking Speed and Placement Position Interactions in the Accuracy of Various Newer Pedometers

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Introduction: Pedometers are increasingly used as a self-monitoring aid for achieving and increasing daily physical activity. Older pedometers had varied levels of accuracy ranging from 0 to 45% difference and were needed to be positioned in a certain way (on the waist). Newer models can be placed anywhere on the body but its accuracy is unknown when they are placed at different bodily sites. **Purpose:** We determined the accuracy of various newer pedometers under controlled laboratory and free walking conditions. **Method:** A total of 40 subjects (20 male and 20 female) varying widely in age (18-61 years) and BMI (18-38 kg/m^2) were studied. The pedometers, including Omron HJ-320, Omron HJ-324U, Lifesource XI-25, Fitbit Ultra, and Virgin Health Miles, were placed at waist, at chest, in a pocket, and on an armband. The number of steps recorded with the pedometers was compared against those counted with a hand tally counter while the subjects walked on the treadmill at 54, 80, 107, 134, and 161 m/min and on paved ground outside at a self-selected pace. **Results**: With the exception of one, all the pedometers were accurate (within ±5% of the criterion measure) at moderate walking speeds (80 and 107 m/min). The results were similar no matter where the pedometers were placed on the body and where the walking was performed. There were general tendencies for the accuracy to decrease at slower and faster walking speeds in most pedometers. The mean difference scores increased particularly when the pedometers were placed in the pockets or in the purse. **Conclusions:** Most of the pedometers examined were accurate when they were placed at waist, chest, and armband no matter what walking speed or what terrain they exercised. But some pedometers did not register accuracy when they were put in the pocket or in the purse particularly at a slow and fast walking speed.

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Review of literature

The following literature review will discuss pedometer and its associated property for actual use.

History of Pedometer

A pedometer is a portable and mechanical or electronic device that counts each step a person takes by detection the motion of the person. Measurement of walking is not new because it is a convenient way of quantifying physical activity level. In ancient Rome, distances were measured by counting steps. In fact, the word "mile" is derived from the Latin phrase, *millia passuum*, meaning "thousand strides". The Roman mile was 1000 strides of an adult citizen. Five hundred years ago, Leonardo da Vince designed an early pedometer (3). This device, worn at the waist, had a protruding vertical lever arm that was attached to the thigh. When the individual walked, the movement of the vertical lever arm caused a gear-and-ratchet mechanism to rotate and steps to be recorded. In 1965, a pedometer called a manpo-kei, meaning "thousand steps meter", was marketed in Japan by Yoshiro Hatano (38). He promoted manpo-kei from 1985, after his research was accepted as providing that 10,000 steps a day was the proper balance of caloric intake and expenditure to maintain a healthy life, manufactured pedometers recognized to be accurate and pedometer is now becoming as an everyday exercise measure and motivator.

At present, concerning principles of operation mechanism, pedometers commonly use two basic mechanisms for recording steps. The original and most basic is a spring-suspended horizontal lever arm. The function principle is that an arm balanced by a delicate spring is displaced upwards and downwards by slight jolts in the direction of suspension (31). The lever arm opens and closes and the number of steps are counted. With the phasing out of this older analog model, the electronic pedometer has emerged (10). This electronic pedometer use a piezoelectric sensor which is a device that uses the piezoelectric effect to measure pressure, acceleration or force by converting them to an electrical charge. The electrical charge has to exceed the threshold to count the steps (15).

The Importance of Physical Activity and Use of Pedometer

Bipedalism adopted for living on the ground rather than living in trees and became a vital part for living of our ancestors. The upper extremities were become free and it resulted in utilizing tools by the hands and fingers. Such complicated movements eventually were coordinated by more highly developed brain and bipedalism may be regarded as the starting point of Homo sapiens. From an evolutionary perspective, it might seriously discuss if the human race is secure when walking is not necessary in the future. Modern humans seem to be walking increasingly less due to the development of technology, especially heavily rely on motor vehicles in regard to transport (18). In addition, the industrialization disconnected from what our ancestors used to do for survival and energy intake is not necessarily linked to energy expenditure anymore and humans have become sedentary (6). Lack of physical activity (PA) in the modern sedentary lifestyle is highly associated with heart disease, hypertension, diabetes, and certain cancers (9). The benefits of a physically active lifestyle are very well known (29). American surgeon general recommends that adults should perform moderate-intensity aerobic PA for a minimum of 30 min on most days of the week (19). The health benefits of physical activity are numerous (i.e., decreased cardiovascular disease, hypertension, stroke, and metabolic syndrome) and, interestingly, participating in only 1 hour per week of moderate intensity PA is associated with decreasing risk of all-cause mortality compared to a sedentary population (29). Therefore, it has become very important to quantify the volume of PA to maintain healthy life for modern population.

As an objective device to monitor the amount of PA, use of the pedometer is practical and widely accepted. In addition, wearing pedometer and setting a step goal motivate individuals to increase their PA and pedometers are effective for increasing PA in previous sedentary adults (5).

Physical Activity Measurement

Accurate measurement of PA is needed for several reasons: 1) to quantify dose-response relationships between PA and health outcomes, 2) to answer questions about the relative merits of vigorous vs. moderate PA, and 3) to document the accurate level of PA performed in longitudinal training studies. To date, there is no commonly accepted way to assess PA, with over 30 different techniques available. These are the self-reported survey methods, job classification, calorimetry, physiologic markers, behavioral observation, mechanical and electronic motion sensors, and dietary measures (7, 24). We will discuss questionnaires, pedometers, and heart rate monitors as a way of quantifying PA.

Physical Activity Questionnaires (PAQs). PAQs are commonly used as a most feasible assessment for large-scale studies because of their low cost and convenience. PAQs are prone to measurement error and bias due to misreporting, either deliberate or because of cognitive limitations related to recall or comprehension (12). The use of PAQs to assess PA in different linguistic or cultural groups presents certain problems such as translating, adapting, and interpreting (33). Despite frequent use of objective methods to assess PA, PAQs still provide a practical method for PA measurement in surveillance systems, and when examining etiology of disease in large observational studies. Most PAQs are designed to be able to measure multiple dimensions of PA by reporting type, location, domain and context of the activity, provide estimates of time spent in activities of various levels of intensity, and may be able to rank individuals according to intensity levels of reported activity (41). Results from studies aimed at evaluating the validity of PAQs assessed in one population cannot be systematically extrapolated to other populations, ethnic groups, or other geographical regions. Consequently, a great variety of PAQs have been recently developed for reliability and validity. Several studies have compared the reliability and validity of already existing and newly developed PAQs with a special focus on their overall performance, or performance in specific age groups (8, 12). Interestingly, newly developed PAQs do not seem to perform any better than already existing PAQs (40). Thus, no matter what type of PAQs used for a study, PAQs are inherently subject to many limitations and the choice of PAQs should be dictated by the research question and the population under study. (39)

Pedometers. An early study found that older, mechanical style pedometers had problems with reliability and validity. These devices were found to be not acceptable for research, unless individual instrument calibration is done with each time for use (16). Recently, newer electronic pedometers have become available. These belt-mounted pedometers are triggered by vertical accelerations of the body that occur during walking. Horizontal spring lever arm moves upward and downward with each step, opening and closing an electronic circuit, and one step is recorded. A previous study found that some pedometers are very accurate for recording steps during self-paced walking (1). One model (Yamax DW-500) recorded steps and distance within 2% of actual values, but this model has been discontinued at the pedometer market.

Reliability of the recently produced pedometer seems to be quite acceptable when walking at a normal velocity. However, step readings tend to register less than the actual number of walking steps in slow walking (34). In slow walking, vertical acceleration of the hip swing is often less than the preregistered threshold value of the instrument. If the threshold value is made more sensitive, smaller hip movements can be registered, and thus the pedometer also becomes available for slow walking. However, more steps may be recorded than actual steps taken in non-walking behaviors because of the sensitive setting (22). In the proposed Japanese Industrial Standard (JIS) set by Ministry of Industry and Trading regulations, the maximum permissible rate of miscounting is .3 percent. Such a discrepancy is practically negligible when walking at a step rate of 100 steps per minute or more (18).

Heart Rate Monitors. Heart rate (HR) is a beneficial way to estimate PA and a physiological parameter that is closely related to energy expenditure. There is a linear relationship between HR and oxygen uptake (VO_2) over a wide range of exercise intensities. HR monitoring has undergone major advances over the past years. With current technology, HR data are sent from a transmitter worn around the chest to a wristwatch or other device (24).

A group of researchers discussed a method of analyzing HR data, use of percent heart rate reserve (%HRreserve) (13). The %HRreserve method can be directly validated against percent oxygen uptake reserve (%VO_2reserve). The latter term expresses the VO_2 as a percent of the difference between resting metabolic rate and maximum oxygen uptake (36). Strath et al. (34) showed the utility of this method in a field setting. Sixty one adults performed various activities including housework, yard work, occupation, conditioning, family care, and recreation. HR and VO_2 were measured simultaneously, over a 15-minute period. Maximal hear rate was estimated from 220-age. Over a wide range of activities, %HRreserve was linearly related to %VO_2reserve, indicating that this method of analyzing HR data agrees closely with measured energy expenditure in the field.

Another method of analyzing HR is FLEX-HR. This technique uses individualized HR-VO_2 regression equations. It takes into account variations in the HR-VO_2 relationship resulting from differences in the age, gender, and fitness level of research participants. FLEX-HR denotes a change in the slope of the HR-VO_2 relationship, representing the point where a person transitions from rest to PA. It is usually determined by taking the average to the HR values recorded during sedentary activities, and light activity. A number of studies have compared this method for estimating total daily energy expenditure against criterion measures such as indirect room calorimetry. In general, while the group estimates are usually within 10% of these criterion measures, the individual errors are sometimes larger (4).

There are potential limitations to using HR to estimate energy expenditure. These include the following: 1) HR is subject to emotional influences, 2) variation in age and fitness level can affect to HR-VO_2 relationship, and 3) arm exercise elicits higher hear rate than leg exercise at the same VO_2. (13)

Introduction

Regular physical activity PA is critical in maintaining and enhancing physical fitness and cardiovascular and metabolic health (27, 30). Yet more than half of United Stated adults do not accumulate enough amount of PA (5). Pedometers are increasingly used as a convenient way to quantify PA levels because it provides an accurate, objective method of monitoring and recording walking and other ambulatory activities (1, 3, 35). Some pedometers also provide comprehensive feedback that can estimate distance traveled and calorie expenditure (11). Interestingly, wearing a pedometer and setting a step goal motivate individuals to increase their PA, and indeed pedometers have been shown to be effective in increasing PA in previously sedentary adults (5, 10). A current public health recommendation indicates that adults should perform moderate-intensity PA for a minimum of 30 min on most days of the week (19). This amount of walking is translated to the accumulation of 7,220 to 10,030 steps (42). On the other hand, the Japanese Industrial Standards recommend that adults should walk at least 10,000 steps a day for maintaining optimal health (18).

There are a number of different types of pedometers in 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 utilizes spring lever arm but uses a magnetic field to count a step. Pedometers with a piezoelectric crystal uses mechanical force from body movement to generate electrical charge for counting a step (11, 32). A previous study reported that a piezoelectric pedometer counts steps more accurately than a spring-levered pedometer for overweight and obese individuals particularly at slower walking speeds (10). Since then, a wide variety of newer pedometers have been emerging in the market and a number of options, including 3D accelerometers and the interface with smart phones, have been incorporated. However, the accuracy of these newer pedometers is not clear. Additionally, the technological advances allowed users to place the pedometers in many convenient locations (e.g., in a pocket, on lanyard, etc.), it is not known if the placement of pedometers in various location would make any differences in its accuracy.

Accordingly, the primary aim of the proposed study was to determine the accuracy of various newer pedometers in the market placed at different parts of the body. We hypothesized that step rates recorded on the pedometers are not different from those recorded manually on the hand tally counter at all the locations. In order to address this as comprehensively as possible, the accuracy of pedometers was assessed at a variety of walking speeds in the controlled laboratory condition and in the self-selected free walking condition on the paved ground. Additionally, to make the study findings more applicable to a wider population, subjects varying widely in age and body fatness were recruited and studied.

Methods

Subjects. A total of 40 volunteers (20 males, 20 females) varying widely in age (18-61 yr) were recruited from the city of Austin and the surrounding community using online advertisements. Subjects with cardiovascular and other chronic degenerative diseases were excluded from the study participation. Subjects must have been able to walk without difficulty. Before taking part 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 reviewed and approved by the Institutional Review Board of the University of Texas at Austin. Body mass was measured to the nearest 0.1kg with a physician`s balance scale (SECA, Hamburg, Germany). Percent body fat was estimated using the skinfold thickness methods. Body mass index (BMI) was calculated according to the formula: body mass (kg) divided by height squared (m^2). Selected physical characteristics of the subjects are presented in Table 1.

Protocol. Five models of commercially available electronic pedometers were evaluated: Fitbit Ultra Activity Plus Sleep Tracker (FB), Lifesource XI-25 Ant eHealth Wireless Activity monitor (XI), Omron HJ-320 (OB), Omron HJ-324U (OU), Virgin GoZone HealthMiles pedometer (VG). Five pedometers were placed, at 3 different locations: inside of the front pockets, on the waist, on lanyard in front of chest. Four pedometers (FB, XI, OB, and OU) were also worn on armband placed on the upper arm at the insertion of deltoid. Only a limited number of VG pedometers were available for the study since the subscription to the Virgin health and fitness plan was required for the acquisition of VG pedometers and was cost inhibitive. Two of the best-performed pedometers (OB and OU) were also placed in a handbag that was carried by subjects by 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. A HR monitor (Polar Electro Inc., Lake Success, NY) was also worn to monitor HR during exercise (data not shown). Before the first trial, the subjects received instructions for the test and walked or jogged on a motor driven treadmill (Full vision Inc., Newton, KS) at speeds of 54, 80, 107, 134, and 161 m/min for 6 min at each speed. During the test, an investigator counted actual steps using a hand-tally counter. Additionally, the subjects performed self-selected speed walking test outside on the paved ground for ~10 min (around the football stadium of the University of Texas at Austin). One investigator guided subjects, and another investigator followed behind them to count steps taken using a hand-tally counter.

Statistical Analyses. One-way analysis of variance (ANOVA) was used to evaluate mean difference score in step counts obtained with various pedometers against the hand-tally counter. For all analyses, $P<0.05$ was used to denote statistical significance. A percent difference score [(comparison – criterion) / criterion x 100] was calculated and used as an outcome measure. The smaller the percent difference score, the better the accuracy. If a significant difference was shown, a follow-up LSD adjustment was performed to locate significant difference.

Results

Table 2 displays the actual steps counted per minute during walking or jogging on the treadmill and self-selected speed walking on the paved ground outside. Figure 1 shows the mean difference scores as a percentage of the steps counted by the hand-tally counter at different wearing locations. With the exception of one (VG), all the pedometers were accurate (within ±5% of the criterion measure) at moderate or normal walking speeds (80 and 107 m/min). The results were similar no matter where the pedometers were placed on the body and where the walking was performed (on the treadmill in the laboratory and outside on the pavement). There were general tendencies for the accuracy to decrease at slower and faster walking speeds in most pedometers. This trend was particularly evident when the pedometers were placed in the pockets. The highest treadmill speed (161 m/min) necessitated most subjects to either jog or run on the treadmill. The mean difference scores increased particularly when the pedometers were placed in the pockets. Overall, pedometers tended to underestimate actual steps at all speed. Only one pedometer (OU) did not significantly differ from accrual steps at any speed and any location ($P>0.05$). The best performed pedometers, OU and OB, were also placed in the purse and were tested for accuracy. They were accurate (within ±5% of the criterion measure) in most walking speeds but at the slowest and fastest speeds, the accuracy was decreased.

Discussion

In the current study, the accuracy of 5 newer commercially-available tri-axial piezoelectric pedometers placed on various sites on the body were examined while subjects walked at different speeds. With the exception of 1 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 lower and higher walking speed. This trend was particularly evident when the pedometers were placed in pockets or a purse. To our knowledge, this is the first study investigating the accuracy of various tri-axial piezoelectric pedometers worn at various locations in a controlled setting where walking or jogging speed were changed.

In the landmark study in this area, Bassett et al. (1) examined the accuracy of five electronic pedometers and found an inaccuracy at slower walking speed. 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 (5, 17, 25) have reported that piezoelectric pedometers are more accurate than spring-lever arm pedometer especially at slower walking speeds. All the pedometers examined in the present study utilize piezoelectric internal mechanisms. Yet the deviations from the criterion measure of hand counts increased at slower walking speed. It is plausible that the vertical movement of slow walking speed may not generate sufficient acceleration to exceed the threshold (e.g., 0.30g for piezoelectric accelerometers) needed for triggering steps (37).

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/min) examined in the present study necessitated most subjects 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 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. Additional studies are needed to determine the efficacy of pedometers at various running speeds so that theses 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. But this trend was particularly evident at slower and faster treadmill speeds. The reason for the inaccuracy is not clear. But it is possible that lifting the thigh when stepping might cause a tilt on the pedometers and causes an inability to maintain the perpendicular position, which is recommended by manufacturer when worn in the pocket (14). Although the present study was the first to examine the accuracy of various pedometers placed at different sites, a few investigators have evaluated the validity of a single pedometer model (20, 21, 43). Zhu et al. (43), who examined the Omron HJ-720 pedometer worn at 10 different locations, found that accuracy was slightly decreased in the pants pocket location when subject walked on a flat sidewalk. Hasson et al. (20) investigated the validity of the Omron HJ-112 pedometer wearing in 4 different positions (hip, neck, shirt pocket, and pants pocket) and found that the error of pedometer worn in the pants pocket increased by five folds. 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 & Lee (43) found that the accuracy of pedometers was worse when they were placed in the backpack as the subjects walked up and down the stairs. Another investigators (21) 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 hand-held purse. As 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) 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 in determining the accuracy of pedometers.

In the present study, most pedometers underestimated the step counts at most walking speeds. The underestimation may be attributed to a random-movement filter function that built into pedometers. This function is incorporated into the device to avoid counting irregular movement. Additionally, some pedometers (e.g., Omron) have a 4-second filter that does not start counting steps unless the walking last only three consecutive seconds (26). In a free living condition, most common walking bout is 4 steps in a row and the second most common bout is 6 steps in a raw, accounting for 17 and 10 % of total bout of walking, respectively (28). At the beginning and the end of each walking trial, subjects 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 the present study. Overall, the VG was the least accurate pedometer among all the pedometers examined in the current study. This can be attributed to the fact that the VG does not have a random-movement filter function like other pedometers have.

The present study has several limitations. First, subjects with overweight, obesity, and elderly age were often unable to jog comfortably on a treadmill at fast speeds. Test had to be minimized from 6 to 3, 2, or 1 min for these subjects at the fastest speeds. Second, 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.

In conclusion, we found that most of the pedometers examined were accurate when they were placed at waist, chest, and armband no matter what walking speed or what terrain they exercised. But some pedometers did not register accuracy when they were put in the pocket or in the purse particularly at a slow and fast walking speed.

Table 1. Selected subject characteristics

	Men	**Women**
N	20	20
Age (yr)	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/m²)	27.4±4.8	26.9±5.5
Body fat (%)	23±8	35±8

Data are means±SEM.

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

54 m/min	**Hand Count**	**OU**	**OB**	**XI**	**FB**	**VG**
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	**Hand Count**	**OU**	**OB**	**XI**	**FB**	**VG**
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	**Hand Count**	**OU**	**OB**	**XI**	**FB**	**VG**
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	130.0±2.3	—	—	—

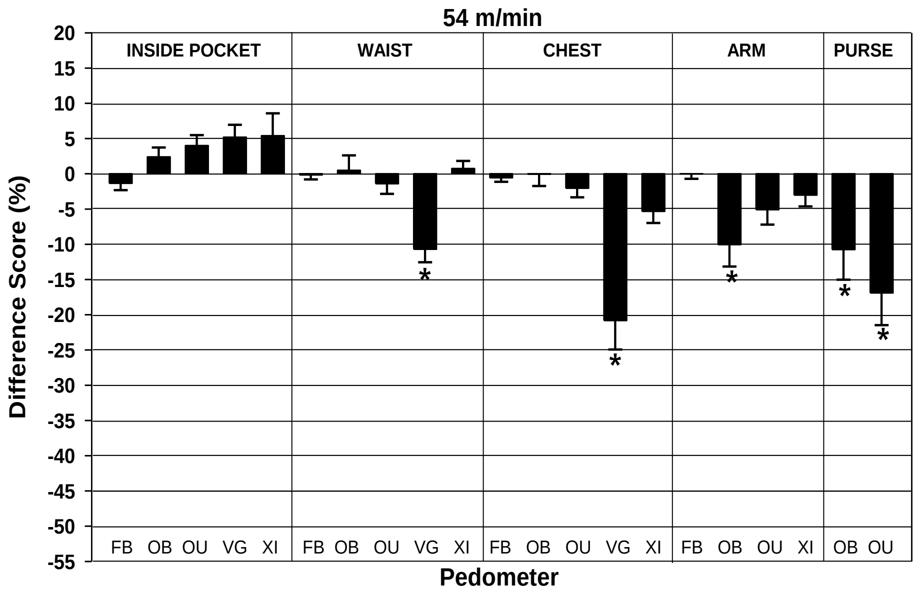
134 m/min	**Hand Count**	**OU**	**OB**	**XI**	**FB**	**VG**
Pocket	163.6±2.4	157.6±3.6	160.0±2.6	152.8±3.1*	113.2±3.8*	168.2±2.9
Waist		158.8±2.9	160.1±2.4	158.1±2.4	155.6±3.3	163.0±3.8
Chest		161.7±2.5	162.2±2.5	161.1±2.6	159.6±2.6	156.4±3.6
Arm		160.4±2.8	159.1±2.2	161.5±2.7	157.5±3.3	—
Purse		160.0±4.1	162.6±3.7	—	—	—

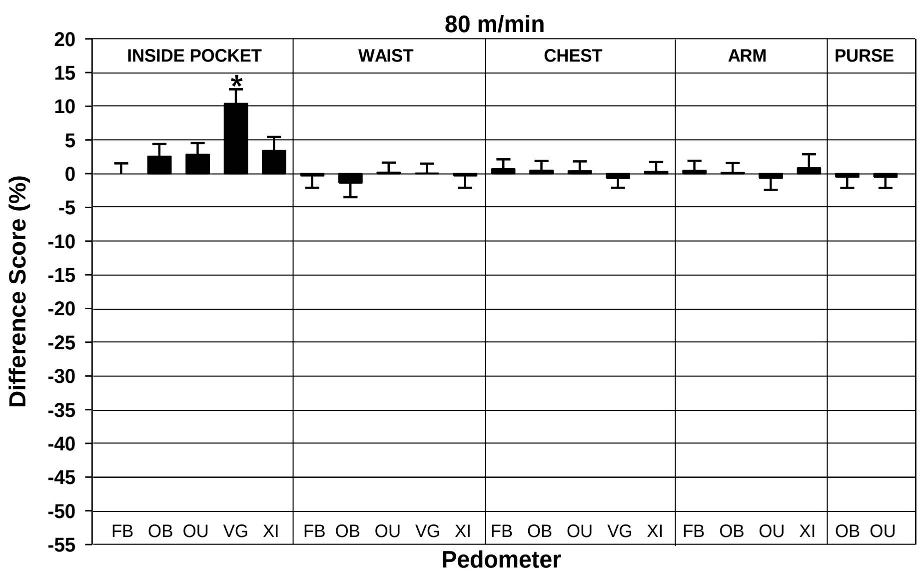
161 m/min	**Hand Count**	**OU**	**OB**	**XI**	**FB**	**VG**
Pocket	171.4±2.5	167.0±2.4	166.7±2.3	156.7±3.0*	99.0±4.5*	163.6±4.3
Waist		167.0±2.2	166.3±2.5	163.1±2.0	155.4±2.9*	163.7±3.7
Chest		169.5±2.4	172.0±4.3	166.0±2.0	164.8±3.0	167.9±2.5
Arm		170.5±2.7	169.0±2.5	163.8±2.4	163.0±2.7	—
Purse		160.4±2.3*	160.0±2.2*	—	—	—

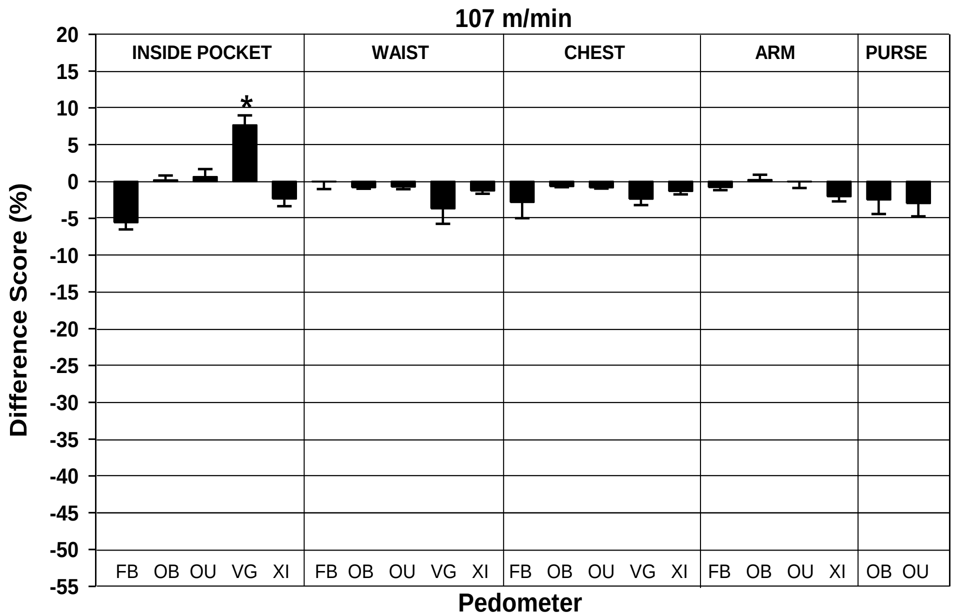
Outside	**Hand Count**	**OU**	**OB**	**XI**	**FB**	**VG**
Pocket	147.1±2.6	148.7±2.6	149.1±2.5	144.7±2.2	143.5±2.3	158.1±2.8*
Waist		143.9±2.3	143.5±2.2	144.2±1.9	144.3±2.1	144.2±2.2
Chest		142.9±2.1	142.7±2.2	142.0±2.2	143.9±2.0	145.5±3.5
Arm		142.5±2.0	143.0±2.3	142.2±2.0	142.9±2.0	—
Purse		140.6±2.1	140.0±2.2*	—	—	—

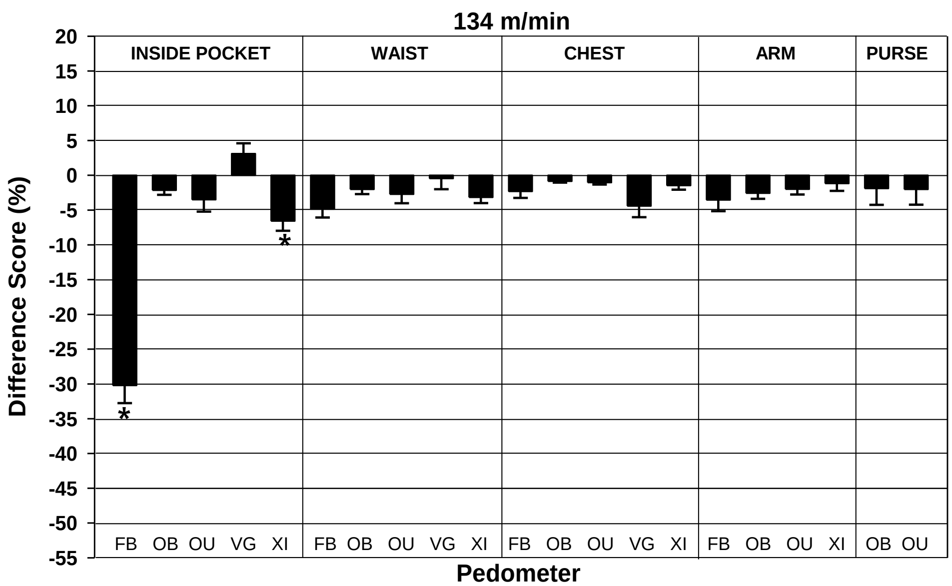
Data are means±SEM. *P<0.05 vs. Hand count.
FB=Fitbit Ultra Activity Plus Sleep Tracker, XI=Lifesource XI-25 Ant eHealth Wireless Activity monitor, OB=Omron HJ-320, OU=Omron HJ-324U, VG=Virgin GoZone HealthMiles pedometer

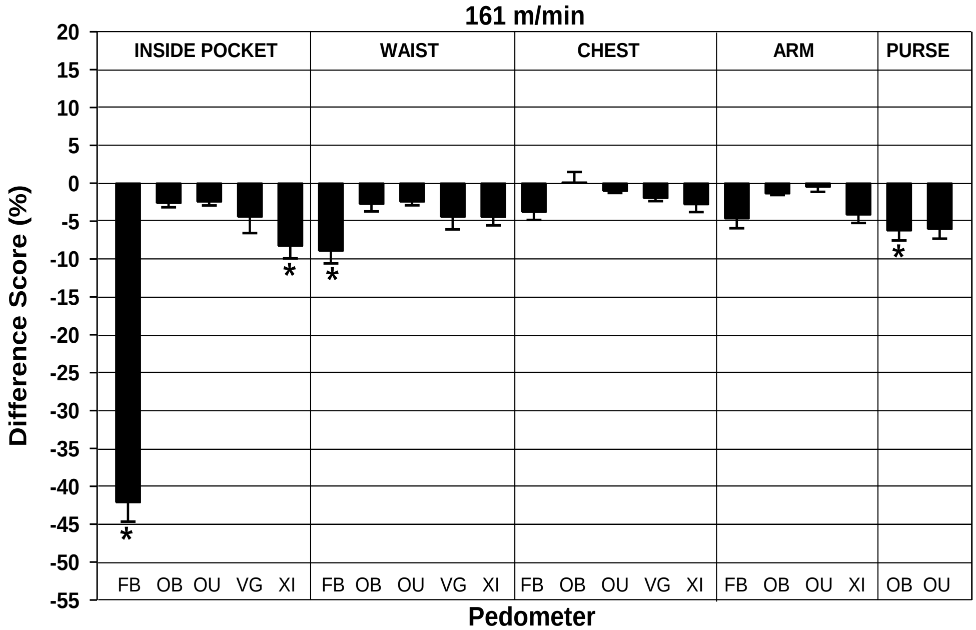
Figure 1. Mean error score [(comparison - criterion) / criterion x 100] ±SEM as a percentage of the criterion estimated steps. * P<0.05 vs. Hand count (criterion).
FB=Fitbit Ultra Activity Plus Sleep Tracker, XI=Lifesource XI-25 Ant eHealth Wireless Activity monitor, OB=Omron HJ-320, OU=Omron HJ-324U, VG=Virgin GoZone HealthMiles pedometer

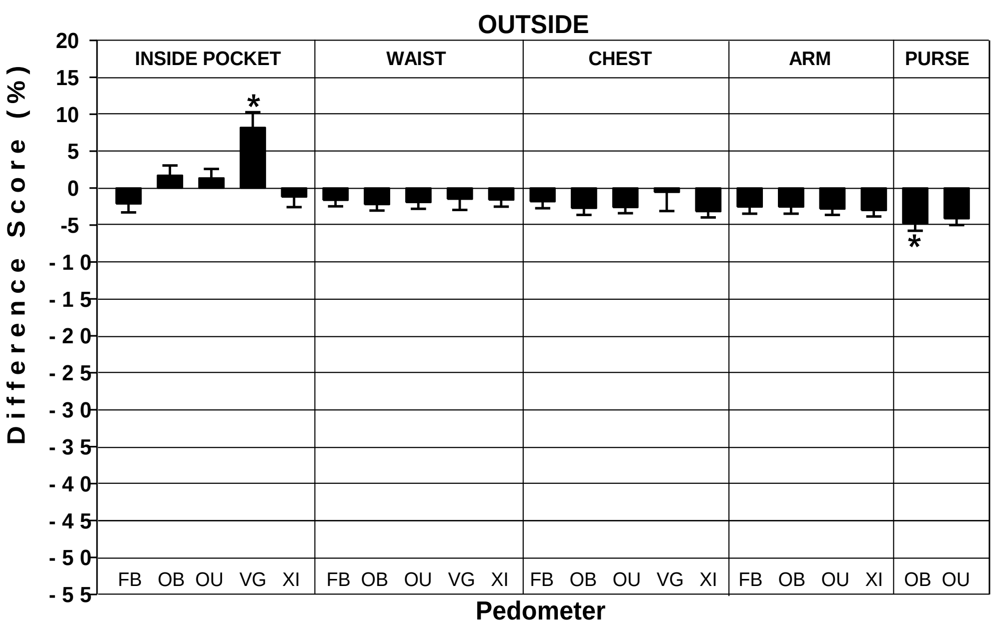





107 m/min
INSIDE POCKET
WAIST
CHEST
ARM
PURSE
Difference Score (%)
20
15
10
5
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50
-55
*
FB OB OU VG XI FB OB OU VG XI FB OB OU VG XI FB OB OU XI OB OU
Pedometer


134 m/min
INSIDE POCKET
WAIST
CHEST
ARM
PURSE
Difference Score (%)
20
15
10
5
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50
-55
*
*
FB OB OU VG XI FB OB OU VG XI FB OB OU VG XI FB OB OU XI OB OU
Pedometer


161 m/min
INSIDE POCKET
WAIST
CHEST
ARM
PURSE
Difference Score (%)
20
15
10
5
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50
-55
FB OB OU VG XI FB OB OU VG XI FB OB OU VG XI FB OB OU XI OB OU
Pedometer


OUTSIDE
INSIDE POCKET
WAIST
CHEST
ARM
PURSE
Difference Score (%)
20
15
10
5
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50
-55
FB OB OU VG XI FB OB OU VG XI FB OB OU VG XI FB OB OU XI OB OU
Pedometer

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