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Pedometer accuracy in slow walking older adults

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Abstract

The purpose of this study was to determine pedometer accuracy during slow overground walking in older adults (Mean age = 63.6 years). A total of 18 participants (6 males, 12 females) wore 5 different brands of pedometers over 3 pre-set cadences that elicited walking speeds between 0.3 and 0.9 m/s and one self-selected cadence over 80 meters of indoor track. Pedometer accuracy decreased with slower walking speeds with mean percent errors across all devices combined of 56%, 40%, 19% and 9% at cadences of 50, 66, and 80 steps/min, and self selected cadence, respectively. Percent error ranged from 45.3% for Omron HJ105 to 66.9% for Yamax Digiwalker 200. Due to the high level of error across the slowest cadences of all 5 devices, the use of pedometers to monitor step counts in healthy older adults with slower gait speeds is problematic. Further research is required to develop pedometer mechanisms that accurately measure steps at slower walking speeds.

Introduction

Older adults who participate in regular physical activity in combination with a healthy lifestyle have been shown to have decreased disability and disease (Marsh et al., 2007). Walking is reported to be the preferred exercise mode among the elderly (Cyarto et al., 2004, Marsh et al., 2007) and pedometers can provide both affordable and feasible measures of physical activity within this population (Holbrook et al., 2009). Pedometers have the

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potential for wide usage with community-dwelling older adults to monitor exercise habits and aid in exercise prescription aimed at preventing age-related health decline. Additionally, it has been shown that the use of pedometers can increase a person's physical activity (Melanson et al., 2004).

With an ever-increasing focus on self-management, pedometers are an important tool for rehabilitation clinicians to utilize with their clients to promote physical activity. One issue to consider is the pedometer accuracy at slow walking speeds. Gait speeds are variable among older adults with chronic health issues and can be as slow as 0.4 m/s for community ambulators (Perry et al., 1995). The literature has primarily tested pedometers in the ranges of 0.9 m/s to 1.8 m/s, which represents a range of normal healthy adult gait speeds.

Only a few studies have looked at pedometer accuracy in walking speeds below 0.9 m/s (Cyarto et al., 2004, Melanson et al., 2004, Esliger et al., 2007, Grant et al., 2008, Ichinoseki-Sekine et al., 2006), and most of these studies utilized a treadmill to control walking speed, with only the studies by Cyarto and colleagues (2004) and Ichinooski-Sekine and colleagues (2006) analyzing overground walking. Treadmill walking has been shown to be significantly different from overground walking, in terms of walking kinematics (Alton et al., 1998) and kinetics (Watt et al., 2010). It is possible that the accuracy of a pedometer's step count could be altered due to the different walking mechanics that result from walking on a treadmill. Further research is needed to determine the most suitable pedometer for use in older populations who walk at slow speeds and it is important to consider the accuracy during overground walking, which represents the majority of walking activity.

Cyarto and colleagues (2004) researched the accuracy of the mechanical Yamax DW 200 pedometer in both nursing home residents and community-dwelling adults aged 69–82 years. Participants were instructed to walk "slow", "normal" or "fast." The researchers found that the pedometers were accurate at speeds over 0.9 m/s, but miscounted steps by up to 74% at the slowest speeds. The nursing home residents also had gait impairments, as indicated by lower scores on the Tinetti's Performance Oriented Mobility Assessment, which were correlated with decreased pedometer accuracy (Cyarto et al., 2004). Ichinoseki-Sekine (2006) studied elderly participants with gait speeds of 0.28 m/s to 0.99 m/s, and found that the Omron HJ 720, a piezoelectric pedometer, undercounted steps by an average of 53.2%. There was also substantial variability in the accuracy of the pedometer, which may be attributed to a very old sample group (mean age = 80.9) and the inclusion of participants who had gait impairments and required the use of a cane as a walking aid.

There are currently a wide variety of pedometers available, which operate under various mechanisms. The most cost effective pedometer is a mechanical pedometer where the vertical movement of the hip causes a lever, resisted by a spring or a magnet, to close a circuit to count a single step (ie. Omron HJ 105, Yamax Digiwalker 200 and Sportline 330). A more costly option is the use of piezoelectric pedometers, where vertical motion deforms a small crystal that then emits an electrical charge and counts a step. These types of pedometers are able to detect movement in three planes which may help increase the accuracy of the step detection mechanism (Crouter et al., 2003). The ActiCal is an accelerometer (Esliger et al., 2007) and senses all directions of motion (Welk et al., 2004, Wong et al., 2011, Esliger et al., 2007). The step count function of the ActiCal detects vertical movement and translates data using piezoelectric technology into a step per minute count (Wong et al., 2011). In a study investigating the validity of the ActiCal accelerometer step count function, Esliger and colleagues (2007) found that the ActiCal was less accurate during slow walking (0.83 m/s), compared to a normal walking speed and running on a treadmill. The accuracy of the ActiCal's step count function at slow walking speeds has not been verified in overground walking.

Due to evidence that the step count reported by pedometers can be affected by slow walking speeds in older adults (Cyarto et al., 2004, Ichinoseki-Sekine et al., 2006), there have been suggestions that more sensitive piezoelectric pedometers, such as the New-Lifestyles 2000, may have more accurate results across a wide range of walking speeds (Crouter et al., 2003, Marsh et al., 2007, Melanson et al., 2004). However, there has been no direct comparison of different pedometer mechanisms at slow walking speeds, in an older adult population. Therefore the goal of this study was to compare the accuracy of five commercially available pedometers with varying mechanisms for counting the number of steps taken by healthy older adults at slow walking speeds, defined as < 0.9 m/s. Accuracy was measured by how closely pedometer counted steps agreed with the criterion measure, which was the number of manually counted steps.

We hypothesized that there would be no statistically significant difference in accuracy between commercially available pedometers, regardless of mechanism, at multiple pre-set gait speeds below 0.9 m/s in healthy older adults. Additionally, the accuracy and reliability of commercially available pedometers would decrease with decreasing gait velocities regardless of brand or internal mechanism. A pedometer will be considered to have unacceptable accuracy if the pedometer undercounts by greater than 20% with respect to the gold standard (manual step count) as described by Schneider and colleagues (2003).

Methods

Participants

Eighteen community dwelling older adults (6 male, 12 female) were recruited from the local community and seniors' recreation centers with additional snowball sampling. Participants were included if they were over 50 years of age, were able to follow instructions in English, could ambulate without the use of a gait aide such as a cane or walker for at least 100 m and had no medical contraindications to exercise as assessed by the ACSM criteria (2009). As there is controversy on the effect of body composition affecting the accuracy of pedometer readings (Crouter et al., 2005, Swartz et al., 2003), we chose to recruit individuals who had a BMI under 30 kg/m^2. In order to ensure that any differences in pedometer accuracy were primarily due to walking speed, individuals with current or recent orthopedic conditions, neurological conditions, or any other condition that may have compromised the lower extremities during normal ambulation were excluded from participating in our study. Age based normal values were used as a cut-off for the timed up and go (TUG) score (Bohannon, 2006); a value higher than the age-based norm (age < 69 years = 8.1s; age 70–79 = 9.2s; age > 80 = 11.3s) warranted exclusion from the study. All participants met the inclusion criteria.

Ethical approval for this study was obtained from the local Ethical Review Board and all participants provided written informed consent prior to commencement of the study.

Instruments

Five brands of pedometers were tested in this study: the Omron HJ 105, YamaxDigiwalker 200, SportLine 330, New-Lifestyles 2000, and the ActiCal Accelerometer (step-count function only). The Omron HJ 105 contains a switch triggered by a magnetic lever displaced by vertical forces during walking (Crouter et al., 2003). The Yamax Digiwalker 200 and SportLine 330 have mechanical switches that create a closed metal circuit with each vertical displacement (Crouter et al., 2003). The New-Lifestyles 2000 and ActiCal accelerometer contain piezoelectric crystals, which are deformed by a horizontal beam and can register movement in various planes, with the New-Lifestyles 2000 sensing motion in 2 planes (Crouter et al., 2003) and the ActiCal sensing motion in 3 planes (Wong et al., 2011). All devices provided immediate visual feedback of the step count, except for the ActiCal. The ActiCal was included as the multi-axis feature of this accelerometers could potentially provide a more accurate indicators of step counts at slower walking speeds. Each device was checked prior to each testing session by having an investigator manually count steps over a 10 m trial while wearing each unit. If the error exceeded ± 5% of steps counted, then the unit would not be used in the study; no devices were excluded.

Procedure

Participants were oriented to the study and written informed consent was obtained. Participant’s age, gender, height, weight and leg length were obtained as described by Karabulut and colleagues (2005). Participants wore their own comfortable walking or running shoes.

A total of three devices of each pedometer were used. Pedometers within each brand were assigned an identification code (A, B or C). During the initial assessment a team member randomly selected a pedometer from the available pool and noted the identification code (A, B, or C). This process was repeated for all five brands as described by LeMasurier and colleagues (2004). Two different pedometers were placed at one time on the participant’s belt or waistband, in the midline of the thigh, as per the manufacturers’ specifications. A previous study by Crouter and colleagues (2003) showed that no difference exists between left and right placement of a pedometer in terms of accuracy.

The participants performed a practice trial of walking with a metronome paced cadence of 50 steps/min, which consisted of two laps of a 40 m indoor track with a linoleum walking surface. The participants were instructed to step in time with the metronome without altering their normal gait pattern. The participants then took part in a series of walks twice around the 40-m indoor track for each pedometer model. Participants completed trials at three preset cadences of 50 steps/min, 66 steps/min, 80 steps/min and one self-selected walking speed. The order of the cadences for each participant was randomized using a random number generator. During the trials, two team members manually counted steps taken with hand held counters. The average step counts were used as the final value if manual step count disagreement was less than five percent of total steps between the two independent counters.

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Pedometer counts were recorded and reset to zero prior to the next trial. The ActiCal device was removed from the participant and data downloaded and extracted between trials. Gait speed was determined by recording the time it took for each participant to walk a 3 m segment of the straight section of the track. Participants performed two trials at each of the four cadences (50, 66 & 80 steps/min and self-selected) for a total of eight trials. Each trial consisted of two laps around the track. The participants wore the ActiCal accelerometer during all trials, and randomly wore two of the four remaining pedometers for the first trial at each cadence and the remaining pedometers for the second trial. The trial that provided the step count data from the ActiCal was randomly selected for each cadence condition, for each participant. There was the same number of data points for each pedometer for all cadence conditions, and for all participants.

Statistical Analysis

Absolute percent error scores were calculated for each model at each speed as:

$$\%\,\text{Error}=|[(\text{Pedometer Counted Steps}-\text{Hand Counted Steps})/(\text{Hand Counted Steps})]\times 100|.$$

Mean percent errors for each model at each speed were calculated by averaging the absolute percent error across all participants and removing any cases where the pedometer returned a recording of zero steps, as previously described by Melanson and colleagues (2004). SPSS version 11.0 (IBM, Armonk NY) was used to calculate a repeated measures ANOVA between speed conditions on the average velocities of each trial to ensure the three pre-selected cadences and self-selected speed resulted in velocities that were significantly different from one another. Two-way mixed intra-class correlation coefficients (ICC(3,2)) (Portney and Watkins, 2009) were calculated in SPSS for each model at self-selected speed to demonstrate within-brand reliability.

Results

All the participants were above the age of 50 (average age 63.6 years), and had a mean BMI of 24.7 kg/m^2. This is within the normal range according to Health Canada (2003). Participants were without apparent lower extremity injuries that would impact their gait. All the participants had TUG scores within the normal community-dwelling category (Bohannon, 2006), and were able to perform the different gait speeds required for the study.

Since the gait speeds used to assess each pedometer were controlled by a target cadence on a metronome, average gait velocity was first calculated to determine the speed that corresponded with each cadence (Table 1). There was a significant main effect of speed in each cadence condition ($F(3,51) = 157.38$; $p < 0.0001$). A post-hoc comparison of Bonferroni corrected means was performed on the mean speeds to determine that the walking speed was unique for each cadence.

There was 100% agreement between the two individuals counting the steps for 88% of trials. None of the trials had discrepancies greater than 5% of total steps, with the majority of discrepancies being only a single step. At some speeds, the pedometer in use did not register steps during a certain number of trials. These cases were documented and then removed

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from statistical analysis, as was the case in the study by Melanson and colleagues (2004). The number of trials omitted in each cadence condition, for each pedometer is shown in Table 2. The Omron, New Lifestyles and ActiCal were the pedometers that did not record any steps during some trials, and thus had these cases removed. At the slowest speed, three of the pedometer brands had instances where they did not record steps, but all progressively improved as the speed of walking increased. The Omron HJ 105 pedometer was the only device to have cases removed from all speeds.

Table 3 shows the difference in calculated means between the pedometer-measured steps and the actual number of steps taken, categorizing the results by gait speed. Figure 1 presents the absolute mean percentage error for each pedometer, which was determined at each velocity. Mean percent error across all devices combined decreased with faster cadences and was 56%, 40%, 19% and 9% at cadences of 50 steps/min, 66 steps/min, 80 steps/min, and self-selected, respectively.

The ICC values (Table 4) were calculated for each pedometer at the self-selected walking speed, with the non-registering trials removed. ICC values were not calculated for target cadences at 50, 66, or 80 steps/min as the percent error was too high to determine meaningful correlations between pedometer-counted steps versus actual steps taken. ICCs for the self-selected speeds were 0.26, 0.98, 0.36, 0.70, 0.82, and 0.94 for the Omron, New-Lifestyles, SportLine, Yamax, and ActiCal respectively. The confidence intervals for the Omron and SportLine were wide and included positive and negative values, suggesting that the results were not robust due to high variability and possibly indicating the presence of a moderating variable.

Discussion

As hypothesized, all pedometers were less accurate at slower speeds and there was no significant difference between mechanisms. This is in contrast to previous studies that suggested that pedometers with piezoelectric mechanisms were superior to mechanical mechanisms across different speeds (Crouter et al., 2003, Marsh et al., 2007, Melanson et al., 2004).

The results of this study showed that accuracy was directly related to walking speed (Figure 1). When comparing error scores across cadences, all pedometers had the lowest accuracy at 50 steps/min, with mean percent error ranging from 66.9% at the highest (Yamax) to 45.3% at the lowest (Omron). The accuracy of each pedometer improved as gait velocity increased. The pedometers performed well at the highest (self-selected) walking velocity, with mean percent error ranging from 21.3% at the highest (ActiCal) to 1.8% at the lowest (New-Lifestyles). Cyarto and colleagues (2004) reported mean percent errors of 25% at 0.95m/s, 46% at 0.8m/s, 55% at 0.64m/s and 74% at 0.4m/s for the Yamax SW 200 for overground walking. The study by Cyarto et al. (2004) had larger errors than our current study, likely due to their nursing home participants who had gait impairments that required some to use gait aids. Ichnoseki-Sekine et al (2006) found that the Omoron HJ 720-IT, a dual axis accelerometer based pedometer, similar to the New-Lifestyles 2000 pedometer used in this study, under counted steps by an average of 53.2% over a range of slow overground walking speeds (0.28 m/s to 0.99 m/s) in older adults. Similar to this study, there were also a number of cases observed where the pedometer counted no steps, and there was a great deal of variability in accuracy of the pedometer.

Piezoelectric or accelerometer based devices such as the New-Lifestyles 2000 have been recommended over mechanical pedometers (Schneider et al., 2003, Marsh et al., 2007). However, in the present study, no differences in accuracy could be discerned between the different pedometers that were tested. Interestingly, the New-Lifestyles 2000 (piezoelectric pedometer) had one of the highest percent errors at the two slowest speeds with 69% and 44% in the 50 steps/min and 66 steps/min cadence conditions, which corresponded to walking speeds of 0.44 m/s and 0.66 m/s.

Several studies have compared pedometers with other measures of activity such as accelerometers, questionnaires, and motion-capture systems. Sophisticated but expensive motion capture systems and multi-axis accelerometers have consistently provided more accurate indicators of step counts at slower walking speeds; e.g. the activPAL in Ryan and colleagues (2006) and Grant and colleagues (2008), and the CSA accelerometer in Le Masurier and colleagues (2004). However, it is important to note that in the present study, the ActiCal accelerometer was no more accurate than any of the other devices even at the fastest, self-selected walking speeds.

Limitations

By forcing participants to walk at specific cadences, their gait pattern was potentially altered, although this approach has been used to control walking speeds in previous analyses of human walking (Winter, 1991). Additionally, care was taken to ensure that the participants maintained a smooth walking pattern at all cadences. Only three units per brand of pedometer were used which may not be a representative sample of that brand of pedometer.

All of the devices used in this study were waist mounted pedometers. Some authors have suggested that ankle mounted devices may be more appropriate for use in slower walking populations due to the greater accelerations at the ankle when compared to the hip (Karabulut et al., 2005). However, Cyarto and colleagues (2004) noted that in elderly populations with cognitive impairments, ankle mounted devices are often fidgeted with or removed more frequently than the waist mounted devices. Additionally, ankle mounted pedometers tend to be less user friendly due to the fact that they require a computer to extract the step count from the device, similar to the ActiCal used in this study. Due to the lack of feedback regarding their activity, the potential benefits of knowing the daily step count may be missed.

Conclusions

As the population is aging and many people are trying to stay active it is important to find an inexpensive, accessible way to monitor and promote physical activity. While pedometers have been shown to be reliable for individuals who walk faster than 0.9 m/s (Bassett and John, 2010, Cyarto et al., 2004, Crouter et al., 2003), the results of this study demonstrate that they remain inaccurate at slower speeds irrespective of internal mechanism. Based on the results of this study, waist mounted pedometers are currently not the best choice for use in clinical populations or for frail elderly who ambulate at slower speeds. The currently available commercial pedometers inaccurately measure step counts in older populations who walk slower than 0.9 m/s. Further research is needed to develop and test measurement devices that would be more appropriate in this population. While we have observed that the accuracy of pedometers was diminished at slow walking speeds in a controlled laboratory environment, it would be interesting to see how this inaccuracy affects the counting of steps in a free-living situation. To do this we would need to have a device that is capable to providing an accurate criterion measure at slow walking speeds.

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Key Phrases

- The accuracy of various pedometer models were tested at overground walking speeds ranging from 0.46–1.31 m/s, in a group of older adults.
- The pedometers tested used various mechanisms to detect step counts.
- All of the pedometers undercounted steps at slower walking speeds.
- There was no detectable difference in the accuracy of the pedometers tested, regardless of mechanism.
- None of the waist mounted pedometers tested provided an acceptable level of accuracy at slower walking speeds, which would be typical of older adults.

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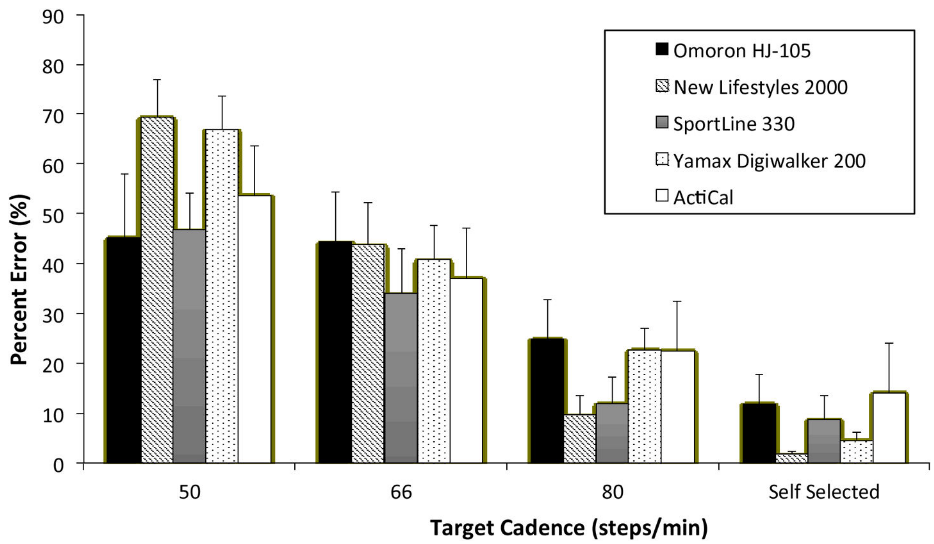

Figure 1.

Percent error for each pedometer in each target cadence condition. The error bars indicate standard error of the mean.

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Table 1

Mean walking speed in each of the target cadence conditions.

Target Cadence (bpm)	Mean Velocity - m/s (95% CI)
50	0.46 (0.41 – 0.50)
66	0.66 (0.60 – 0.72)
80	0.85 (0.79 – 0.91)
Self-selected	1.31 (1.19 – 1.42)

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Table 2

Number of trials that did not register any steps stratified by pedometer model and target cadence. A total of 18 trials were recorded for each pedometer, within each cadence condition.

Target Cadence (bpm)	Omron	New-Lifestyles	SportLine	Yamax	ActiCal
50	8	2	0	0	4
66	3	0	0	0	1
80	4	0	0	0	0
Self-selected	3	0	0	0	0

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Table 3

values comparing the mean number of steps counted by the pedometers and the mean of the actual number of steps taken. The standard deviation is ted in parentheses.

	Omron		New-Lifestyles		SportLine		Yamax		ActiCal	
Cadence (bpm)	Pedometer Steps	Actual Steps Taken	Pedometer Steps	Actual Steps Taken	Pedometer Steps	Actual Steps Taken	Pedometer Steps	Actual Steps Taken	Pedometer Steps	Actual Steps Taken
50	74.3 (52.2)	142.9 (24.7)	40.7 (32.9)	147.2 (23.23)	77.0 (42.8)	150.0 (24.7)	45.3 (33.7)	150.8 (22.5)	63.2 (36.6)	146.8 (24.3)
66	74.0 (51.0)	137.9 (21.4)	72.4 (43.1)	135.3 (17.4)	87.0 (50.0)	134.8 (18.4)	78.9 (35.3)	138.7 (18.6)	81.9 (37.7)	135.2 (18.9)
80	97.4 (36.1)	126.7 (16.4)	115.1 (21.6)	127.5 (15.2)	113.4 (34.7)	126.5 (16.9)	98.4 (19.9)	129.3 (16.0)	97.6 (24.1)	127.5 (16.1)
Self-selected	103.5 (29.2)	111.0 (12.5)	113.1 (11.3)	113.0 (12.3)	103.4 (24.6)	113.2 (12.5)	108.0 (8.9)	112.8 (12.8)	97.1 (18.2)	112.8 (12.4)

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Table 4

ICC values of the pedometers at the participants' self-selected walking speed.

	Omron	New-Lifestyles	SportLine	Yamax	ActiCal
ICC Value (95% CI)	0.26 (−1.20 – 0.75)	0.98 (0.95 – 0.99)	0.36 (−0.71 – 0.76)	0.70 (0.20 – 0.89)	0.81 (0.62 – 0.90)