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Original paper

Influence of non-level walking on pedometer accuracy

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Abstract

The YAMAX Digiwalker pedometer has been previously confirmed as a valid and reliable monitor during level walking, however, little is known about its accuracy during non-level walking activities or between genders. Subsequently, this study examined the influence of non-level walking and gender on pedometer accuracy. Forty-six healthy adults completed 3-min bouts of treadmill walking at their normal walking pace during 11 inclines (0–10%) while another 123 healthy adults completed walking up and down 47 stairs. During walking, participants wore a YAMAX Digiwalker SW-700 pedometer with the number of steps taken and registered by the pedometer recorded. Pedometer difference (steps registered − steps taken), net error (% of steps taken), absolute error (absolute % of steps taken) and gender were examined by repeated measures two-way ANOVA and Tukey's post hoc tests. During incline walking, pedometer accuracy indices were similar between inclines and gender except for a significantly greater step difference (-7 ± 5 steps vs. 1 ± 4 steps) and net error ($-2.4 \pm 1.8\%$ for 9% vs. $0.4 \pm 1.2\%$ for 2%). Step difference and net error were significantly greater during stair descent compared to stair ascent while absolute error was significantly greater during stair ascent compared to stair descent. The current study demonstrated that the YAMAX Digiwalker SW-700 pedometer exhibited good accuracy during incline walking up to 10% while it overestimated steps taken during stair ascent/descent with greater overestimation during stair descent. Stair walking activity should be documented in field studies as the YAMAX Digiwalker SW-700 pedometer overestimates this activity type.

Keywords: Locomotion; Gender; Ambulatory monitoring; Exercise; Incline

1. Introduction

Over the past decade, the use of pedometers to monitor physical activity levels has increased dramatically as evident by a recent *PubMed* search using the term "pedometer" (52 studies prior to 1997, 262 studies after 1996). During this time, the suitability of pedometers to monitor physical activity in various populations has been confirmed with significant correlations reported between pedometer recordings and other physical activity measures such as questionnaires[1–3] and accelerometers.[4–6] Additionally, the impact of walking speed,[7–9] body mass index,[9–11] pedometer brand/type[7–9,12,13] and pedometer placement[8,11,14] on pedometer function have all been examined with some brands of pedometers recognised as valid and reliable monitors of physical activity.

Nonetheless, most of these prior studies have examined pedometer validity and reliability during level walking with little examination during non-level walking. Schmalzried et al.[15] examined pedometer use during stair ascent/descent over 12 stairs and reported a 2–4% underestimation by the pedometer. In contrast, Shepherd et al.[10] reported that the pedometer overestimated by 10.8–19.9% during stair ascent/descent. The use of a small number of stairs and/or a pedometer brand (i.e. Sportline) exhibiting moderate accuracy[13] and substantial errors during normal walking speeds,[8] makes it difficult to confirm the effect of stair walking on pedometer accuracy. In contrast to the Sportline pedometer, the YAMAX Digiwalker has been consistently reported as a valid and reliable monitor of physical activities in laboratory[2,7,8] and field[7,12,13] studies. However, the Digiwalkers' capabilities may also be compromised during non-level walking as reflected by the "Notes on Measurement" material from the YAMAX Corporation (Tokyo, Japan) that states "The meter is intended to use on the flat ground. Incorrect measurements may result under the fol-

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lowing conditions: . . .suddenly stand up or sit down, . . . walk up or down steep slopes, or get on and off automobiles, or buses.". Therefore, non-level walking may alter the vertical characteristics of hip acceleration resulting in modification of pedometer lever arm movements and pedometer inaccuracy. The lower pedometer accuracy reported with pedometer tilt angles greater than 10% from the body[16] provides further support that changes in body position and pedometer verticality during walking may impact on pedometer accuracy. This potential inaccuracy has significant implications on physical activity monitoring as daily activities typically include some form of non-level walking/movement.[1,17]

To our knowledge, the influence of walking geography on pedometer accuracy has not been examined extensively and is of significant interest given that daily walking may be undertaken over variable grades and/or include stairs.[1,17] With the inclusion of non-level walking in daily activities[1,17] and widespread use of YAMAX Digiwalkers to monitor physical activity levels,[12,18–20] it is important that the Digiwalker's accuracy during non-level walking be identified with any possible inaccuracy acknowledged for field studies that may include non-level walking. Therefore, the aim of the current study was to examine the effect of non-level (Part 1—incline; Part 2—stair) walking on YAMAX Digiwalker accuracy. As previous studies have documented a gender difference in pedometer error[10,21,22] and gait,[23–25] a second aim was to examine the effect of gender on pedometer validity during non-level walking.

2. Methods

This study consisted of two components: incline walking with 46 healthy, university students (22 males, 24 females) and stair walking with 123 (70 males, 53 females) healthy, university students. Their descriptive characteristics are shown in supplemental file online. All participants were healthy and without gait irregularities as indicated by standard pre-screening questionnaire responses, and provided informed written consent prior to participation. All procedures were approved by the institution Human Ethics Sub-committee.

Participants' height was determined using a stadiometer (Seca 202, Seca, Hamburg, Germany) while body mass and body composition (fat %) were determined via bioelectrical impedance scales (TANITA TBF 521, TANITA Corporation of America, Arlington Heights, USA). Body mass index (BMI) was determined as mass in kg/height in m^2. Following these determinations, step length was obtained in accordance with manufacturer's instructions (YAMAX Corporation, Tokyo, Japan). Briefly, participants completed five trials of walking at their normal walking pace with the distance walked and the time taken recorded to calculate the average step length and normal walking speed. A pedometer (SW-700 Digiwalker, YAMAX Corporation, Tokyo, Japan) was then attached to the waistband of the participant's shorts or skirt in line with the mid thigh of the right leg for either incline or stair walking.

For incline walking, participants, in a randomized order, completed 3-min bouts of treadmill walking at their previously determined, normal walking speed during 11 different inclines (0–10%). For each walking bout, participants stood astride a treadmill (TRACKMASTER TMX55, JAS Manufacturing, Carrollton, TX) and then stepped onto the moving belt when the appropriate treadmill incline was attained. At the completion of the walking bout, participants straddled the treadmill while steps registered by the pedometer were recorded. The pedometer was then reset and the next walking bout undertaken within 1 min. Steps taken during each 3-min walking bout were determined using a hand-counter.

For stair walking, participants walked up and down a flight of 47 stairs at their preferred walking pace. The flight of stairs consisted of standard concrete steps (27 cm deep × 18 cm high) and extended over two floors of a building with mid-floor platforms to enable a change in walking direction. Participants followed the inside stair rail to minimise the number of steps taken on the mid-floor platforms during the direction change. During the ascent, the number of steps taken was counted while the time of ascent was recorded via a stopwatch. Participants ascended the stairs, one at a time and did not run, jump or hop while walking. Upon reaching the top of the flight of stairs, time of ascent, steps taken and steps registered by the pedometer were recorded. The pedometer and stopwatch were reset and the participant then walked down the stairs with time of descent, steps taken and steps registered by the pedometer recorded at the bottom of the stairs. This procedure was repeated another two times to obtain an average of three trials for stair ascent and descent.

Data were expressed as mean ± 95% confidence interval and analysed using the Statistical Package for the Social Sciences (SPSS v14, SPSS Inc., Chicago, IL). Data normality was determined using the Kolmogorov–Smirnov statistic with a Lilliefors significance correction. As pedometer accuracy has been reported in a variety of ways,[8,10,14,19,26] the following indices of pedometer accuracy were calculated to enable comparison with prior studies:

1) step difference = steps registered − steps taken[8,26];
2) net error = (steps registered − steps taken)/steps taken × 100. Pedometer overestimation was represented by positive values and pedometer underestimation was represented by negative values[10,14,19];
3) absolute error = (absolute difference between steps registered and steps taken)/steps taken × 100.[26] Absolute error was determined as the magnitude rather than the direction of the error has been reported to be more important in determining the accuracy of the pedometer.[26]

Significant differences between genders for descriptive characteristics were determined using independent *t*-tests or Mann–Whitney *U*-tests, where appropriate. For incline walking, a two-way (incline × gender) repeated measures ANOVA with Tukey's post hoc tests was conducted for each variable. For stair walking, significant differences between variables were examined using a two-way (ascent/descent × gender) repeated measures ANOVA. The level of significance was set at 0.05 for all analyses.

3. Results

Compared to the female participants, males were significantly taller, heavier with a greater BMI and had less body fat (see supplemental file online). Despite the difference in height, step length was similar between males and females (see supplemental file online).

During incline walking, the number of steps taken was similar between each incline ($p = 0.384$) and similar between genders (male 315 ± 9 vs. female 326 ± 9, $p = 0.07$). In contrast, the number of steps registered by the pedometer was significantly greater during walking at 2% incline compared to 8% incline (323 ± 7 steps vs. 312 ± 10 steps, $p = 0.001$). Significantly more steps were registered by the pedometer for females compared to males (325 ± 11 steps vs. 309 ± 11 steps, $p < 0.05$) with this gender effect most apparent during walking at 9% (328 ± 11 steps vs. 299 ± 16 steps, $p < 0.05$) and 10% (325 ± 14 vs. 301 ± 15, $p < 0.05$) inclines.

For pedometer accuracy, the step difference was significantly greater during walking at 9% incline compared to 2% incline (−7 ± 5 steps vs. 1 ± 4 steps, $p = 0.007$) while there was no significant gender effect ($p = 0.242$). The net error was significantly greater during walking at 9% incline compared to 2% incline (Fig. 1) while there was no significant gender effect ($p = 0.237$). The absolute error was similar between each incline ($p = 0.295$) and gender ($p = 0.177$) (Fig. 2).

Participants took longer to ascend the flight of stairs compared to the descent (Table 1) while males took longer compared to females (28.2 ± 0.8 s vs. 26.2 ± 0.9 s, $p < 0.01$). There was a significantly greater number of steps taken during stair descent compared to stair ascent (Table 1) while a similar number of steps was taken by males and females (53 ± 1 steps vs. 51 ± 1 steps, $p = 0.06$). A significantly greater number of steps was registered by the pedometer during stair descent compared to stair ascent (Table 1) with males exhibiting a significantly greater number of registered steps compared with females (57 ± 1 steps vs. 54 ± 2 steps, $p < 0.01$).

The step difference was significantly greater during stair descent compared to stair ascent (Table 1) while there was no significant gender effect (male 4 ± 1 steps vs. female 2 ± 1 steps, $p = 0.077$). The net error was significantly greater during stair descent compared to stair ascent (Table 1) while there was no significant gender effect (male 7.6 ± 2.3% vs. 4.6 ± 2.7%, $p = 0.088$). The absolute error was significantly greater during stair ascent compared to stair descent (Table 1) and similar between genders ($p = 0.228$).

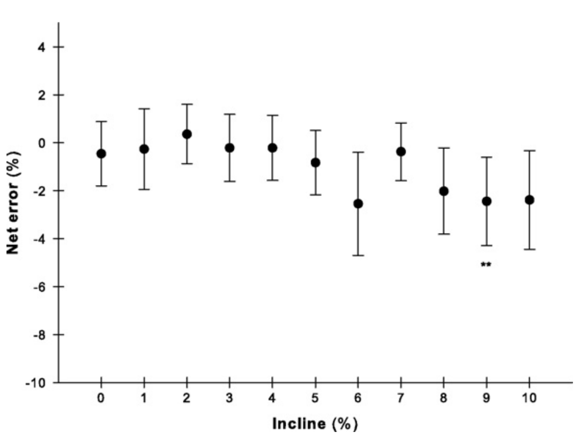

Fig. 1. Net error (mean ± 95% confidence interval) exhibited for the YAMAX Digiwalker SW-700 during incline treadmill walking for all participants. **$p < 0.01$ vs. 2% incline.

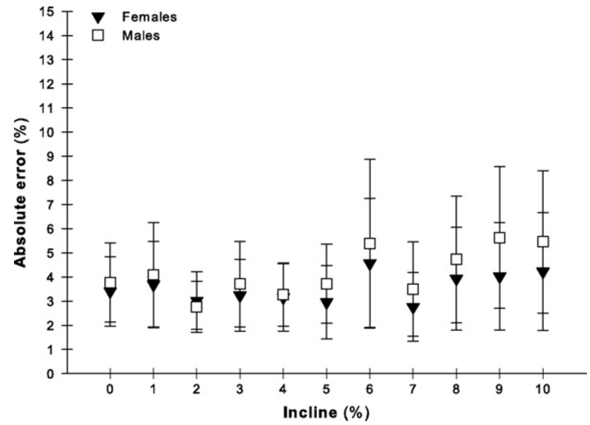

Fig. 2. Absolute error (mean ± 95% confidence interval) exhibited for the YAMAX Digiwalker SW-700 during incline treadmill walking by female and male participants.

Table 1
Time, steps taken, steps registered, step difference, pedometer error and absolute error for males, females and all participants during stair ascent and descent

	Males ($n = 70$)	Females ($n = 53$)	All ($n = 123$)
Stair ascent			
Time (s)	29.3 ± 1.0	27.4 ± 0.9	28.5 ± 0.7
Steps taken	52 ± 1	51 ± 1	52 ± 1
Steps registered	55 ± 2	52 ± 2	53 ± 1
Step difference (steps)	3 ± 2	1 ± 2	2 ± 1
Net error (%)	5.6 ± 3.4	2.0 ± 3.3	4.0 ± 2.4
Absolute error (%)	11.9 ± 2.5	10.6 ± 2.2	11.4 ± 1.7
Stair descent			
Time (s)	27.0 ± 1.0	25.0 ± 0.8	26.1 ± 0.7***
Steps taken	53 ± 1	52 ± 1	53 ± 1***
Steps registered	58 ± 1	56 ± 1	57 ± 1***
Step difference (steps)	5 ± 1	4 ± 1	4 ± 1***
Net error (%)	9.6 ± 2.1	7.2 ± 1.7	8.5 ± 1.4***
Absolute error (%)	10.2 ± 2.0	8.2 ± 1.6	9.4 ± 1.4*

Values are mean ± 95% confidence interval; *$p < 0.05$, ***$p < 0.001$ vs. stair ascent.

4. Discussion

The current results demonstrated that the error of the YAMAX Digiwalker SW-700 pedometer was: (1) approximately 0–6% during incline treadmill walking and similar for most inclines up to 10%, (2) approximately 4–11% during stair walking with a greater overestimation and net error during stair descent compared to ascent and (3) statistically similar between genders during incline treadmill walking and stair ascent/descent.

As stated by the manufacturer, the YAMAX Digiwalker was intended to be used on flat ground only. Contrary to this notion, pedometer accuracy was within approximately 0–6% of steps taken during incline walking and similar to that previously reported for YAMAX pedometers during level treadmill walking,[4,7–9,26] level ground walking[13] and free-living physical activity.[12] To our knowledge, the current study is the only study that has examined pedometer accuracy during incline walking and provides additional evidence of the YAMAX Digiwalker's ability to monitor walking activity during free-living activities. The similar step count and pedometer accuracy during incline walking may reflect a subconsciously adjusted walking stance,[27] resulting in a vertically positioned pedometer regardless of the incline. This altered walking stance may negate any possible impact of incline on the vertical movements of the pedometer lever arm during walking. The current and prior[16] results imply that the angle of the pedometer relative to the vertical and hip movement plane, rather than to the walking surface, is more critical for pedometer accuracy. It remains to be seen whether similar pedometer accuracy exists during decline walking as no studies have examined decline walking and pedometer accuracy to our knowledge.

The YAMAX Digiwalker has been consistently reported as an accurate and reliable monitor of physical activity during laboratory and field studies.[2,7,8,12,13,26] However, the Digiwalker's accuracy during a common free-living activity such as stair climbing[17] has been rarely examined. In the current study, the YAMAX Digiwalker SW-700 pedometer overestimated steps taken by approximately 2–6% during stair ascent and 7–10% during stair descent, values smaller than those previously reported for stair ascent/descent using a Sportline pedometer[10] but similar or greater than that recently reported for the YAMAX SW-200 pedometer.[14] Differences between studies could not be attributed to different populations or stair configurations as both studies utilised young participants with comparable characteristics who walked a similar stair height at a similar rate.[14] Like previous studies,[10,14] the current study demonstrated pedometer overestimation during stair ascent/descent with a more prominent overestimation during stair descent. The exact mechanism for pedometer overestimation during stair walking has not been established but it may be related to altered lower limb kinematics during stair walking as altered foot placement[28] and greater forces on the knee and hip[29] have been reported during stair walking compared to level walking. Subsequently, this altered gait may result in multiple hip and pedometer level arm movements and an overestimation of steps taken. Stair walking activity should be documented in field studies utilising the YAMAX Digiwalker as a monitor to account for activity overestimation.

In most studies utilising pedometers, accuracy has been expressed as a net error[10,14,19] that accounts for direction of error rather than magnitude. In the current study, both indices of pedometer accuracy were utilised with greater values exhibited for the absolute compared to the net error, similar to that previously reported.[26] Importantly though, the net error during stair ascent was less than the absolute error and reflected a greater range of error in opposite directions (i.e. large underestimates and overestimates) during stair ascent. By examining the magnitude as well as the direction of the error, we were able to identify large variations in pedometer responses. Therefore, as previously suggested[26] the magnitude and direction of error should be documented when reporting pedometer accuracy as both indices reflect important aspects of pedometer function.

A second aim of the current study was to examine the impact of gender on pedometer accuracy during non-level walking. Interestingly, females in the current study took ($p = 0.07$) and registered ($p = 0.001$) more steps compared to males during incline walking, particularly at the higher inclines. As all indices of pedometer accuracy were similar between males and females, this gender difference in steps taken and registered, most likely reflected a change in gait such as reduction in stride length for females during the higher inclines. Despite this altered gait pattern, pedometer accuracy was similar for male and females during incline walking. In contrast, males exhibited a greater step difference ($p = 0.077$), net error ($p = 0.088$) and overestimation compared to females during stair walking. It was anticipated that gender differences in lower limb kinematics and gait[23–25] would be exacerbated during non-level walking resulting in a significant gender difference in pedometer accuracy, as previously reported.[10,21,22] Although not consistently exhibited in the current study, a gender difference in pedometer accuracy should be considered when examining physical activity levels via YAMAX Digiwalker recordings.

In conclusion, the current results demonstrated that the accuracy of the YAMAX Digiwalker SW-700 pedometer during incline walking up to 10% was approximately 0–6% and similar regardless of incline and gender. In contrast, the YAMAX Digiwalker overestimated steps taken during stair ascent/descent by 4–9% with greater overestimation during stair descent, possibly due to altered gait and/or walking speed. Potential gender differences in pedometer accuracy should be examined when determining physical activity levels via YAMAX Digiwalker recordings.

5. Practical implications

- The YAMAX Digiwalker pedometer accurately estimates walking activity on both flat ground and inclines.
- Records of walking and daily physical activity levels by the YAMAX Digiwalker pedometer may be exaggerated with the inclusion of stair walking activities.
- Documentation of stair walking activity and subsequent adjustment of pedometer recordings may contribute to more accurate calculations of daily physical activity levels.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.jsams.2008.01.007.

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