Accuracy of Pedometer Steps and Time for Youth With Disabilities

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The purpose of the study was to examine the accuracy of pedometer steps and activity time (Walk4Life, WL) for youth with developmental disabilities. Eighteen youth (11 girls, 7 boys) 4-14 years completed six 80-meter self-paced walking trials while wearing a pedometer at five waist locations (front right, front left, back right, back left, middle back). Trials were video taped to determine actual steps and activity time. Time exhibited a smaller percent error in comparison to steps across locations. Apart from the front left, location had minimal influence on accuracy. The WL demonstrates acceptable accuracy for steps and activity time.

There is considerable need to improve the activity levels of youth (i.e., children and adolescents) with developmental disabilities (Developmental Disabilities Assistance and Bill of Rights Act of 2000; Fernhall & Unnithan, 2002). Yet prior to developing interventions that would assist local, state, and national agencies in
formulating policies to improve the activity levels of youth with developmental disabilities (Lollard, 2002), accurate measures of physical activity need to be established.

Motion sensors (e.g., accelerometers, pedometers) are the most practical measure of physical activity for youth with developmental disabilities. They are relatively simple to use (e.g., affix to hip or wrist) and can provide information regarding their typical activity patterns, either daily or for specific time frames (e.g., weekends vs. weekdays). Importantly, motion sensors place limited cognitive demands on the respondent to recall a specific time frame’s activity (e.g., previous day, past 7 days), an issue of concern when working with youth possessing intellectual impairments (e.g., mental retardation, Down Syndrome). Of the motion sensors available, pedometers have gained in popularity due to the ease of assessment and documentation of physical activity. However, relatively little attention has been given to the examination of the utility of pedometers for youth with developmental disabilities.

Previous studies have evaluated the precision (i.e., the number of steps registered vs. actual steps taken) of various models and brands of pedometers with both adults without disabilities (Bassett et al., 1996; Crouter, Schneider, Karabulut, & Bassett, 2003; Le Masurier, Lee, & Tudor-Locke, 2004; Le Masurier & Tudor-Locke, 2003; Welk et al., 2000), adults with disabilities (Stanish, 2004), and children without disabilities (Beets, Patton, & Edwards, 2005; Ramirez-Marroco, Smith, Kirby, Leenders, & Sherman, 2002). A consistent finding has been the inaccuracy (plus/minus) of step counts that all pedometers display when the wearer is moving at slow speeds ($\leq 54$ m·min$^{-1}$; Beets et al., 2005; Crouter et al., 2003). These findings suggest that using pedometers to assess daily step counts in populations where the normal walking speed is suspected to be slow would be ill-advised, given the potential inaccuracy of the step counts registered. While limited information exists on the typical walking speeds of youth with developmental disabilities, based on informal observations, youth with developmental disabilities in the current study appeared to display walking speeds that are slower than their peers without disabilities. In addition, several of the youth used assistive devices (e.g., walker, leg braces), which were likely to further influence the speed at which an individual walks.

Slow walking originating from the presence of a developmental disability appears to limit the utility of pedometers to assess activity patterns of this population. While step count accuracy may be compromised, steps are but one of several parameters assessed by pedometers. Some pedometers have the ability, in conjunction with steps, to measure distance traveled, caloric expenditure, and time spent ambulatory (i.e., activity time; Beets et al., 2005; Beighle & Pangrazi, 2006; Crouter et al., 2003). Of these, activity time derived from pedometers could be useful in assessing activity levels when step count accuracy is diminished due to slower walking speeds (Beets et al., 2005). Given many public health recommendations for daily activity levels of children (National Association for Sport and Physical Education, 2004) and adolescents (U.S. Department of Health and Human Services, 2000) are time-based (e.g., minimum of 60 min of activity per day), quantifying ambulation with these units (i.e., hours, min, seconds) may prove useful for practitioners, researchers, and educators whose goal is to determine whether youth with developmental disabilities are meeting daily activity recommendations.
This study was conducted to examine the accuracy of pedometer measured steps and time in a population of youth diagnosed with developmental disabilities. From the authors’ observations, the speed at which the participants in this study ambulated was likely to alter the precision of the steps registered (i.e., slow walking speeds equals less accurate step count). In addition, some of the participants’ diagnoses included mobility limitations (visually impaired, juvenile arthritis). Therefore, it was hypothesized that step count accuracy would be compromised (i.e., demonstrate greater error when compared to observed steps) in this population and that pedometer activity time would exhibit greater precision (i.e., less error when compared to observed activity time) independent of step count accuracy.

Methods

Participants

Eighteen elementary and middle school youth (girls n = 11, M = 9.4, SD = 3.1yrs; boys n = 7, M = 10.0, SD = 3.4yrs) with single or multiple disabilities participated in the study (see Table 1 for participant demographics). All participants were classified as having a developmental disability that was attributable to a mental or physical impairment or combination of mental or physical impairments (Developmental Disabilities Assistance and Bill of Rights Act of 2000). All participants were enrolled in adapted physical education. Classification as having mild mental retardation was determined by qualified school district personnel according to the model for diagnosis by the American Association on Mental Retardation (American Association on Mental Retardation, 2002). Individualized Education Plan (IEP) diagnoses were used to classify the participants’ disabilities. The following disabilities were represented, either singularly or in combination (number of participants with disability in parentheses): autism (3), mild mental retardation (17), Down syndrome (3), traumatic brain injury (1), visually impaired (2), seizure disorder (1), and/or juvenile arthritis (1). Diagnosis of mobility limitations was made by the participants’ pediatrician. Two of the youth with visual impairments walked with an assistive device (i.e., cane).

Purposeful sampling was employed, whereby all youth enrolled in adapted physical education were eligible to participate in the study (Henry, 1990; Sherrill & O’Conner, 1999). Written informed parental consent and child voluntary assent,

Table 1  Participant Demographics

<table>
<thead>
<tr>
<th>Variable</th>
<th>Boys (n = 7)</th>
<th>Girls (n = 11)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yrs)</td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>10.0</td>
<td>3.4</td>
</tr>
<tr>
<td>Height (m)</td>
<td>31.7</td>
<td>13.6</td>
</tr>
<tr>
<td>Body Mass Index (kg/m²)</td>
<td>1.28</td>
<td>0.2</td>
</tr>
<tr>
<td>Walking Speed (m•min⁻¹)</td>
<td>18.5</td>
<td>4.1</td>
</tr>
<tr>
<td></td>
<td>49.0</td>
<td>8.0</td>
</tr>
</tbody>
</table>
along with district, school administration, and Institutional Review Board approval were obtained prior to participation in the study. All measures were administered during regularly scheduled adapted physical education class. Standing height (cm) and weight (lbs) were obtained without shoes using a portable stadiometer (Seca 214 Portable Height Rod, Hamburg, Germany) and physician’s scale (Detecto Balance Beam Scale, Daugherty Webb City, MO). The units (e.g., lbs to kg) were converted and body mass index (BMI) calculated. Participant’s age (in decimal) was calculated by subtracting their date of birth from the date of assessment and age-sex specific BMI percentiles were calculated (National Center for Health Statistics, 2006).

Pedometer

The Walk4Life Duo (WL, Plainfield, IL) was used throughout the study. This specific model was selected because it assesses both steps and activity time (hours, min, seconds) and is deemed an accurate measure of activity steps and time for children without disabilities (Beets et al., 2005). The pedometer records steps and time from the motion of the lever arm. While the lever arm is in motion, an internal stopwatch accrues time (i.e., seconds) during ambulation. To prevent the recording of ambulatory movement less than three seconds, the pedometer timer has a delay feature, so that when three or more seconds of ambulation occur, the device begins recording (Beighle & Pangrazi, 2006).

A total of ten pedometers were used, with five pedometers serving as the primary pedometers for the entirety of the study. The remaining five pedometers served as reserve models in case of primary unit failure. No primary unit failure occurred during the study. All units were subjected to a modified version of the “shake-test” (Vincent & Sidman, 2003) at pre, mid, and post testing. Briefly, all units were reset to zero and placed in single compartments inside a plastic container (30 × 20 × 4cm). The container was then shaken 100 times while the research staff member counted the number of shakes with a hand tally counter. This procedure was performed three times at each shake test and no unit exhibited more than ±5% error across the shake tests.

Self-Paced Walking

Each child completed six self-paced walking trials while wearing the WL pedometer placed at five positions around the waist using an adjustable belt. The pedometer positions were front right hip (manufacturers’ recommended placement), back right hip, front left hip, back left hip, and middle back at the spine. These positions were selected to determine the following: (a) appropriate placement of the pedometers for accurate register of steps and time, and (b) whether placements out of direct view of the child (i.e., back left/right hip and specifically the middle back) could be used to minimize the children interfering (e.g., shaking or attempting to remove) with the pedometer while wearing (i.e., “out of sight, out of mind”).

Prior to each walking trial, the pedometers were positioned around the waistline of the participants at the five locations (see above). The pedometers were then reset to zero and closed. To ensure that nonwalking movements were minimized (e.g., bouncing, shaking, or jumping in place) before beginning the walking trials,
participants were instructed to hold still or physically held by the adapted physical education teacher. Once all pedometers were in the proper positions, reset to zero, and closed, the participants began their walking trials.

A 10 meter distance was marked with cones and colored tape in a gymnasium or hallway, depending on the accommodations available. The 10 meter distance was walked eight times at the child’s self-determined walking speed. One 80 meter distance (i.e., eight 10 meter lengths) comprised one walking trial. Each child walked in a straight line, between the markers, with the assistance of one research staff member (i.e., walk-leader, holding a single hand). Upon approaching the opposite marker line, the child was instructed/led to turn around prior to the marker line so that his/her feet stayed within the 10 meter marked distance, yet touched the end marker tape. The walk-leader maintained the walking speed designated by the child. The walk-leader was used to ensure the child walked the appropriate distance and stopped after completing the eight 10-meter lengths. Because of issues with participant compliance and fatigue, the six trials were completed over several days, with children completing anywhere from one to six trials on any given day. This procedure was carried out until a total of six trials were collected for each child. At the end of each trial, the number of registered steps and time (min and seconds) were recorded from each pedometer.

**Step/Time Criterion Measure**

Video tapes of the walking trials were used as the criterion measure to determine pedometer step and time accuracy. A single video camera (Sony Multi-Language Tilter Handycam Vision, Model Number CCD-TRV15) affixed to a tripod, was placed at one end of the 10 meter distance. The camera was positioned at a one meter height and at an angle in order to record foot falls at both ends of the 10 meter distance. The camera was set to record continuously for the entirety of the walking trials. The videos were transferred to DVD and two observers (i.e., two of the authors) not present at the primary data collection watched them independently on computers using Windows Media Player 10™ (Microsoft Corporation, Inc.). Trials were viewed at one-half speed (i.e., slow motion) in order to ensure an accurate count of the number of steps taken and time to complete each trial.

A step was defined as the elevation of the foot from the ground. Since pedometers do not require a forward movement to register a step (jumping in place registers steps), all elevations of the foot were included in the criterion step count tally. Actual steps were recorded using hand-held tally counters. Time to complete the 80 meter distance was determined by using the digital elapsed time readout (hours: min:seconds) appearing in the media information window. Several youths’ walking patterns consisted of walking short distances, pausing, followed by self-stimulation in the form of rocking back-and-forth from foot to foot, and walking again. Durations of pausing longer than one second were tallied and subtracted from the total time to complete the 80-meter distance. This adjusted time to complete the 80-meter distance (minus pauses) was used as the criterion to compare activity time (as measured via the pedometer) and determine walking speed.
Data Analysis

Inter-Observer Agreement

Two-way mixed model single measure intraclass correlation coefficients (ICC) and 95% confidence intervals (95CI) were calculated to determine the agreement between the two observers for actual steps and activity time (i.e., criterion measure, see above) estimates from the videos. Single measure ICCs (95CI) for actual pedometer steps and activity time were ICC\(_{steps} = .99\) (.99, .99) and ICC\(_{time} = .99\) (.99, .99), respectively. Given the high agreement between the two raters, the average of actual steps and activity time were calculated and used as the criterion measure to determine accuracy for all subsequent analyses.

Step and Activity Time Level of Agreement

Single measure ICCs (95CI) were calculated to assess the level of agreement between registered pedometer steps and activity time (i.e., the steps and activity time recorded by the pedometers during the walking trials) versus observed steps and activity time for each pedometer placement (Beets et al., 2005). The level of agreement was compared to established guidelines (Baumgartner, Jackson, Mahar, & Rowe, 2003): (a) \(\leq .79\), low agreement; (b) .80 to .89, moderate agreement; and (c) \(\geq .90\), high agreement.

Step and Activity Time Percent Error Comparisons

For each trial, the absolute difference among registered steps and activity time to actual steps and activity time was computed (registered steps minus actual steps) for each of the five pedometer locations, separately (Le Masurier & Tudor-Locke, 2003). The difference scores were transformed into percentages, (registered steps minus criterion steps)/criterion steps \(\times 100\) to reflect the percent error from observed. Preliminary analyses revealed no significant differences existed across trials in percent error scores, therefore, the percent error scores were averaged across trials by the individual so that each participant had ten percent error scores, representing the deviation from observed steps and activity time for the five pedometer placements. Additionally, preliminary analyses indicated no significant differences existed between boys and girls’ percent error scores for steps and activity time across the five pedometer locations. Therefore, all subsequent analyses were conducted on the total sample. This transformation was performed to examine the difference in the accuracy between steps and activity time in the subsequent analyses. Means (standard deviations) of the percent error scores were calculated for all variables. Distributional plots (e.g., histograms and normal Q-Q plots) were examined for normality. Results indicated the percent error scores violated the assumption of normality and were log transformed for all subsequent analyses.

Comparison of Percent Error Scores by the Five Pedometer Locations

Overall, two one-way within-subjects ANOVAs, assessing the effects of pedometer placement (i.e., five locations) on the percent error scores (dependent variable) for
steps and activity time, were computed separately. For all ANOVAs, Mauchly’s test for sphericity was examined for violation, with significant violations corrected using the Greenhouse-Geisser adjusted degrees of freedom and corresponding \( p \) values (Greenhouse & Geisser, 1959). The magnitude of the effect was determined by the partial eta squared (\( \eta^2 \)). Paired sample \( t \)-tests were calculated to examine differences in percent error scores for steps and activity time for each pedometer placement (e.g., front right steps percent error vs. front right activity time percent error). An alpha level of \( p \leq .05 \) was used to indicate significant differences. Graphical representations of the non-transformed percent error scores for steps and activity time by the five pedometer locations (see Figure 1A), and average percent error scores for steps and activity time across BMI percentiles (see Figure 2) and walking speeds (see Figure 3) are presented.

Further, the percent error scores for steps and activity time across the five pedometer locations are presented for a reduced sample \((n = 17)\) that excludes one participant’s percent error scores due to excessive deviation (\( \pm 3 \) \( z \) scores) from the rest of the sample (see Table 2 and Figure 1B). Since this sample excludes an individual with legitimate, albeit excessive, percent error scores, no formal analyses were conducted on this reduced sample and are presented for illustrative purposes solely.

**Results**

**Step and Activity Time Level of Agreement**

The levels of agreement (ICC, 95CI) for steps and activity time by the five pedometer locations are presented in Table 3. Only one location (front right, ICC = .83) exhibited a moderate level of agreement for steps; all other locations exhibited low levels of agreement (ICC range .46 to .69). The level of agreement for activity time resulted in only one location (middle back) with a low level of agreement (ICC = .65), whereas two locations had moderate levels of agreement (back right, ICC = .80 and front left, ICC = .90) and two locations a high level of agreement (front right, ICC = .99 and back left, ICC = .94).

**Step and Activity Time Percent Error Comparisons**

The mean (standard deviation) percent error scores for pedometer steps and activity time are presented in Table 2 and graphically illustrated in Figure 1A. The percent error scores for the two one-way within-subject ANOVAs indicated the comparison among the five pedometer placements for the percent error scores for steps was significant, \( F(2.9, 49.3) = 4.91, p < .01, \eta^2 = .22 \), and revealed the front left location had significantly greater deviation than the front right (\( p = .02 \)) and back left (\( p = .03 \)) step percent error. The percent error scores for activity time across locations resulted in no significant differences, \( F(2.5, 43.0) = 2.57, p = .08, \eta^2 = .13 \). Follow-up paired comparisons between percent error scores for steps and activity time for each of the five pedometer placements indicated the front left steps and activity time were significantly different (\( p < .01 \), with a trend toward significance between the back right steps and activity time (\( p = .06 \)).
Figure 1 — Percent error scores for pedometer steps and activity time by five locations for the full (Figure 1A, n = 18) and with the outlier excluded (Figure 1B, n = 17) sample. Error bars represent one standard deviation.
Figure 2 — Average, across pedometer location, absolute percent error difference for pedometer steps (●, black circle) and activity time (○, white circle) by age-sex specific Body Mass Index percentile for each participant.
Figure 3 — Avergage, across pedometer location, absolute percent error difference for pedometer steps (●, black circle) and activity time (○, white circle) by walking speed (m•min⁻¹) for each participant.
Table 2  Absolute Percent Error Scores for Pedometer Steps and Activity Time by Location for the Full (n = 18) and With the Outlier Excluded (n = 17) Samples*

<table>
<thead>
<tr>
<th>Sample</th>
<th>Parameter</th>
<th>Pedometer Location</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Front Right</td>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td>Full (n = 18)</td>
<td>Steps</td>
<td></td>
<td>6.6</td>
<td>8.7</td>
<td>9.5</td>
<td>16.7</td>
<td>8.4</td>
<td>18.8</td>
<td>6.7</td>
<td>12.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Back Right</td>
<td>3.7</td>
<td>3.2</td>
<td>5.7</td>
<td>10.8</td>
<td>7.5</td>
<td>15.2</td>
<td>5.7</td>
<td>6.2</td>
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<tr>
<td></td>
<td>Activity time</td>
<td></td>
<td>3.6</td>
<td>2.8</td>
<td>3.7</td>
<td>2.7</td>
<td>4.2</td>
<td>3.7</td>
<td>4.9</td>
<td>3.2</td>
</tr>
<tr>
<td>Outlier Excluded (n = 17)</td>
<td>Steps</td>
<td></td>
<td>5.6</td>
<td>6.7</td>
<td>5.9</td>
<td>6.4</td>
<td>3.8</td>
<td>3.9</td>
<td>4.0</td>
<td>5.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Activity time</td>
<td>5.6</td>
<td>6.7</td>
<td>5.9</td>
<td>6.4</td>
<td>3.8</td>
<td>3.9</td>
<td>4.0</td>
<td>5.4</td>
</tr>
</tbody>
</table>

*Significance tests based on log-transformed absolute percent error scores.
‡ No tests of significance were conducted on the outlier excluded sample, with the information presented to illustrate the effect of the outlier on the percent error scores.
Abbreviations: Percent error scores with the same letters (e.g., ‘a’ and ‘a’) indicate significant (p < .05) difference. † p = .06.
Youth with developmental disabilities engage in less recreational activity (Longmuir & Bar-Or, 2000) and are at a greater risk of becoming overweight (Bandini, Curtin, Hamad, Tybor, & Must, 2005) than their peers without disabilities. However, determining whether population-based activity interventions are effective will be limited until an accurate and low-cost method for measuring the activity levels of youth with developmental disabilities is established. Thus, the ability to accurately assess the physical activity levels of youth with developmental disabilities has become a priority issue (Fernhall & Unnithan, 2002).

Although numerous methods to measure physical activity levels exist (e.g., self-report, accelerometers, heart rate monitors, pedometers, observation), few can be successfully utilized in this population given the unique characteristics individuals with disabilities exhibit (e.g., limited cognitive function, nontypical responses to sensory input—heart rate monitor around the chest, mobility limitations). Objective monitoring techniques (i.e., accelerometers, pedometers, observation) are perhaps the most promising yet have their own limitations, such as cost (accelerometers), inability to measure certain types of activities (e.g., strength training, swimming—accelerometers and pedometers), and staff training and time commitment (observation). Despite limitations, pedometers have grown increasingly popular for monitoring children’s (Tudor-Locke, Pangrazi et al., 2004; Vincent & Pangrazi, 2002) and adult’s (Rooney, Smalley, Larson, & Havens, 2003; Tudor-Locke & Bassett, 2004) physical activity levels.

While previous studies have found pedometers to be accurate with able-bodied children (Beets et al., 2005; Ramirez-Marrero et al., 2002) and adults with mental retardation (Stanish, 2004), no studies to date have determined their accuracy with youth with developmental disabilities. Because of the issues surrounding the speed at which certain populations ambulate (e.g., slow walking), and with this the potential to reduce pedometer accuracy (Beets et al., 2005; Crouter et al., 2003), the examination of a pedometer model that has demonstrated precision under these circumstances is warranted. In a single study, examining the accuracy of pedometers under two walking speeds (normal and fast paced), Stanish (2004) found

Table 3 Intraclass Correlation Coefficients (95CI) Between Registered Steps and Activity Time and Observed Steps and Activity Time by Pedometer Location (N = 18)

<table>
<thead>
<tr>
<th>Location</th>
<th>Steps ICC (95CI)</th>
<th>Activity time ICC (95CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Front right</td>
<td>.83 (.76, .88)</td>
<td>.99 (.98, .99)</td>
</tr>
<tr>
<td>Back right</td>
<td>.48 (.32, .61)</td>
<td>.80 (.73, .86)</td>
</tr>
<tr>
<td>Middle back</td>
<td>.43 (.30, .59)</td>
<td>.65 (.53, .75)</td>
</tr>
<tr>
<td>Back left</td>
<td>.69 (.58, .77)</td>
<td>.94 (.91, .96)</td>
</tr>
<tr>
<td>Front left</td>
<td>.56 (.42, .67)</td>
<td>.90 (.85, .93)</td>
</tr>
</tbody>
</table>

Note. Abbreviations: ICC = Intraclass correlation coefficient; 95CI = 95% confidence interval; Single = single measure ICC.
no influence of speed on pedometer accuracy for adults with mental retardation. However, no report of the speed for either normal or fast paced was provided, thereby limiting the ability to compare the walking speeds of Stanish (2004) to the current study. Nevertheless, the results from the current study are similar to those reported by Stanish (2004) and indicate that both steps and activity time exhibit acceptable accuracy under self-paced walking, with activity time the more accurate of the two (see Table 2 and Figure 1B). The hypothesis that activity time would demonstrate a higher level of agreement than steps was, therefore, supported (see Table 3 and Figures 1, 2, and 3). Further, the average walking speed observed in the sample was 49.0 ± 12.9 m•min\(^{-1}\) (1.8 ± 0.5 mph), which is below walking speeds reported in studies of children (5-11yrs) without disabilities (Beets et al., 2005)—76.7 ± 4.45 m•min\(^{-1}\) (2.9 ± 0.2 mph) and 77.5 ± 6.03 m•min\(^{-1}\) (2.9 ± 0.2 mph) for boys and girls, respectively—supports the authors’ informal observations that the youth with developmental disabilities in the current study walked at slower speeds than did their peers without disabilities.

In review of the individual raw data (untransformed, as illustrated in Figures 2 and 3), however, pedometer steps and activity time exhibited acceptable accuracy in all but one of the participants (girl, 8.6 yrs old, BMI 34.9, walking speed 33.9 m•min\(^{-1}\)). It is, therefore, imperative to address the issue of this outlier in the current study. Certain characteristics of this individual, specifically the high BMI age-sex specific percentile (BMI percentile 100\(^{th}\)), and the slow walking speed (33.9 m•min\(^{-1}\)) may have contributed to the excessive error scores (under predict, ±3 z scores) observed in relation to the rest of the sample. The outlier’s walking speed, however, was not the slowest observed. In fact, two other participants displayed slower walking speeds (31.6 m•min\(^{-1}\) and 25.6 m•min\(^{-1}\)). The two slowest walkers had percent error scores across pedometer locations ranging from 2.5% to 10.9% for steps and 1.7% to 6.7% for activity time, whereas the outlier exhibited percent error scores ranging from 25.1% to 70.7% for steps and 6.5% to 51.2% for activity time. These differences indicate that additional factors, apart from slow walking, were affecting the error score rate for the outlier. A recent study (Crouter, Schneider, & Bassett, 2005) on the effects of overweight and obesity in adults on pedometer accuracy found pedometer tilt (angle of deviation away from or toward the body) contributed to inaccuracy in registered step counts. This is likely to have influenced the accuracy of the pedometers with the outlier, given the high BMI percentile. Since no angle of deviation was collected in the current study, we are unable to confirm this; however, in visually reviewing the videos, it appears the pedometers were upright and thus may not have been subjected to this potential source of error. Further, six other participants exhibited age-sex specific BMI percentiles at or above the 95th percentile (see Figure 2). Thus, excessive weight and corresponding pedometer tilt may not have influenced the accuracy of steps and activity time for the outlier.

After further review of the video, the participant outlier appears to have been stepping with minimal foot elevation from the ground. This would likely affect the vertical velocity by which the hips/waist move and in turn would serve to dampen the amount of vertical force generated to trigger the pedometer lever arm. Unfortunately, gait analysis was not conducted to confirm this and suggests an area of future research. Overall, it appears several sources of error may have contributed to the pedometer step and activity time error scores for this one individual. Of
interest, the ICCs for the front right (.99) and back left (.94) placement for activity
time exhibited acceptable agreement, even with the outlier’s error scores included
in the calculations (see Table 2). Although inflated error scores for steps with this
individual were observed, the activity time parameter appears to be less sensitive
to potential sources of error and thus inaccuracy, suggesting activity time may be
the more appropriate measure when using pedometers with individuals exhibiting
similar characteristics to the outlier.

Prior accuracy studies in both children (Beets et al., 2005; Ramirez-Marrero et
al., 2002) and adults (Crouter et al., 2003) found slow walking speeds influenced
step count accuracy ($\leq 54 \text{ m}\cdot\text{min}^{-1}$ and $\leq 80 \text{ m}\cdot\text{min}^{-1}$, respectively). The average
speed of the entire sample in the current study was $49.0 \pm 12.9 \text{ m}\cdot\text{min}^{-1}$. This sug-
uggests that slow walking speeds may not be as influential to pedometer accuracy
as previously concluded (Beets et al., 2005; Crouter et al., 2003; see Figure 3).
The use of a treadmill to simulate slow walking in previous studies (Beets et al.,
2005; Crouter et al., 2003), in comparison to over ground walking, may account
for this discrepancy. Previous research examining the vertical ground reaction
forces between treadmill and over ground walking have found lower peak forces
for treadmill walking (White, Yack, Tucker, & Lin, 1998). In a comparison of
joint kinematics between treadmill and over ground walking, Alton and colleagues
(1998) found differences in hip range of motion and maximum hip joint flexion
angle and cadence favoring treadmill walking. Both of these studies (Alton et al.,
1998; White et al., 1998) were conducted with adults and the treadmill protocol
consisted of “normal” (i.e., self-selected) walking speeds for each participant. It is
unclear if differences may have resulted from simulating slower walking speeds.
The length of time on a treadmill may also affect kinematics, with time periods of
two min or longer resulting in knee angles approximating over ground walking,
whereas differences were observed between the initial time walking on a treadmill to
approximately 2 min (Matsas, Taylor, & McBurney, 2000). However, like previous
studies (Alton et al., 1998; White et al., 1998), these measures were taken during
“normal” walking speeds on the treadmill. Nevertheless, these studies suggest
simulated treadmill walking may not directly reflect kinematic patterns (Alton et
al., 1998; Matsas et al., 2000) and vertical ground reaction forces (White et al.,
1998) observed during over ground walking. This, in turn, may account for the
differences in the current findings to those previously reporting pedometer inac-
curacies during slow treadmill walking (Beets et al., 2005; Crouter et al., 2003;
Ramirez-Marrero et al., 2002).

The results examining the differences among the five locations suggest that
while significant differences existed (see Table 2), they may have been attributed
to variations in manufacturer quality rather than the influence of placement itself
(Bassett et al., 1996; Beets et al., 2005). This can be seen by the inflated percent
error scores for steps for the front left placement in relation to the other locations
(see Table 2 and Figure 1). Previous research has indicated this is a likely rationale
behind observed variation in front right and left placement (Bassett et al., 1996;
Beets et al., 2005). Notably, although the percent error for steps was inflated for
the front left placement, this was not the case for activity time. Thus, manufacturer
quality may not affect the accuracy of the activity time parameter to the degree
it affects step registry. If pedometer quality deviates from unit to unit, using the
activity time parameter to measure physical activity is likely to provide a more
accurate assessment of how much ambulation an individual is accruing over the course of the day. A previous study (Ramirez-Marrero et al., 2002) examining the accuracy of the Digiwalker in two different locations, midline of thigh and midline of torso, found the midline of the torso placement to exhibit considerable accuracy (average of 2% to 5% error) across three walking speeds, whereas the midline of hip placement deviated anywhere from 1% to 15% from observed steps. Based on the current findings, it appears that location has limited influence on pedometer accuracy, with the least amount of influence for the activity time parameter. If tampering is a concern when using pedometers with youth with developmental disabilities, placement of the pedometer out of direct sight (back right and left and middle) will, therefore, not substantially influence its accuracy.

In conclusion, the present study suggests a moderate level of accuracy for both steps and activity time when using this specific pedometer (WL) with youth with developmental disabilities. Placement of the pedometer results in minimal changes in accuracy, thereby allowing practitioners the flexibility in placing the pedometers in locations around the waist where tampering of the devices can be minimized. Future research needs to determine the accuracy of steps and activity time during unstructured activities and the feasibility of collecting pedometer steps and activity time in this population (multiple days).

References


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**Disclosures**

The development, collection, analysis, and interpretation of the current study was not connected with nor influenced by the manufacturers of the pedometer model. No financial compensation was received prior to, during, or after the completion of the study.