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Research article

Pedometer accuracy during stair climbing and bench stepping exercises

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Abstract
The purpose of the present investigation was to examine pedometer accuracy during stair climbing and descending as well as during the performance of a bench stepping exercise. Ten healthy men participated in the present investigation. All subjects ascended and descended an 18 cm high public staircase, and performed a bench stepping exercise by using a 10, 20 and 30 cm high platforms, while wearing three different commercial pedometers (DW-800, YM, HJ-700IT; OM, Lifecorder; KZ). In both situations, the stepping rate was controlled at 40, 50, 80, 100 and 120 steps·min^{-1}. The pedometer scores tended to underestimate the actual number of steps during stair climbing with a slower stepping rate and/or the lower height of a platform. During the stair ascending and descending and the bench stepping exercise using 20 to 30 cm high platforms at 80 to 120 steps·min^{-1}, the magnitude of the measurement error was -3.8± 10.8 % for KZ, -2.1 ± 9.8 % for YM and -11.0± 18.9 % for OM. These results indicate that the KZ and the YM can accurately assess the number of steps during stair climbing using 20 to 30 cm high platforms at 80 to 120 steps·min^{-1}.

Key words: Digi-walker, LIFECORDER, activity monitor, accelerometer.

Introduction

Pedometers have been widely used in the field of health promotion in order to evaluate physical activity levels for both assessment and motivational purposes. Recent investigations have demonstrated that various health benefits can be achieved by increasing the number of steps taken over a day (Bassett and Strath, 2002). Although general pedometers cannot assess the intensity of physical activity, the cost of such instruments and the fact that they are easy to use are the main advantages, in contrast to the other physical activity monitors such as accelerometers (Bassett and Strath, 2002; Tudor-Locke et al., 2002).

The validity of pedometers has already been well documented under both the controlled and free-living conditions (Schneider et al., 2003; 2004). Although pedometers tend to underestimate ambulation during slow walking, the magnitude of measurement error has been found to be within acceptable ranges during usual walking (Melanson et al., 2004). Therefore, pedometers have been considered to be useful devices for assessing the walking behavior of most individuals, except for the frail elderly (Cyarto et al., 2004).

Previous validation investigations with pedometers have mainly focused on their accuracy during horizontal walking (Cyarto et al., 2004; Melanson et al., 2004; Schneider et al., 2003; 2004). However, accuracy of pedometers during stair climbing and descending has not yet been reported. Bench stepping is an effective exercise regimen to improve physical fitness levels (Mori et al., 2006; Olson et al., 1996). Furthermore, epidemiological studies have shown stair climbing to demonstrate clear health benefits (Lee and Sesso, 2000; Paffenbarger et al., 1986). Therefore, it would be useful if pedometers could accurately assess the number of steps during stair climbing. Moreover, pedometer accuracy should be evaluated under not only walking, but also a bench stepping exercise and a stair climbing condition.

Therefore, the objective of the present investigation was to examine pedometer accuracy during stair ascending and descending as well as during the performance of a bench stepping exercise.

Methods

Ten apparently healthy men (24 ± 3 years of age, 1.76 ± 0.06 m of height, 73.0 ± 10.4 kg of body weight and 23.6 ± 2.6 kg·m^{-2} of body mass index) participated in the present investigation.

After explaining the study design and requirements to all subjects, all participants read and signed a consent form. All procedures of this investigation were approved by the ethics committee of the School of Health and Sports Science, Juntendo University.

All participants ascended and descended stairs at a 40, 60, 80, 100 and 120 steps per minutes. These stepping rates were controlled by means of a digital metronome (DM-17, Seiko, Tokyo, Japan). All climbing activities were conducted in the building of Juntendo University which had 5 staircases of 21 stairs with 18 cm in height and 30 cm in depth, for a total vertical displacement of 15.12 meters. Therefore, there was a total of 84 stairs for this building, and there was a horizontal space at the middle and end of each floor. All subjects ascended from the first floor to the fifth floor, and then descended from the fifth floor to the first floor.

Furthermore, all participants performed a single bench stepping exercise at the same stepping rate as that for stair climbing (40, 60, 80, 100 and 120 steps per minute) by means of a platform (ARGO, Tokyo, Japan) at a height of 10, 20 and 30 cm. The duration of each stage was one minute, and a sufficient resting period was established between the stages. The stepping rate was controlled by a digital metronome.

A spring-levered pedometer (DW-800, YAMAX, Tokyo, Japan; YM) and two piezo-electric pedometers

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(Lifecorder, Suzuken, Nagoya, Japan; KZ, HJ-700IT, OMRON, Kyoto, Japan; OM) were all used in this investigation. All instruments were small and light weight (YM: 5.0 × 3.5 × 2.5 cm and 20g, OM: 5.2 × 7.4 × 1.5 cm and 50g, KZ: 6.0 × 4.5 × 2.5 cm and 40g). Previous investigations demonstrated that both YM and KZ have superior accuracy under controlled and free-living conditions in comparison to the instruments from the other brands (Schneider et al., 2003, 2004). Furthermore, OM was a recently released unique pedometer which contains a dual-axial accelerometer. The mechanism and algorisms for this pedometer (HJ-112 is the English version of HJ701IT) have been found to be valid and reliable based on the findings of recent studies (Hasson et al., 2005; Haller et al., 2005).

During the course of the present investigation, all subjects wore the same pedometers. These three pedometers were checked to confirm that the magnitude of measurement error was below 3% under 1000 steps of usual walking, before all experiments. In addition, accuracy of these Japanese pedometers has been confirmed based on the manufacturing process, according to the Japanese Industrial Standards. Briefly the error in the step counts must be below +/-3% per 1000 artifacts at 0.24 G and 0.5G.

The pedometers were placed on the left anterior mid-line of the thigh on the waist band of the participant's clothing. One of the three pedometers was placed at that position, and the remaining two pedometers were placed at the right and left of the central pedometer. Therefore, all of the pedometers were placed within +/- 7 cm of the mid-line of the thigh. A previous investigation suggested that the placement of pedometer on the front, side or back of the waistband did not affect accuracy of the pedometer for counting steps (Swartz et al., 2003). Furthermore, the order in which the pedometers were worn was randomized to avoid any order effects (Bassett et al., 1996). Although these three pedometers can assess calorie expenditure as well as walking distance, the present investigation examined only accuracy of the number of steps. After each stage of exercise, the number of steps that each pedometer displayed was recorded. In addition, a video recording was used to confirm that the subjects took the prescribed number of steps during all experiments. Furthermore, in stair ascending and descending, the number of steps on the horizontal spaces was obtained from a video recording in order to accurately calculate the actual number of steps.

The data are presented as the mean with standard deviation (Mean ± SD). The difference between the actual number of steps and the number of steps determined by pedometers was examined using paired t-tests. Furthermore, error scores were graphically illustrated according to the procedure specified by Bland and Altman (1986). A p-value of <0.05 was to be considered statistically significant for all analyses.

Results

Figure 1 shows pedometer accuracy during stair ascending and descending. The average difference between the pedometer scores and the actual number of steps (average ± standard deviation) was -16.1 ± 25.0 % in KZ, -8.6 ±18.5 % in YM and -48.8± 43.9 % in OM for the over all stepping rates of stair ascending and descending. During stair ascending at 40 to 60 steps·min^{-1}, the pedometers significantly underestimated the number of steps ($p < 0.05$). In contrast, at 80 to 120 steps·min^{-1}, the number of steps assessed by KZ and YM did not differ significantly in comparison to the actual number of steps, whereas OM significantly underestimated the number of steps at 80 steps·min^{-1} ($p < 0.05$). The measurement error during stair ascending and descending at 80 to 120 steps per minutes were -1.5 ± 3.4 % in KZ, 1.4 ± 4.3 % in YM and -1.3± 3.8% for OM.

Figure 2 shows pedometer accuracy during the

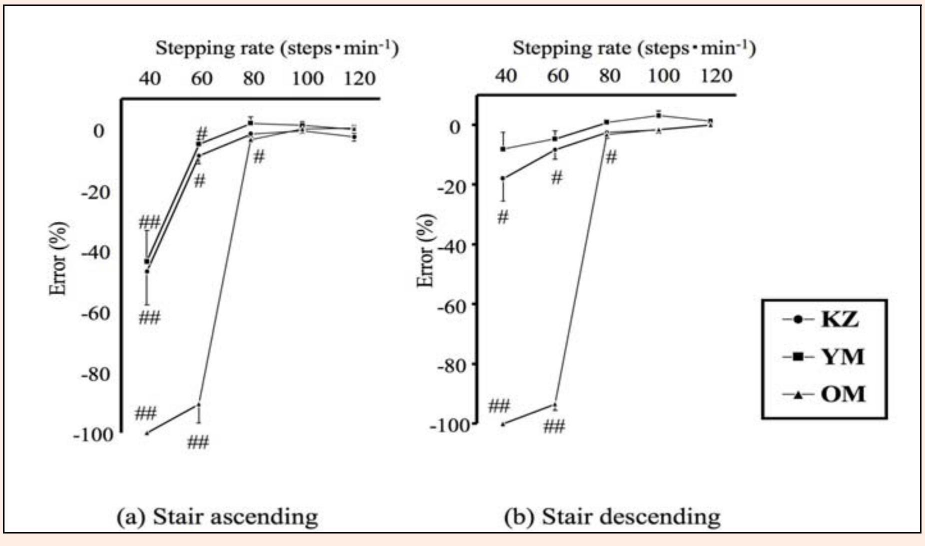

Figure 1. Pedometer accuracy during stair ascending and descending. Two illustrations show pedometer accuracy during stair ascending (a) and descending (b), respectively.
KZ; Lifecorder: YM; DW-800: OM; HJ-700IT. #, ## Significantly underestimated the number of steps (# $p < 0.05$, ## $p < 0.01$).

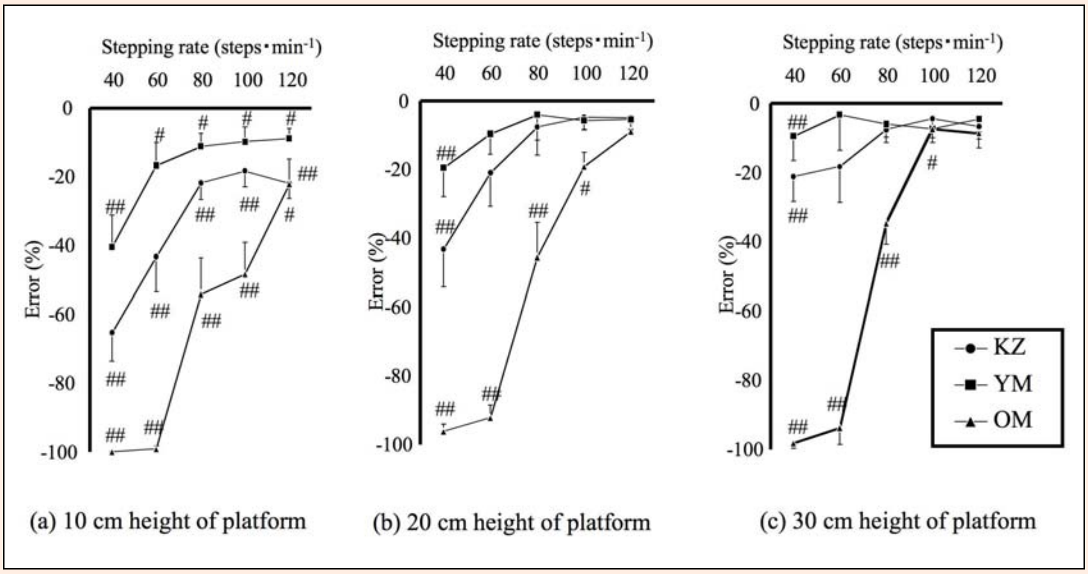

Figure 2. Pedometer accuracy during bench stepping. Three illustrations show pedometer accuracy during a bench stepping exercise by means of platforms that are 10 cm (a), 20 cm (b) and 30 cm (c) high, respectively.
KZ; Lifecorder: YM; DW-800: OM; HJ-700IT. #, ## Significantly underestimated the number of steps (# $p < 0.05$, ## $p < 0.01$).

bench stepping exercise (Figure 2). The average difference between the pedometer scores and the actual number of steps (average ± standard deviation) was -20.7 ± 27.2 % in KZ, -10.9 ±18.7 % in YM and -55.3± 40.4 % for OM for over all bench stepping exercise. Furthermore, the measurement error was -34.2 ± 27.6 % in KZ, -17.5 ±21.3 % for YM and -64.8± 37.4 % for OM with a 10 cm high platform, -16.3 ± 28.0 % for KZ, -8.9 ±18.8 % for YM and -52.5± 40.2 % for OM at a 20 cm high platform and -11.7 ± 20.5 % for KZ, -6.2 ±13.7 % for YM and -48.6± 42.3 % for OM at a 30 cm high platform, respectively. The pedometer scores for KZ and YM did not differ significantly in comparison to the actual number of steps and the magnitude of measurement error was -6.0 ± 14.5 % for KZ, -5.6 ± 12.2 % for YM at a 60 to 120 steps·min^{-1} of stepping rate with 20 and 30 cm high platforms. In contrast, the OM significantly underestimated the number of steps during most bench stepping exercises ($p < 0.05$).

Figure 3 shows Bland-Altman plots for the three pedometers. The limit of agreement (mean±2 standard deviations of error) was -29 to 46 steps in KZ, -29 to 40 in YM and -53 to 129 in OM during stair ascending and descending, and was -19 to 46 steps in KZ, -16 to 30 in YM and -13 to 80 in OM during the bench stepping exercise.

Discussion

Pedometers are popular devices for measuring daily physical activity (Bassett and Strath, 2002; Tudor-Locke et al., 2002). The current study demonstrated that pedometers could assess the number of steps accurately during horizontal walking (Crouter et al., 2005; Schneider et al., 2003). In addition, the present study demonstrated that pedometers could also assess the number of steps within an acceptable error during climbing activities such as walking up and down stairs. An original finding of the present study was that the magnitude of the measurement error averaged during stair ascending and descending and the bench stepping exercises with 20 to 30 cm high platforms at an 80 to 120 steps·min^{-1} stepping rate was -3.8± 10.8 % for KZ, -2.1 ± 9.8 % for YM and -11.0 ± 18.9 % for OM. These results indicate that the KZ and the YM could assess the number of steps within ±5% of measurement error during stair climbing using 20 to 30 cm high platforms at rates of 80 to 120 steps·min^{-1}.

The results of the present investigation clearly indicate that accuracy of pedometers during stair climbing as well as bench stepping depends on the speed of the stepping rate and the height of the platform. During stair ascending and descending, the measurement error ranged from ± 2 % at a stepping rate of 80 or faster steps·min^{-1}, whereas the pedometers significantly underestimated the number of steps at a stepping rate of 60 or fewer steps·min^{-1}. In addition, during the bench stepping exercise, the pedometer scores for KZ and YM did not differ significantly in comparison to the actual steps at a stepping rate of 60 steps·min^{-1} or higher with 20 and 30 cm high platforms, whereas both pedometers significantly underestimated the number of steps at all stepping rates with a 10 cm high platform. These results indicate that KZ and YM seem suitable for assessing the number of steps during stair climbing, and a measurement error of +/- 5% is expected during stair ascending and descending and during bench stepping exercise with 20 to 30 cm high platforms at an 80 to 120 steps·min^{-1}.

In contrast to KZ and YM, accuracy of OM was sometimes problematic. The measurement error during the climbing activities with 20 cm or higher platforms at a stepping rate of 80 to 120 steps·min^{-1} was also above 10 % for OM (-11.0±18.9 %), whereas that for KZ and YM was below 5% (-3.8±10.8 % in KZ and -2.1±9.8 % in YM).Therefore, KZ and YM seem to be more suitable for the assessment of the number of steps during stair climbing than OM. This result is supported by previous investigations where the KZ and YM also showed superior

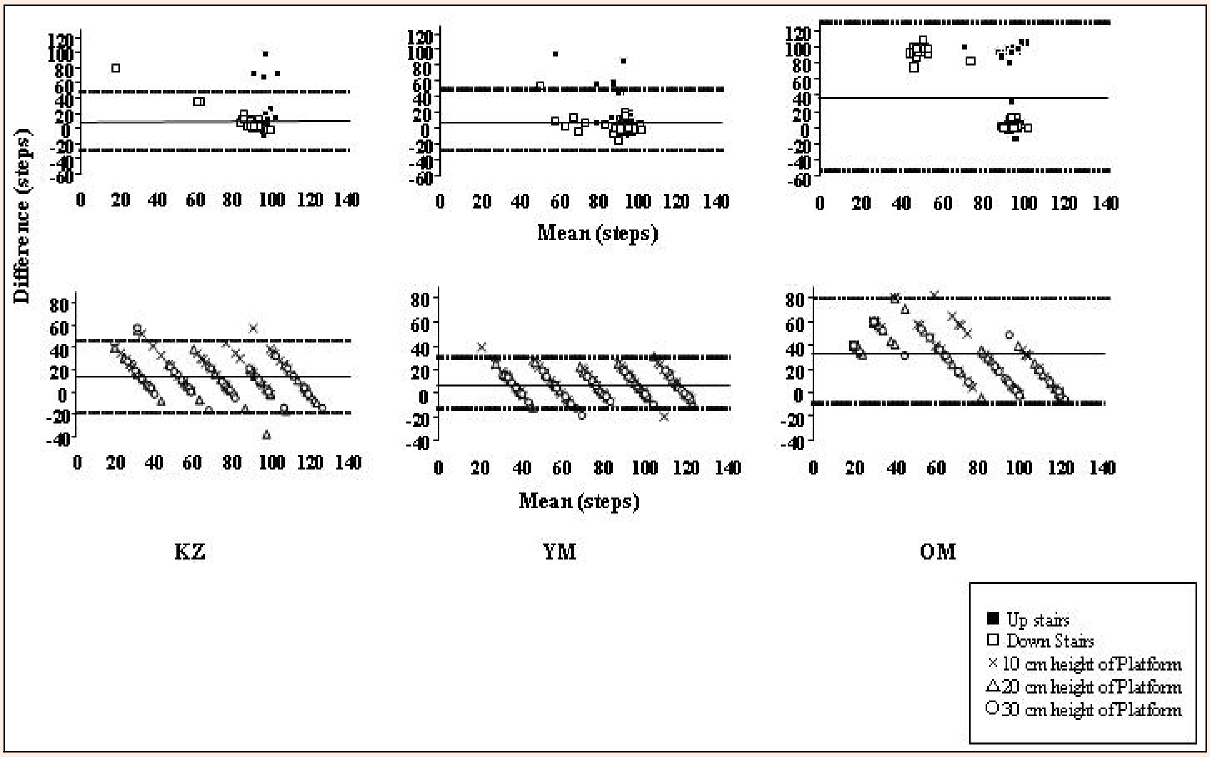

Figure 3. Bland-Altman Plots for three pedometers during stair climbing and bench stepping.
KZ; Lifecorder: YM; DW-800: OM; HJ-700IT. At the upper side, the three illustrations show pedometer accuracy during stair climbing and the three illustrations on the at lower side show pedometer accuracy during bench stepping. The X–axis is the mean of the actual- and pedometer determined steps. The Y-axis shows the difference of the actual and pedometer determined steps (actual step minus pedometer-determined step). The horizontal solid lines show the mean error score, and the horizontal dashed lines show the 95% confidence intervals of the individual observation.

accuracy in comparison with other pedometers during horizontal walking (Schneider et al., 2003; 2004). However, when limited to stair ascending and descending at 80 steps per minute or higher, OM was able to assess the number of steps within ±2 % (-1.3 ± 3.8 %) as well as KZ (-1.5 ± 3.4 %) and YM (1.4 ± 3.4 %).

Teh and Aziz (2002) reported the usual stepping rate for stair climbing to be 95 ± 14 steps·min^{-1} for stair ascending and 106 ± 14 steps·min^{-1} for stair descending in 103 middle-aged individuals using a public-access staircase with steps that were 15 cm high. Since the results of the present investigation demonstrated that the magnitude of the measurement error with pedometers was below 2% during stair ascending and descending at 80 to 120 steps·min^{-1} (Figure 1), pedometers would be expected to assess the number of steps accurately during normal stair ascending and descending. Furthermore, the bench stepping exercise at 80 to 120 steps·min^{-1} with the 20 to 30 cm high platforms also provides an appropriate intensity for young to older individuals in order to obtain health benefits (Ayabe et al., 2003; 2004). Since the present study confirmed validity of KZ and YM during the bench stepping exercise at 80 to 120 steps·min^{-1} with 20 to 30 cm high platform (Figure 2), the pedometers would be expected to assess the number of steps accurately during the normal bench stepping exercise. These results indicate that pedometers seem to be sufficiently accurate for general stair climbing activities.

However, the present investigation demonstrated that the pedometer underestimated the number of steps during stair climbing with a lower height platform at a slower stepping rate. Therefore, pedometer accuracy may be problematic for a light intensity workout during stair climbing. Similarly, recent studies demonstrated that pedometer accuracy significantly decreased during walking at slower speed (Cyarto, 2004; Melanson et al., 2004). Furthermore, a recent publication also demonstrated pedometer accuracy to decrease at a higher step frequency such as a running at above 240 steps·min^{-1} (3.5 Hz; Rowland et al., 2007).Therefore, pedometer accuracy may decrease during stair climbing corresponding to light- and very vigorous-intensity.

Thus, based on the present investigation as well as the results of previous findings (Melanson et al., 2004; Schneider et al., 2003; 2004), pedometers can accurately assess the number of steps during ambulatory activity. Furthermore, it also seems desirable to evaluate the number of steps associated with stair climbing separately from that of horizontal walking. Since stair climbing is a body bearing exercise, in comparison to horizontal walking, stair climbing may, therefore, provide some unique health benefits such as increasing lower limb muscle power and improving the bone density (Mori et al., 2006; Olson et al., 1996). Furthermore, if a pedometer can successfully detect horizontal walking and stair climbing separately, then accuracy for assessing calorie expenditure will be improved.

There are some limitations in regard to the present investigation. First, since the subjects of the present study consisted of 10 young men, the results of the present investigation should also be confirmed in women as well as in middle- to older aged individuals in future studies. Second, body mass index of the subjects was below 25 $kg \cdot m^{-2}$. Since accuracy of a spring-levered pedometer could be affected by the body mass index, accuracy of YM during stair climbing may, therefore, decrease in overweight and obese individuals. Furthermore, the present investigation used pedometers based on the spring lever (YM) or a one-axial accelerometer (LC and OM). However, it is unclear whether different make pedometers can accurately assess the number of steps during stair climbing. Another type of pedometers based on a uniaxial accelerometer and an omni-directional accelerometer has recently been released (Rowland et al, 2007; Esliger et al., 2007). Therefore, while the KZ and YM have, up to now, been used as standard pedometers, further studies should, therefore, examine pedometer accuracy during stair climbing using other types of pedometers in a heterogeneous group of people.

Conclusion

In conclusion, the present investigation demonstrated that pedometers could assess the number of steps within ±5% of error margin during stair climbing with 20 cm or higher platforms at stepping rate of 80 to 120 $steps \cdot min^{-1}$. Therefore, pedometers can apparently detect the number of steps accurately within the acceptable margins of error during normal climbing activities. In addition, an inter-device difference in pedometer accuracy, and the KZ and YM devices are thus considered to be suitable for use in clinical and research purposes. Further study is required in middle to older aged individuals as well as individuals with gait disorder to establish pedometer accuracy during bench stepping.

References

Ayabe, M., Yahiro, T., Mori, Y., Takayama, K., Tobina, T., Higuchi, H., Ishii, K. , Sakuma, I., Yoshitake, Y., Miyazaki, H., Kiyonaga, A., Shindo, M. and Tanaka, H. (2003) Simple assessment of lactate threshold by means of the bench stepping in older population. *International Journal of Sports & Health Science* **1,** 207-215.

Ayabe, M., Yahiro, T, Ishii, K., Kiyonaga, A., Shindo, M. and Tanaka, H. (2004) Validity and usefulness of the simple assessment of lactate threshold in younger adults. *International Journal of Sports & Health Science* **2**, 84-88.

Bland, J.M. and Altman, D.G. (1986) Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet* **8**, 307-310.

Bassett, D.R., Ainthworth, B.E., Leggett, S.R., Mathien C.A., Main, J.A., Hunter, D.C. and Duncan, G.E. (1996) Accuracy of five electric pedometers for measuring distance walked. *Medicine & Science in Sports & Exercise* **28**, 1071-1077.

Bassett, D.R. and Strath, S.J. (2002) Use of pedometer to assess physical activity. In: *Physical activity assessments for health-related research.* Ed: Welk, G.J. Champaign: Human Kinetics. 166-170.

Campbell, K. L., Crocker, P.R. and McKenzie, D.C. (2002) Field evaluation of energy expenditure in women using Tritrac accelerometers. *Medicine & Science in Sports & Exercise* **34**, 1667-1674.

Crouter, S.E., Schneider, P.L. and Bassett, D.R. (2005) Spring-levered versus piezo-electric pedometer accuracy in overweight and obese adults. *Medicine & Science in Sports & Exercise* **37**, 1673-1679.

Cyarto, E.V., Myers, A.M. and Tudor-Locke, C. (2004) Pedometer accuracy in nursing home and community-dwelling older adults. *Medicine & Science in Sports & Exercise* **36**, 205-209.

Esliger, D.W., Probert, A., Gorber, S.C., Bryan, S., Laviolette, M. and Tremblay, M.S. (2007) Validity of the Actical accelerometer step-count function. *Medicine & Science in Sports & Exercise* **39**,1200-1204.

Hasson, R.E., Pober, D.M. and Freedson, P.S. (2005) *Evaluation of Omron HJ-112 and YAMAX Digiwalker SW-701 pedometers during variable speed walking.* Walking for Health. October 13-15, Urbana Champaign-USA. Book of Abstract. 26.

Haller, J., Hasson, R.E., Pober, D.M. and Freedson, P.S. (2005) *Validation of the Omron HJ-112 pedometer at various walking speeds.* Walking for Health. October 13-15, Urbana Champaign-USA. Book of Abstract. 26.

Lee, I.M., Sesso, H.D. and Paffenbarger, R.S. (2000) Physical activity and coronary heart disease risk in men: does the duration of exercise episodes predict risk? *Circulation* **102**, 981-986.

Melanson, E.L., Knoll, J.R., Bell, M.L., Donahoo, W.T., Hill, J.O., Nysse, L.J., Lanningham-Foster, L., Peters, J.C. and Levine, J.A. (2004) Commercially available pedometers: considerations for accurate step counting. *Preventive Medicine* **39**, 361-368.

Mori, Y., Ayabe, M., Yahiro, T., Tobina, T., Kiyonaga, A., Shindo, M., Yamada, T. and Tanaka, H. (2006) The effect of home-based exercise training using bench stepping on the aerobic capacity, lower extremity power, and static balance in older adults. *International Journal of Sports & Health Science* **4**, S570-S576.

Olson, M.S., Williford, H.N., Blessing, D.L. and Brown, J.A. (1996) The physiological effects of bench/step exercise. *Sports Medicine* **21**, 164-175.

Paffenbarger, R.S., Hyde, R.T., Wing, A.L. and Hsieh, C.C. (1986) Physical activity, all-cause mortality, and longevity of college alumni. *New England Journal of Medicine* **314**, 605-613.

Rowland, A.V., Stone, M.R. and Eston, R.G. (2007) Influence of speed and step frequency during walking and running on motion sensor output. *Medicine & Science in Sports & Exercise* **39**, 716-727.

Schneider, P.L., Crouter, S.E., Lukajic, O. and Bassett, D.R. (2003) Accuracy and reliability of 10 pedometers for measuring steps over a 400-m walk. *Medicine & Science in Sports & Exercise* **35**, 1779-1784.

Schneider, P.L., Crouter, S.E. and Bassett, D.R. (2004) Pedometer measures of free-living physical activity: comparison of 13 models. *Medicine & Science in Sports & Exercise* **36**, 331-335.

Swartz, A.M., Bassett, D.R., Moore, J.B., Thompson, D.L. and Strath, S.J. (2003) Effects of body mass index on accuracy of an electric pedometer. *International Journal of Sports Medicine* **24**, 588-592.

Teh, K.C. and Aziz, A.R. (2002) Heart rate, oxygen uptake, and energy cost of ascending and descending the stairs. *Medicine & Science in Sports & Exercise* **34**, 695-659.

Tudor-Locke, C.E., Williams, J.E., Reis, J.P. and Pluto, D. (2002) Utility of pedometers for assessing physical activity: Convergent validity. *Sports Medicine* **32**, 795-808.

Key points

- Pedometers can assess the number of step accurately within an acceptable range of measurement error during the stair climbing activities at a stepping rate of 80 $step \cdot min^{-1}$ or faster with 18 cm or higher stairs.

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