The Validity and Intramodel Reliability of the Omron HJ-005 Pedometer for Quantifying Steps in Free-Living Conditions and Over a 400-Meter Walk

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ABSTRACT: The purpose of this study was to determine the validity and intramodel reliability of the Omron HJ-005 pedometer under free-living conditions and over a 400-meter walk. For the first part of the study, data were analysed from subjects who wore both motion sensors (the Kenz Lifecorder e-Steps accelerometer and the Omron HJ-005 pedometer) during waking hours for two consecutive weekdays and one weekend day. For the second part of the study, subjects walked 400 meters around an outdoor track while wearing two Omron HJ-005 pedometers (one each on the right and left side of the waist and centred over the foot). Under free-living conditions, the subjects reported an averaged 6,588 ± 1,240 accelerometer steps per day and 7,676 ± 1,327 pedometer steps per day. There was a significant correlation between the mean accelerometer outputs and the mean pedometer outputs for two consecutive weekdays and one weekend day ($r = 0.954$, $p < 0.001$). The mean difference in steps detected between the Kenz Lifecorder e-Steps accelerometer and the Omron HJ-005 pedometer was 1,088 ± 399 steps per day [$t(53) = 20.037$, $p < 0.001$]. On a 400-meter outdoor track, the Omron HJ-005 pedometer reported step counts with an absolute percent error (APE) of less than 5% for pedometers at both the right and left sides of the waist (at slow, moderate and fast paces) compared to manual step counts. Pedometer step counts at the right and left sides of the waist were significantly correlated (intra-class correlation coefficient >0.9) at slow, moderate and fast paces. In conclusion, the Omron HJ-005 pedometer demonstrated validity and intramodel reliability over a 400-meter walk at slow, moderate and fast paces. The correlation between the outputs from the Kenz Lifecorder e-Steps accelerometer and the Omron HJ-005 pedometer supports the interchangeability of the outputs (steps per day) from two motion sensors if only relative values are desired.

Keywords: Motion Sensor, Physical Activity, Walking

Introduction

Current technological advancement has drawn considerable concern regarding the objective measurement of physical activity, which is evident from the special supplement publications of *Medicine and Science in Sports and Exercise* (Troiano, 2005). The objective measurement of physical activity using accelerometers and pedometers is backed by technology that can monitor free-living physical activity information in the form of step counts.

The employment of objective monitoring is to ascertain which individuals attain recommended minimal levels of physical activity. Physical activity guidelines have been expressed as step counts for objective monitoring. The development of objective monitoring of physical activity using accelerometers and pedometers offers a chance to broaden guidelines to integrate recommendations for objectively monitored physical activity in free-living circumstances. The accelerometer and pedometer outputs are evidently correlated (Tudor-Locke *et al.,* 2002a).

Though accelerometers provide more information about activity, pedometers are more likely to be employed in huge populations owing to their relatively cheaper price (Tudor-Locke *et al.,* 2011). For instance, the single-axis Lifecorder e-Steps accelerometer (Suzuken Company Limited, Japan) has a memory function that can capture movement parameters over seven days. The vertical oscillations detected were translated into the total number of steps per day and the total daily energy expenditure, with intensity being depicted. However, this technology is might not be affordable to many as it costs as much as RM175 per unit. Although accelerometers have become a crucial physical activity assessment instrument, they may be less feasible for use in self-monitoring due to the cost and technical requisite for their function (Tudor-Locke *et al.,* 2002b).

Pedometers have exhibited evidence of reliability (Tryon *et al.,* 1996) and construct validity (Tudor-Locke and Myers, 2001). Various electronic pedometers are commercially available. A product comparison study performed by Bassett *et al.* (1996) indicated that the Yamax SW-500 pedometer (Yamax Corporation, Tokyo, Japan) was suitable in monitoring step counts under controlled conditions. However, this pedometer is no longer manufactured by the Yamax Corporation (Bassett, 2000). Yamax SW-200 pedometer exhibited a correlation (r = 0.80–0.90) with accelerometers, including Computer Science and Applications (CSA) accelerometers, under laboratory conditions (Bassett *et al.,* 2000). It provided representative information on the total accumulated physical activity based on its significant correlation (r = 0.84–0.93) with outputs from other accelerometers, including Tritrac and CSA accelerometers, under controlled conditions (Leenders *et al.,* 2000).

Until now, there is a lack of validation studies for the Omron HJ-005 pedometer among the adult population. The Omron HJ-005 pedometer is the most affordable pedometer in the Omron line and an attractive option for large-scale studies. There is no need to unclip the pedometer in order to look at the number of steps taken as the screen display is sufficiently large.

There is a need to investigate the validity and reliability of the Omron HJ-005 pedometer for use among Malaysian adults due to the apparent scarcity of pertinent data concerning its employment among this group of users. Hence, the purpose of this study was to verify whether the Omron HJ-005 pedometer provided an objective, valid and reliable measure of physical activity among Malaysian adults. The correlation and agreement between the outputs from the Kenz Lifecorder e-Steps accelerometer [which was validated in a study conducted by Heng and Hazizi (2010)] and the Omron HJ-005 pedometer were assessed concurrently under free-living conditions. Furthermore, the validity and intramodel reliability of the Omron HJ-005 pedometer were assessed over a 400-meter walk at slow, moderate and fast paces.

Methods

Subjects

A convenience sample recruited from a university community composed of 54 subjects (non-academic staff) was enrolled in this study for the validity evaluation of the Omron HJ-005 pedometer. The determination of a sample size of 54 was based on a similar study that was sufficient to detect a significant correlation (Sugden *et al.,* 2008). The Lifecorder e-Steps accelerometer and the Omron HJ-005 pedometer were worn concurrently during waking hours by subjects as an approach to validate the Omron HJ-005 pedometer with the Lifecorder e-Steps accelerometer. The Lifecorder e-Steps accelerometer was validated in a study conducted by Heng and Hazizi (2010). In the second part of the study, 30 subjects (non- academic staff and students) were instructed to perform self-paced walking (slow, moderate and fast paces) at a 400-meter outdoor track. Each subject was given two pedometers to be clipped on the right and left sides of the waist. Actual step counts were determined by the researcher walking behind the subjects. The age, gender, height and weight of all subjects were recorded. The body mass index (BMI) was calculated using the following formula: weight in kilograms divided by height in meters squared. Waist circumference (WC) was measured at the end of normal expiration between the lowest rib and the iliac crest using an inelastic measuring tape to the nearest 0.1 cm.

Motion sensor

Under the free-living conditions, the Omron HJ-005 spring-levered device was worn on the left side of the waist, centred over the foot. Vertical movement moves a horizontal-levered arm up and down and thus opens and closes an electrical circuit. In this study, the piezoelectric accelerometer was worn at the right side of the waist. Both the Lifecorder e-Steps accelerometer and the Omron HJ-005 pedometer are small, lightweight, non-invasive objective motion sensors that can be worn concurrently with comfort. Subjects were asked to wear both motion sensors from the time they woke up in the morning until they went to bed at night, excluding water-based activities (such as swimming) and bathing time, for two consecutive weekdays and one weekend day. The subjects were asked to write day-end values for pedometer steps and to reset to zero every day. The subjects were instructed to carry out their normal lives without restriction. Each subject was asked to walk 100 steps at his or her usual pace, wearing the pedometer in the presence of the researcher prior to wearing it under free-living conditions. If the step counts displayed were five steps more than actual total, the 'ADJ' knob was shifted slightly to the negative side and vice versa. The 100-steps test was repeated, and the 'ADJ' knob was adjusted accordingly until±5-step count validity was reached against the actual series (Omron, 2013).

In the second part of the study, each subject was given two pedometers to be clipped on the right and left sides of the waist. The two pedometers were chosen at random from a pool of devices before the respective 400-meter walking trials. Pedometers were adjusted to be in line with the midline of the right and left thighs. All pedometers were reset to zero and checked for functionality prior to the distribution. The 'ADJ' knob was left in the neutral (middle) position at all times (slow, moderate and fast paces). The actual steps taken were determined by a researcher via manual counting. The researcher walked behind the subjects to avoid influencing the subjects' pace. Each subject walked at his or her self-defined slow, moderate and fast paces.

Data analysis

Descriptive data were presented as mean ± SD. Inter-class correlation (Pearson product-moment correlation coefficient, r) was performed to quantify the linear relationship between the outputs from the Kenz Lifecorder e-Steps accelerometer and the Omron HJ-005 pedometer, specifically the number of steps per day. The Guildford Rule of Thumb (Guildford, 1956) was used for interpretation purposes, where <0.2 is negligible, 0.2 to 0.4 is weak, 0.4 to 0.7 is moderate, 0.7 to 0.9 is strong and 0.9 or above is very strong. Agreement between the outputs from the accelerometer and the pedometer was assessed using the Bland-Altman method (Bland and Altman, 1986), plotted as the differences between outputs from the accelerometer and the pedometer against the mean of both. The relationship between measurement error and the mean value of the motion sensors (the Kenz Lifecorder e-Steps accelerometer and the Omron HJ-005 pedometer) was demonstrated through this plot. The limits of agreement were considered as the mean difference ± 2 SDs between the outputs from the accelerometer and the pedometer. Paired sample *t*-tests were carried out to test the differences in the number of steps detected by the two motion sensors. The absolute percent error (APE) was calculated between the actual number of steps and the number of pedometer-determined steps (APE = [pedometer steps – actual steps] / actual steps x 100). In accordance with the standards for evaluating the intra-class correlation coefficient (ICC) (Baumgartner *et al.,* 2003), the following guidelines were used to categorize the ICC: (a) 0.60 to 0.79 is low agreement, (b) 0.80 to 0.89 is moderate agreement and (c) ≥0.9 is high agreement. Statistical significance was set at an alpha level of 0.05. Statistical analyses were conducted using SPSS version 20.

Results

Demographic information for subjects in the first part and second part of the study is presented in **Table 1** and **Table 2**, respectively.

Table 1: Sample demographic information for first part of the study
(Comparison between output from the Lifecorder e-Steps accelerometer and the Omron HJ-005 pedometer)

	Male (n= 23)	**Female (n= 31)**
Age (Year)	36.57±6.34	34.55±7.32
Height (m)	1.71±0.05	1.56±0.06
Weight (kg)	74.17±10.77	62.70±9.97
Body mass index (kg/m^2)	25.45±3.57	25.76±3.50
Waist circumference	92.06±6.58	84.13±6.96

Note: Values are in Mean±SD

Table 2: Sample demographic information for second part of the study
(Comparison between output from the Omron HJ-005 pedometer and a manual count)

	Male (n= 14)	**Female (n= 16)**
Age (Year)	26.64±4.77	24.81±4.58
Height (m)	1.72±0.03	1.61±0.03
Weight (kg)	78.07±7.05	68.25±9.10
Body mass index (kg/m^2)	26.48±2.09	26.43±3.37
Waist circumference	91.25±3.16	81.93±3.66

Note: Values are in Mean±SD

The accelerometer steps per day recorded an averaged 6,588 ± 1,240, while the pedometer steps per day recorded an averaged 7,676 ± 1,327 for the 54 subjects under free-living conditions with significant correlation (**Figure 1**) [r = 0.954, p<0.001]. **Table 3** displays the descriptive variables, explicitly accelerometer steps per day and pedometer steps per day for the 54 subjects under free-living conditions. Values were expressed as means ± SDs. The mean difference in the number of steps detected between the motion sensors was 1,088 ± 399 steps per day [outputs from the accelerometer were less than from the pedometer; t (53) = 20.037, p < 0.001]. **Figure 2** displays the Bland-Altman plot illustrating the difference between the outputs from the accelerometer and the pedometer under free-living conditions. The differences were normally distributed. The limits of agreement (depicted as bold lines) were 290 to 1,886 steps per day.

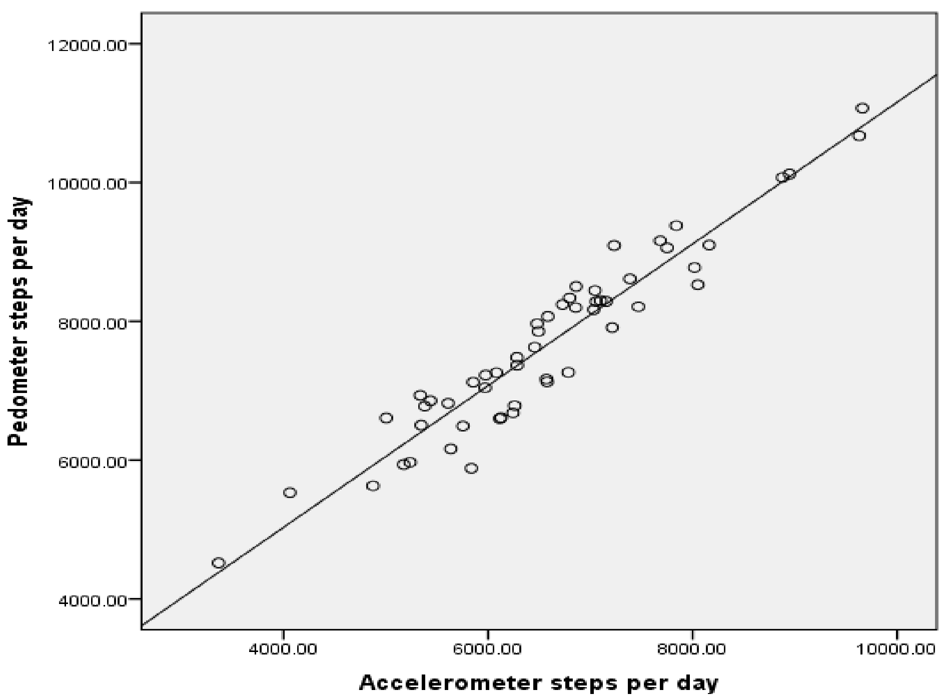

Figure 1: Accelerometer steps per day significantly correlated with pedometer steps per day under free living condition (r= 0.954, p<0.001).

Table 3: Accelerometer-steps per day and pedometer-steps per day under free-living conditions

Variable	Mean ± SD (n= 54)
Accelerometer- steps per day	6588 ± 1240
Pedometer- steps per day	7676 ± 1327

Note: Values are in Mean±SD

Significant correlation was found between accelerometer-steps per day and pedometer-steps per day under free-living conditions (r= 0.954, p<0.001)

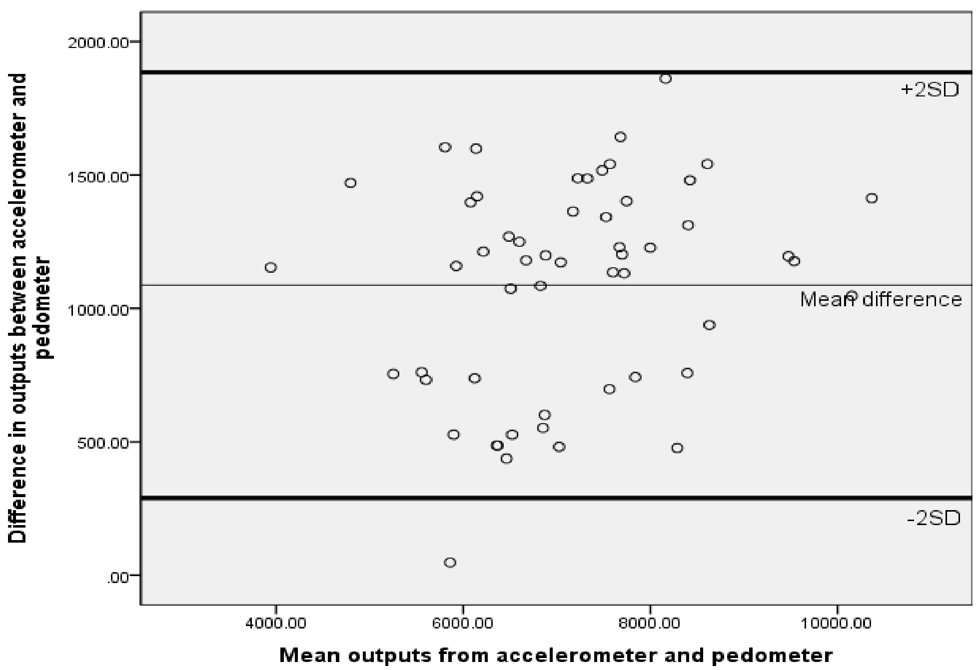

Figure 2: Bland-Altman plot (accelerometer steps per day and pedometer steps per day under free-living conditions) (t (53) = 20.037, p<0.001).

Table 4 displays the descriptive variables, specifically the pedometer steps output at both sides (left and right) of the waist and actual steps for a 400-meter outdoor walking trial. Values were expressed as means ± SDs. The correlation between pedometer steps (right side of the waist) in comparison with pedometer steps (left side of the waist) for a 400-meter outdoor walking trial was high across slow (ICC = 0.995, p < 0.001), moderate (ICC = 0.989, p < 0.001 and fast paces

(ICC = 0.990, $p < 0.001$). The intramodel reliability between the right and left pedometer steps output was consistent across different paces. The paired *t*-test was employed to determine whether there was any large systematic bias in the pedometer output at the right and left sides of the waist. Results showed that there was no significant difference between the pedometer output at the right and left sides of the waist across slow [t (29) = 0.798, p = 0.431], moderate [t (29) = -0.107, p = 0.916] and fast paces [t (29) = 0.327, p = 0.746].

Table 4: Step counts for a 400-meter outdoor walking trial (n = 30)

	Number of steps (Steps)		
	Slow pace	**Moderate pace**	**Fast pace**
Pedometer- steps (Right side of the waist)	577 ± 33	577 ± 23	488 ± 23
Pedometer- steps (Left side of the waist)	576 ± 32	577 ± 24	488 ± 24
Actual steps	576 ± 28	576 ± 22	487 ± 23

Note: Values are in Mean±SD

Comparison between pedometer- steps at right side of the waist vs left side of the waist:

Significant correlation was found (ICC= 0.995, p<0.001 at slow pace; ICC= 0.989, p<0.001 at moderate pace; ICC= 0.990; p<0.001 at fast pace).

No significant difference was found [t(29)= 0.798, p= 0.431 at slow pace; t(29)= -0.107, p= 0.916 at moderate pace; t(29)= 0.327, p= 0.746]

Comparison between pedometer- steps at right side of the waist vs actual steps:

Significant correlation was found (ICC= 0.968, p<0.001 at slow pace; ICC= 0.970, p<0.001 at moderate pace; ICC= 0.982; p<0.001 at fast pace)

No significant difference was found [t(29)= 0.865, p= 0.394 at slow pace; t(29)= -0.811, p= 0.424 at moderate pace; t(29)= -1.081, p= 0.289]

Comparison between pedometer- steps at left side of the waist vs actual steps:

Significant correlation was found (ICC= 0.961, p<0.001 at slow pace; ICC= 0.957, p<0.001 at moderate pace; ICC= 0.968; p<0.001 at fast pace)

No significant difference was found [t (29)= -0.553, p= 0.584 at slow pace; t(29)= -0.694, p= 0.493 at moderate pace; t(29)= -0.607, p= 0.549].

The correlation between pedometer steps (right side of the waist) in comparison with the actual steps for the 400-meter outdoor walking trial was significant across slow (r = 0.968, p < 0.001), moderate (r = 0.970, p < 0.001) and fast paces (r = 0.982, p < 0.001). The paired *t*-test shows no significant difference between pedometer output at right side of the waist and manual-counted steps across slow [t (29) = 0.865, p= 0.394], moderate [t (29) =-0.811, p=0.424] and fast paces [t (29) =-1.081, p= 0.289].

The correlation between pedometer-steps (left side of the waist) in comparison with actual steps for a 400-meter outdoor walking trial was significant across slow (r= 0.961, p < 0.001), moderate (r= 0.957, p < 0.001) and fast paces (r= 0.968, p < 0.001). Paired t-test reveals no significant difference between pedometer output at left side of the waist and actual steps across slow [t (29) =-0.553, p= 0.584], moderate [t (29) =-0.694, p= 0.493] and fast paces [t (29) =-0.607, p= 0.549]. The absolute percent error (APE) was calculated between actual steps and pedometer-determined steps [APE = (pedometer steps – actual steps) / actual steps x 100] and is displayed in **Table 5** for a 400-meter outdoor walking trial.

Table 5: Absolute percent error (APE) was calculated between actual steps and pedometer-determined steps for a 400-meter outdoor walking trial (n = 30)

	Absolute Percent Error (%)		
	Slow pace	**Moderate pace**	**Fast pace**
Actual steps and pedometer- determined steps at right side of the waist	0.21 ± 1.53	0.14 ± 0.98	0.18 ± 0.90
Actual steps and pedometer- determined steps at left side of the waist	0.14 ± 1.59	0.15 ± 1.24	0.13 ± 1.23

Note: Values are in Mean±SD

Discussion

One of the purposes of this study was to compare outputs from an accelerometer and a pedometer measured under a free-living context. The correlation ($r = 0.954$, $p < 0.001$) identified between outputs from the accelerometer and the pedometer implies a significant linear correlation between the two motion sensors. Closer scrutiny of the data revealed a notable lack of agreement in the outputs between the two motion sensors, as evidenced by the Bland-Altman plot (**Figure 2**). The mean difference in outputs detected by the accelerometer and the pedometer was approximately 1,088 steps per day, and the limits of agreement between the motion sensors were broad (290 to 1,886 steps). Collectively, these data imply that output from one motion sensor may not be simply replaced for the other if an absolute number of steps per day is required. Nevertheless, the significant correlation between the two motion sensors supports the interchangeability of the outputs (steps per day) from two motion sensors if only relative values are desired. On the other hand, it has been demonstrated that the Omron pedometer may be sensitive to non-step movements (Le Masurier, 2004).

All of the mean outputs over two consecutive weekdays and one weekend day from the pedometer cases were higher than those of the accelerometer in a free-living context. The difference in the outputs between the two motion sensors may be due to the difference in sensitivity in detecting vertical accelerations (spring-levered versus piezoelectric). It is plausible that the difference detected in this study is due to the inability of the pedometer to filter out external vibration not produced by the body, such as the vibration that occurs while riding a motorcycle. In addition, it may be that the motion sensors were worn in some different ways that caused the jolting of the motion sensors, though we are unable to verify the truth. Differences in mean steps per day may also be due to the differences in the attachment site (the right and left sides of the waist). The true number of steps taken per day by the subjects in this field study is unknown, so it is inappropriate to argue the superiority of one motion sensor over the other to measure accurately the true number of steps taken per day. A criterion measure of steps taken per day, such as tallying with the findings from direct observation, is not feasible for such field studies that involve free-living populations. However, 400-meter walking trials with direct observation were conducted in this study to validate the field study results.

It is perhaps a more valid conclusion to say that each motion sensor detected steps with acceptable validity that fell within their specific but different ranges of sensitivity. Objective motion sensors, specifically accelerometers and pedometers, should be chosen based on the needs in terms of budget, purpose and sensitivity. Pedometers provide the exclusive promise of a feasible method for surveillance in view of their cheaper price relative to accelerometers. There was a correlation between their outputs ($r = 0.954$, $p < 0.001$), which is consistent with the findings of others (Bassett *et al.,* 2000; Leenders, Sherman and Nagaraja, 2000). The consistent strength of this correlation allows us to investigate the accelerometer- and pedometer-determined pattern of physical activity.

Physical activity level differed prominently between weekdays and weekend days (Gretebeck and Montoye, 1992). Hence, assessments on both weekdays and weekend days were taken and analysed. A period of three to five days of monitoring is essential for a reliable physical activity monitoring (Trost *et al.,* 2005). Furthermore, any three days can offer an adequate estimate based on the conclusion of Tudor-Locke *et al.* (2005). It has been demonstrated that readings obtained for three days account for 94% of the variance of readings obtained for seven days (Australian Institute for Health and Welfare, 2003).

Under 400-meter walking trials, an APE of 5% or less (five or fewer steps per every 100) has become an accepted criterion for pedometer validity (Tudor-Locke *et al.,* 2006). The intramodel reliability of step counts derived by the Omron HJ-005 (intra-class correlation coefficient between pedometer step counts at the right and left sides of the waist >0.9) is more than satisfactory for the quality control and tight manufacturing tolerances. A lower number of steps at fast paces was found. This could be explained by a simultaneous increase in stride length and a succeeding decrease in the number of actual steps taken when the pace of locomotion is increased. For instance, runners have fewer steps than walkers for the same distance covered. The Omron pedometer does detect within 1% APE most of the time for steps taken at 80 m/min^{-1} (3 miles $hour^{-1}$) (Crouter *et al.,* 2003; Le Masurier, 2004). In addition, a study conducted by Holbrook *et al.* (2009) revealed that the Omron HJ-151 and the Omron HJ-720ITC accurately reported step counts under prescribed and self-paced conditions with APE below 3.0%.

Validity and intramodel reliability describe the quality of the Omron HJ-005 pedometer for intervention, surveillance and program evaluation. The first part of the study was designed under a free-living context, and the second part was conducted on a 400-meter outdoor track under self-defined paces (slow, moderate and fast paces). A significant correlation was demonstrated between the outputs from the Kenz Lifecorder e-Steps accelerometer and the Omron HJ-005 pedometer as well as between the outputs from the Omron HJ-005 pedometer and the actual number of steps. The Omron HJ-005 pedometer is an accurate and reliable measurement tool that can be employed to quantify physical activity. It is suitable to be employed as a self-monitoring motion sensor considering of its cost and technical requisite for its function. However, output from a pedometer may not simply replace the output from an accelerometer if an absolute number of steps per day is required. Further investigation is warranted with larger sample sizes and across various populations to improve the stability of the correlations.

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