MEASUREMENT ACCURACY OF A MOTION SENSOR USED TO ESTIMATE STEP COUNT

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Abstract
Pedometers are objective motion sensor instruments used to estimate the step count of subjects and are readily available to researchers. Validity studies on pedometers usually use a 'walk' test or a 'shake' test by hand and a manual numerical count of steps, therefore, there is a possibility of human error. There is limited research on testing the accuracy of pedometers with precise machinery. The purpose of the present study was to investigate measurement consistency of pedometers using a permanent magnet shaker. 338 pedometers (Yamax SW-200) were shaken at two different frequencies (1 Hz and 3 Hz) using a mechanical shaker. Mean counts of the two trials were 77.1±1.5 and 106.2±2.1, with coefficients of variation computed as 1.98% and 1.94%, respectively. Further, six pedometers were randomly picked from the tested sample for a treadmill walk test to confirm accuracy under ecological conditions. Results showed that the pedometers were at least 90% accurate for walking or jogging speeds of 4 km/h (1.1 m/s) and above. Researchers should be mindful of these results when interpreting findings from studies that employ the use of the Ymax SW-200 motion sensor.

Key words*: pedometer accuracy, magnet shaker test*

Introduction

Concerns about the global rise in obesity and physical inactivity continue to increase and this has generated much research interest in the accurate measurement of daily physical activity and physical inactivity. Advances in technology allow for the objective monitoring of physical activity or inactivity using body-worn sensors such as pedometers (Masurier & Tudor-locke, 2003). Pedometers are portable devices, usually electromechanical, that record the number of steps individuals take by detecting the vertical displacement of the hip during gait cycles of subjects (Schneider, Crouter, Lukajic, & Bassett, 2003). It provides researchers with a convenient and affordable tool for measuring physical activity (Strycker, Duncan, Chaumeton, Duncan, & Toobert, 2007) as step counts can be used to determine physical activity (Schneider, Crouter, & Bassett, 2004) or for that matter, physical inactivity (Chia, 2008) of large samples of subjects. For research studies on the activity or inactivity of subjects, it is important to establish the validity of the assessment tool. In the present study, we investigated the use of a mechanical shaker to determine the variability and measurement accuracy of the Yamax SW-200 pedometer and established how this accuracy varied in a laboratory treadmill walk test.

Methods

Mechanical shaker test
Three hundred and thirty eight Yamax SW-200 pedometers (Yamax Corporation, Tokyo, Japan) were tested using a mechanical shaker (Labwork Incorporated ET126) that was programmed to oscillate vertically at two frequencies (1 Hz and 3 Hz). The frequency of vertical head and trunk translation while walking for adults is between 1.4 Hz at 0.6m/s to 2.5 Hz at 2.2 m/s (Hirasaki, Moore, Raphan, & Cohen, 1999). In this regard, 1 Hz and 3 Hz were chosen to simulate the slow and fast walking speed of an average adult. A 35cm by 31 cm by 1cm rectangular wooden board was used as a flat surface to place and secure the pedometers by means of an adhesive. The pedometers were tested in batches of 8 with each pedometer placed 3cm from the centre of the shaker in a circle as shown in Figure 1.

Figure 1: Set up for the pedometer shake test using a mechanical shaker

The pedometers were shaken for 30 seconds at each frequency. The counts displayed on for each pedometer was recorded. All the pedometers were tested at 3Hz and then at 1Hz.

Treadmill walk test
Institutional ethics clearance was sought and granted for the test. A treadmill walk test (Le Masurier & Tudor-Locke, 2003) conducted to investigate the measurement accuracy of the pedometers under laboratory and pedometer placement conditions. Six pedometers were randomly picked from the pool of 338 pedometers for this test. Two volunteer adult subjects performed the walk test. Each subject wore three pedometers at three different hip positions (aligned to left mid hip, right mid hip and back mid hip). The subjects walked on the treadmill (Technogym, Excite Run 700, Italy) at five different speeds (i.e. 3.2, 4, 4.8, 5.6, 6.4 km/h) for five minutes at each speed. A research assistant counted in real time and recorded the steps for taken each subject at each of the walking speed. The manually determined counts were compared with the counts displayed on the pedometers after each test speed.

Data treatment
Descriptive statistics (i.e. means, standard deviations and coefficient of variation) of the data were computed. Statistical analyses were completed using SPSS Version 21. Coefficients of variation at 1 Hz and 3 Hz respectively, were derived by expressing the standard deviation as a percentage of the mean for at the set frequency of the mechanical shaker. Differences between the manually counted steps and those logged on the pedometer at the five different treadmill speeds were compared using Independent t-tests with Bonferroni adjustments. Differences in counts worn on different hip placements were analysed using paired-sample t-tests. The level of statistical significance was set at $p<0.05$.

Results
Mechanical shaker test
The means and standard deviations of the counts that are recorded by the pedometers tested by the Labwork Incorporated mechanical shaker at 1Hz and 3Hz, respectively for 30 seconds each, were calculated. These are shown in Table 1.

Shaker frequency	Pedometer counts (Mean±SD)
1 Hz	77.1±1.5
3 Hz	106.2±2.1

Table 1: Pedometer counts (N=338) recorded at 1 Hz and 3 Hz

Subsequently, the coefficients of variation (CVs) were computed as 1.98% and 1.94%, respectively for 1 Hz and 3 Hz.

Treadmill walk test
The results of the counts displayed on the pedometers divided by the counts counted by the assistants are shown in Table 2.

Speed (km/h)	Pedometer counts compared to actual (logged by research assistant in real time)					
	Subject A			Subject B		
	L	B	R	L	B	R
3.2	128.9%	34.3%	110.4%	128.1%	29.4%	107.4%
4	93.1%	58.2%	90.0%	93.2%	56.0%	90.6%
4.8	96.9%	88.5%	96.7%	96.9%	89.0%	95.1%
5.6	97.9%	96.2%	97.5%	98.1%	96.3%	97.1%
6.4	100.3%	100.8%	101.1%	100.7%	101.5%	101.3%

Table 2: Pedometer counts expressed in relation to observer counts.
L=mid left hip; B=mid back; R=mid right hip.

Pedometer counts for the different hip wear positions are shown in Table 3.

	Treadmill speed (km/h)									
Wear position	3.2		4		4.8		5.6		6.4	
	Counted Steps	Pedom.	Counted Steps	Pedom.	Counted Steps	Pedom.	Counted Steps	Pedom.	Counted Steps	Pedom.
L	387 (11)	301 (7)*	512 (15)	478 (19)	607 (13)	564 (9)	753 (17)	737 (8)	891 (23)	889 (6)
R	387 (11)	299 (5)*	512 (15)	466 (23)	607 (13)	559 (14)	753 (17)	734 (11)	891 (23)	885 (10)
B	387 (11)	116 (27)*	512 (15)	258 (29)*	607 (13)	489 (24)	753 (17)	715 (20)	891 (23)	883 (11)

Data are in Mean (Standard deviation) * observed counts vs. pedometer counts $p<0.05$
L=mid left hip; R=mid right hip; B=mid back

Table 3: Observed counts versus pedometer counts for the different hip wear positions at the five treadmill speeds

Our results showed that the measurement accuracy of the Ymax SW-200 increases with increasing treadmill walking speed, attaining close to100% accuracy for the three hip wear positions at 6.4 km/h (1.8 m/s) Contrarily at a low walking speed of 3.2 km/h (0.9 m/s) the pedometer counts at the three hip wear positions were significantly lower ($p<0.05$) than the observer recorded counts.

Discussion

The measurement accuracy of motion sensors used to estimate physical activity or physical inactivity in daily life is important in understanding the extent of the problem of physical inactivity. In the present study, a frequency of 1Hz is equivalent to 1 vertical displacement of the hip (or 1 shake of the pedometer) per second and 3 Hz is equivalent to three shakes per second. At 1 Hz, pedometer count was 77 (when it should read 30) and 106 when it should read (90). Others also report somewhat similar findings- the reliability of the Yamax digi-walker increased with higher jogging speeds (Welk et al, 2000 and Melanson et al, 2004) reported that for slow walking speed (1.0 mph or 0.4 m/s) for spring-levered pedometers such as Yamax SW-200, measurement accuracy was 7-20%. Our present results showed that counts were significantly different ($p<0.05$) from observer counts for 3.2km/h and the accuracy of the pedometers increase at higher speeds with almost 100% accuracy at a speed of 6.4km/h. These findings are quite consistent with a study reported by Le Masurier & Tudor-Locke (2003) where the Yamax pedometers were at least 90% accurate, except the mid back position, at speeds of 67m/min or 4km/h and above.

In conducting motion sensor studies on human subjects, the instructions from the manufacturer are to wear the Yamax pedometers is on the right hip (Hirasaki et al., 1999). However, the Yamax SW-200 pedometer is reported to be more accurate when worn on the left hip (Beets, Patton, & Edwards, 2005; Horvath, Taylor, Marsh, & Kriellaars, 2007). Our present results showed that the mid left hip wear position of the pedometer in the treadmill walk test were closest to the actual observer counts at walk speeds of 4 km/hr and above. The mid back wear position was the least accurate, probably due to a less pronounced vertical displacement of the back at the hip (Welk et al., 2000).

Conclusion

This study showed that a mechanical shaker could be used to test the measurement accuracy of motion sensors like a pedometer that is widely used in research. Our data show that the Yamax SW-200 motion sensor was most accurate when used at vertical displacement speeds of 3 Hz and also at walking speeds above 4 km/h.

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TOČNOST MJERENJA SENZORA POKRETA KOJI SE KORISTI ZA PROCJENU BROJA KORAKA

Sažetak

Pedometri su objektivni instrumenti senzora pokreta koji se koriste za procjenu broja koraka subjekata i dostupni su istraživačima. Studije valjanosti pedometara obično koriste test "hoda" ili "mrdanja" rukom i ručno numeričko brojanje koraka, stoga postoji mogućnost ljudske pogreške. Postoje ograničena istraživanja o ispitivanju točnosti pedometara s preciznim strojevima. Svrha ovog istraživanja bila je istražiti mjernu konzistenciju pedometara pomoću vibratora za trajni magnet. 338 pedometara (Yamax SW-200) tresli su se na dvije različite frekvencije (1 Hz i 3 Hz) pomoću mehaničkog vibratora. Prosječne vrijednosti u dva ispitivanja iznosile su 77,1 ± 1,5 i 106,2 ± 2,1, a koeficijenti varijacije iznosili su 1,98% odnosno 1,94%. Nadalje, šest pedometara nasumce je odabrano iz testiranog uzorka za testiranje hoda na pokretnoj traci kako bi se potvrdila točnost u ekološkim uvjetima. Rezultati su pokazali da su pedometri bili barem 90% točni za brzine hodanja ili jogginga od 4 km / h (1,1 m / s) i više. Istraživači bi trebali biti svjesni tih rezultata pri tumačenju nalaza iz studija koje koriste Ymax SW-200 senzor pokreta.

Ključne riječi*: točnost pedometra, magnetni test mrdanja*

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