Measurement of children's walking using a pedometer with a built-in memory

Abstract

Objectives: We evaluated the accuracy of the Accusplit AH120 pedometer (built-in memory) for recording step counts of children during treadmill walking against 1) observer counted steps; and 2) concurrently measured steps using the previously validated Yamax Digiwalker SW-700 pedometer.

Design: This was a cross-sectional validation study performed under controlled settings.

Method: Forty five 9-12 year-olds walked on treadmills at speeds of 42, 66 and 90 m/min to simulate slow, moderate and fast walking wearing Accusplit and Yamax pedometers concurrently on their right hip. Observer counted steps were captured by video camera and manually counted. Absolute value of percent error was calculated for each comparison. Bland-Altman plots were constructed to show the distribution of the individual (criterion-comparison) scores around zero.

Results: Both pedometers under-recorded observer counted steps at all three walk speeds. Absolute value of percent error was highest at the slowest walk speed (Accusplit=46.9%; Yamax=44.1%) and lowest at the fastest walk speed (Accusplit=8.6%; Yamax=8.9%). Bland-Altman plots showed high agreement between the pedometers for all three walk speeds.

Conclusions: Using pedometers with built-in memory capabilities eliminates the need for children to manually log step counts daily, potentially improving data accuracy and completeness. Step counts from the Accusplit (built-in memory) and Yamax (widely used) pedometers were comparable across all speeds, but their level of accuracy was dependent on walking pace. Pedometers should be used with caution in children as they significantly undercount steps, and this error is greatest at slower walk speeds.

Keywords

Accusplit AH120, Yamax Digiwalker SW-700, motor activity, walking, child, validation studies

Introduction

Self-report and recall methods of measuring physical activity are problematic in children because of a limited ability to accurately recall their behavior.[1, 2] Pedometers (i.e., small, battery-powered mechanical devices that count steps) are a feasible method of objectively measuring children's physical activity derived from bipedal locomotion (e.g. walking, running, skipping and jumping). As a result, pedometers are widely used in physical activity research and guidelines based on steps are now being published.[3-5]

Yamax SW series pedometers (Yamax Corp., Tokyo, Japan) are widely used in research and have become the criterion pedometer against which others may be compared because of their consistent performance in studies of adults.[6-8] Biomechanically, children's walk patterns are less mature than that of adults due to maturational events like changes in body proportions, increases in muscular strength and postural control.[9] Moreover, children have higher variability in their walking and running stride frequency compared with adults.[10] Thus, the performance of the Yamax SW series in children is less clear. Five pedometer validation studies measuring children's physical activity in a controlled setting, using observer counted steps as the criterion, found that the Yamax Digiwalker SW-200 performed well at moderate and fast walk speeds; but undercounted steps by from 25%[11] to 100%[12] at lower speeds.[13-15]

In studies of children, other factors that may impact the validity and reliability of pedometer data relate to pedometer tilt angle,[16] being overweight,[12] and pedometer placement.[15] Data from a pilot study for the TRavel, Environment and Kids (TREK) project showed that children (n = 199 10-12 year olds) were unable to reliably record their daily pedometer steps in a diary. Issues encountered included missing data, failure to manually reset the pedometer to zero each morning, inaccurate recording of data in the diary (i.e., too many or too few digits) and illegible handwriting. Although this could be overcome by visiting child participants at school each morning and recording pedometer data from the previous day, this method is impractical, time consuming, costly (in terms of staff time to visit each school and class) and not feasible on weekends when children are at home.[14] Alternatively, recent pedometer models incorporate an internal clock and multiday memory function (e.g., New Lifestyles NL-2000, Accusplit AH120M9, and now the Yamax CW-700). The advantage that these pedometers have over conventional pedometers (e.g., Yamax SW-200) is that the in-built memory function allows step counts on weekdays and weekends to be analyzed separately and negates the need for either researcher or child to manually record step counts each day and to reset the pedometer.

Despite this new feature, to-date only one study has validated a built-in memory pedometer in children. This study of 85 children aged 5-7 and 9-11 years, found that the New Lifetstyles NL-2000 (New Lifestyles Inc., lee's Summit, MO) MDM pedometer offered similar accuracy and better precision than the widely used Yamax SW-200 pedometer.[16] The accuracy of the NL-2000 may be related to its piezo-electric (versus spring-levered) internal mechanism that makes it less susceptible to errors due to tilt.[17] However, the considerably higher cost of the NL 2000 (approximately twice as expensive as spring-levered pedometers) may preclude its use in large-scale studies, worksite wellness programs, school physical education and other health promotion programs with limited financial resources.[15] Further research validating the use of pedometers with built-in memory in children is required.

The purpose of this study was to evaluate the accuracy of the spring-levered Accusplit AH120M9 pedometer (built-in memory) for recording step counts of children during treadmill walking against 1) observer counted steps and 2) concurrently measured steps using the previously validated spring-levered Yamax Digiwalker SW-700 pedometer (note: the Yamax SW-700 uses the same spring loaded mechanism as the previously validated Yamax SW-200).

Methods

One TREK study primary school was invited to take part in this sub-study. The school was selected because of its high level of co-operation to the study team. Parents and children had signed informed consent forms to participate in the main TREK study. However, parents were also asked to complete and return an ‘opt out’ form if they did not want their child to participate in this sub-study, and children provided verbal consent prior to participation. This method of consent was chosen because of the non-sensitive nature of the study, the low risk to participants, and because parents and children had previously provided written consent to participate in TREK. It also aimed to maximize the number of participants and reduce non-participation bias.[18] The University of Western Australia (UWA) Human Research Ethics Committee (HREC) provided ethics approval for the TREK study overall and the sub-study, including the methods of consent used (RA/4/1/1394). Age and sex was determined from a child-report questionnaire. Bassett and colleagues[8] suggest that a 10% error rate in pedometers is acceptable within a field setting. Therefore to detect a 90% level of agreement, a minimum sample size of 32 children was estimated to be required (each with three ratings: Accusplit step counts, Yamax step counts and observer counted steps) with 80% power and an alpha of 5%.[19] Children were selected at random to participate (49 in total). Data were collected in May 2008 during class time.

Children’s weight status was calculated using objectively measured height and weight to compute body mass index (BMI, kg/m^2). All BMI estimates were collapsed into age and sex-specific weight categories (acceptable, overweight and obese) based on internationally-recognized cut-off values.[20]

Three new spring-levered Accusplit AH120 (Accusplit, Inc., Livermore, CA, USA) (herein referred to as “Accusplit”) pedometers and three new spring-levered Yamax Digiwalker SW-700 (Yamax Corp., Tokyo, Japan) pedometers were used. Prior to use, all pedometers were fitted with new batteries and checked for faults using two repetitions of a 20-step short-walk test.[21] Absolute error was no more than 1 step for each of the 10 pedometers tested. A purpose-made, firm, adjustable, elastic waistband holding two pedometers (i.e., one Accusplit and one Yamax) was placed around each child's waist. These waistbands were used to improve stability and reduce any undercounting caused by large pedometer tilt angles (≥10%).[16] Pedometers were positioned at the right hip (at the anterior superior iliac spine) in line with the front of each foot. Pedometers were proximal but not touching each other, with the Accusplit medial to the Yamax.

Two identical motorized treadmills (TMR-802) placed on a flat surface were used to conduct the walk sessions. To record observer counted steps, a video camera (placed perpendicular to each treadmill approximately 1.5 meters away) filmed each participant's walk session from the waist down. Numbered ID cards facing the video cameras were used to identify children and walk speeds in the footage. Without shoes, participants were encouraged to walk for several minutes on the treadmill to become familiar with it. Children were then asked to walk normally for three walk sessions of three minutes at speeds of 42, 66 and 90 m/min (in this order). These speeds were chosen as they have been used in previous pedometer validation studies to simulate slow, moderate and fast walking in children and the speed at which children walk to and from school.[16, 22] Each pedometer was set to "0" immediately prior to observation. At the completion of each walk speed, children were instructed to straddle the treadmill whilst pedometer steps were recorded and reset to zero. A break of approximately two minutes was given, during which the treadmill was left running and set to the next speed. Using the video footage, steps taken in each walk session were tallied twice by the same person using a hand counter. If step counts varied by ≥1 step then the footage was reviewed and tallied a third time.

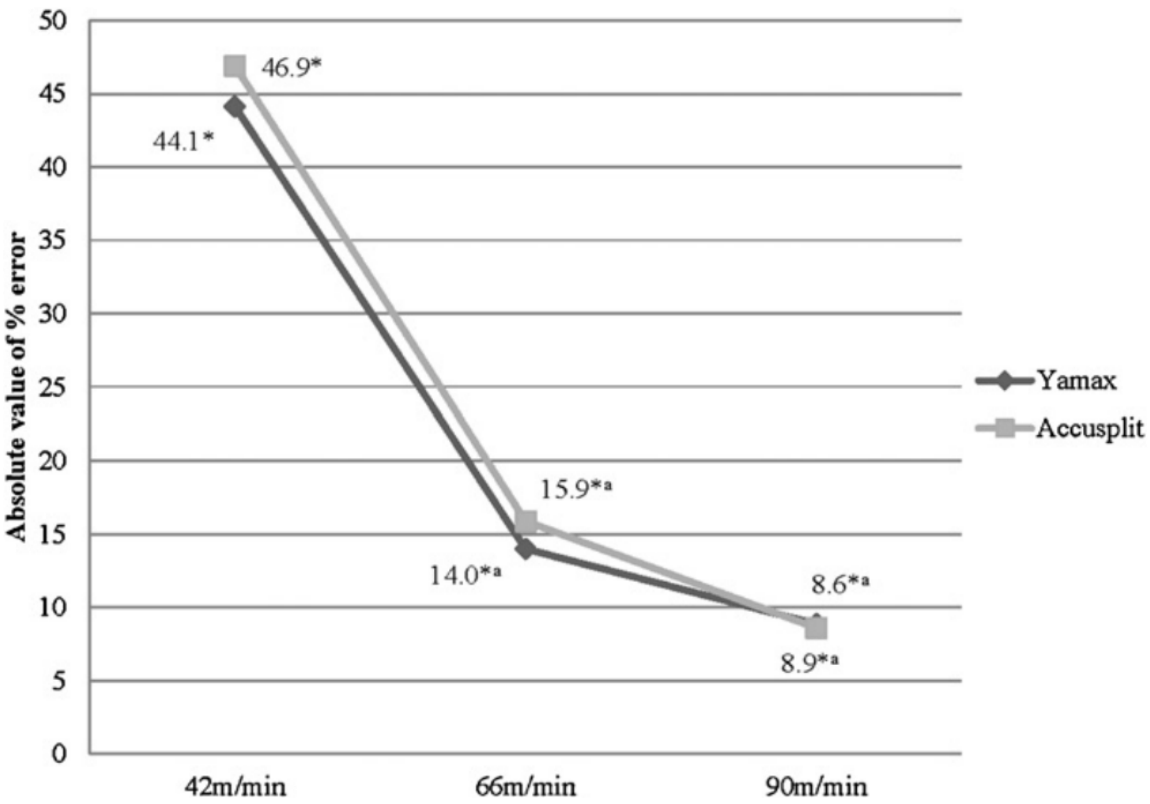
Data for a total of 45 children were included in the study (four children were excluded because the child's clothing inhibited the correct placement of the pedometer belt). Absolute value of percent error (i.e. ((pedometer steps – observer counted steps)/observer counted steps)*100) was calculated for each comparison according to the procedures described elsewhere [6]. Descriptive statistics were obtained for all demographic and anthropometric variables. Paired samples *t*-tests were used to compare mean raw error scores and mean absolute value of percent error scores. A one-sample *t*-test was used to compare mean absolute value of percent error scores to a test value of zero. Independent samples *t*-tests were used to examine the difference between absolute value of percent error scores according to sex, age and weight status. Bland-Altman plots[23] were constructed to show the distribution of the individual (criterion-comparison) scores around zero. This is a standard method to compare estimates from biomedical devices.[24]

Results

The sample consisted of 45 children aged 10.67 ± 0.77 years. There were no differences in mean age, height, weight or weight status between boys (n=22) and girls (n=23) participating in this study (all $p>0.05$).

The Yamax and Accusplit pedometers under-recorded the steps taken at each walk speed, with raw error largest at the slowest walk speed and decreasing at subsequent speeds (Table 1), and no significant differences ($p>0.05$) between pedometer raw error scores within each walk speed.

As shown in Figure 1, the absolute value of percent error was greatest at the slowest walk speed (42 m/min) and lowest at the fastest walk speed (90 m/min) for both pedometers. There were significant differences in percent error scores between the 42 m/min and 66 m/min and the 66 m/min and 90 m/min walk speeds (all $p<0.05$) for both pedometers. Although the absolute value of percent error exhibited by the Accusplit was greater than the Yamax at 42 m/min and 66 m/min and smaller than the Yamax at 90 m/min, these between-pedometer differences were not significant (all $p>0.05$).



Bland-Altman plots depicting levels of agreement between the Yamax and observer counted steps and the Accusplit and observer counted steps were constructed (Figure 2) and revealed that both pedometers (individually) were in agreement with observed steps for walk speeds of 66 m/min (Yamax: regression coefficient = 0.219, p = 0.143, 95% limits of agreement = 155.1; Accusplit: regression coefficient = 0.219, p = 0.143, 95% limits of agreement = 175.6) and 90 m/min (Yamax: regression coefficient = 0.204, p = 0.301, 95% limits of agreement = 185.4; Accusplit: regression coefficient = -0.099, p = 0.662, 95% limits of agreement = 182.1) but not 42 m/min (Yamax: regression coefficient = 0.681, $p<0.001$, 95% limits of agreement = 213.4; Accusplit: regression coefficient = 0.586, p = 0.001, 95% limits of agreement = 208.7).

Although not shown, Bland-Altman plots depicting levels of agreement between the Yamax step counts and Accusplit step counts were constructed and revealed that the two pedometers were in agreement for all three walk speeds (42 m/min: regression coefficient = 0.145, p = 0.312; 66 m/min: regression coefficient =

0.110, $p = 0.467$; 90 m/min: regression coefficient = 0.246; $p = 0.063$). The 95% limits of agreement were 220.5, 160.9 and 134.1 steps for 42, 66 and 90 m/min, respectively (plots not shown).

Discussion

The results of this study indicate that the accuracy of the Accusplit pedometer was comparable to the Yamax pedometer for measuring treadmill walking steps in children. However, both the Accusplit and the Yamax pedometers significantly undercounted observer counted steps, and this error was greatest at slower walk speeds. Indeed, one of the most consistent findings in the pedometer literature is that pedometer accuracy is lowest at slow speeds in children, adults and older adults.[6, 8, 12] A likely explanation for the inaccuracy of pedometers at slow walk speeds is that not enough vertical hip acceleration force is generated, particularly in children, to cause the internal mechanism to register a step. The relative importance of reduced pedometer accuracy during slow walking in studies of free-living activity depends upon the rationale for use (i.e. health promotion tool or research measurement device). In effect, the pedometer may automatically adjust for intensity by undercounting slow steps. Lowering the sensitivity threshold to improve the accuracy of pedometers is not a viable option because an inevitable sensitivity (i.e. ability to detect low step forces) / specificity (the ability to distinguish between actual steps and those that are non- ambulatory in nature) trade-off exists.[25, 26] Thus, any subsequent increase in motion sensor sensitivity will be accompanied by a reduction in specificity under free-living conditions. It is a priority for future research, therefore, to investigate this trade-off and determine the optimal sensitivity threshold that maximizes specificity for step counts in children. This could then be used as a useful indicator of motion sensor quality.[25]

Bassett and Colleagues[27] suggest that a 10% error rate in pedometers is acceptable within a field setting. Using this criterion, the Accusplit and Yamax pedometers only show acceptable accuracy for recording step counts in children at fast walking speeds (i.e. ≥90 m/min) with a significant underestimation of steps at lower speeds. Thus, caution must be used when using pedometer-referenced cut points (e.g., 12,000 steps/day for girls and 15,000 steps/day for boys to avoid overweight/obesity[3]) when different brands of step-counting activity monitors are used, which may not consistently under-record steps at slow and moderate walk speeds. Consistency of instruments is essential to prevent misclassification and allow results to be compared to other studies.

It is important to note that in order to duplicate the protocol used in the TREK study, this study placed pedometers on the right hip. Whilst pedometer validation studies performed on adults have shown hip placement does not affect pedometer accuracy,[28, 29] studies in children have had mixed results.[11, 30] The impact of right and left hip placement of pedometers in relation to children's gait patterns could be further explored in future studies. In addition, future studies may like to consider a validation study that includes other forms of physical activity.

This study has a number of limitations. First, data were collected under controlled conditions and do not reflect a free-living state. Second, the measurements were only conducted once on each participant and intra-instrument reliability was not assessed. Third, we did not measure pedometer tilt angle, leg length, stride length or waist circumference. This may have influenced step-counting accuracy when comparing pedometer steps with observer counted steps. Finally, it was limited to comparing one commercially available pedometer with an in-built memory.

Conclusions

Using pedometers with built-in memories for future studies may prove beneficial, allowing step data to be stored for multiple days thereby reducing the potential error and bias associated with children logging their step counts daily. This study found the accuracy of the Accusplit pedometer was similar to the Yamax pedometer, however, both pedometers were less accurate at slower walking speed. This appears to be the first study to compare the Accusplit and Yamax for studies in children. If other studies confirm these findings, the Accusplit may prove a useful tool for research involving children.

Practical implications

- Recent pedometer models incorporate a multiday memory function that eliminates the need for children to log step counts daily, potentially improving data accuracy and completeness.
- This study showed that the spring-levered Accusplit pedometer (built-in memory) was shown to be comparable in accuracy to the widely used Yamax pedometer in children. However;
- Pedometers may not be sufficiently accurate for research purposes in children as they significantly undercount steps, and this error is greatest at slower walk speeds.

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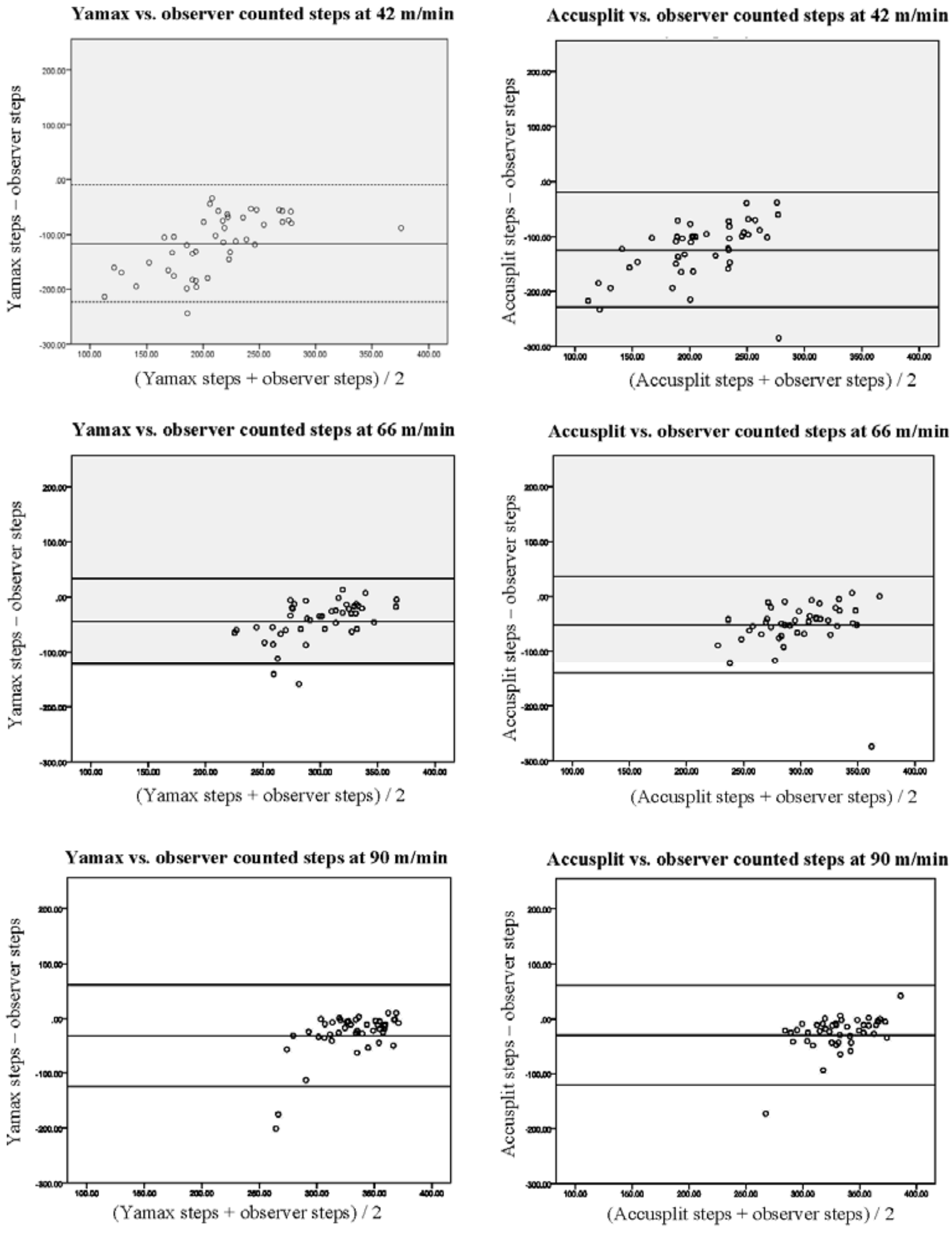

Figure 2. Bland-Altman plots depicting agreement between the Accusplit pedometer and actual step counts, and the Yamax pedometer and actual step counts. Solid horizontal line = mean difference, dashed lines = 95% prediction intervals (i.e., 95% confidence intervals of the individual observations)

Tables

Table 1. Total number of steps and raw error scores

Walk speed	Device	Steps	Raw error
42m/min (slow)	Observer counted steps	269.9 ± 38.2	NA
	Yamax	153.6 ± 68.3	-116.3 ± 53.4
	Accusplit	145.5 ± 60.6	-124.4 ± 52.2
66m/min (medium)	Observer counted steps	323.6 ± 39.7	NA
	Yamax	279.0 ± 47.5	-44.58 ± 38.8
	Accusplit	271.6 ± 43.5	-52.0 ± 43.9
90m/min (fast)	Observer counted steps	349.4 ± 39.5	NA
	Yamax	318.2 ± 45.6	-31.2 ± 46.3
	Accusplit	319.8 ± 37.0	-29.7 ± 45.5

Values are mean ± standard deviation

Raw error scores = pedometer steps minus observer counted steps

Figure Legends

Figure 1.

*P<0.05, significantly different from zero

[a]P<0.05, significantly different from previous walk speed

Absolute value of percent error = ((pedometer steps – observer counted steps)/observer counted steps)*100