The Accuracy of Pedometers for Adults With Down Syndrome

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The purpose of this study was to examine the accuracy of spring-levered and piezoelectric pedometers for adults with and without Down syndrome (DS). Twenty adults with DS and 24 adults without a disability walked for two minute periods on a predetermined indoor course at a self-selected, slower and faster pace. Pedometer recorded and criterion observed steps were compared to determine pedometer error. There was a significant interaction between pedometer model and walking speed. Piezoelectric pedometers demonstrated significantly less measurement error than spring-levered pedometers, particularly at slower walking speeds. There were also significant differences in pedometer error between adults with and without DS. The study concludes that pedometer measurement error is significantly different for adults with DS but also that piezoelectric pedometers can be used in the future to measure walking activity for adults with and without DS.

The physical activity habits of adults with intellectual disabilities (ID), particularly those with Down syndrome (DS), are relatively unknown. The current literature does indicate that the vast majority of individuals with ID are not sufficiently active, yet the methodology under which these behaviors have been examined is questionable (Temple, Frey, & Stanish, 2006). Individuals with DS typically exhibit characteristics unlike other forms of ID, including unique body and facial features, obesity and growth stature differences, muscle hypotonia, joint laxity, significant delays in motor development, and a variety of medical conditions including congenital heart disease (Latash, 2000; Roizen, 2002). There is also evidence that individuals with DS walk with a unique gait pattern, marked by additional medio-lateral variability (Agiovlasitis, McCubbin, Yun, Mpitosos, & Pavol, 2009; Kubo & Ulrich, 2006). Although individuals with DS may not be at risk for cardiovascular disease to the extent that adults with intellectual disabilities without DS (Draheim, McCubbin, & Williams, 2002), this population still experiences preventable health disparities that could be remedied by increased access to physical activity (Frey, Stanish, & Temple, 2008; Stanish, Temple, & Frey, 2006; U.S. Department of Health and Human Services, USDHHS, 2002). Of what little evidence is available, it appears walking is the most common form of physical

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activity for individuals with ID, both with and without DS (Draheim, Williams, & McCubbin, 2002; Stanish & Draheim, 2005a, 2005b; Temple, Anderson, & Walkley, 2000). Thus, efforts should be made to maximize the accuracy, reliability, and efficiency of methodology used to measure this behavior.

A few studies have examined the walking activity of individuals with and without DS. These studies used pedometers and a 10,000 step/day criteria consistent with many public health standards (Tudor-Locke & Bassett, 2004). Stanish (2004) measured the walking activity of individuals with mild ID with and without DS. Walking activity was measured over seven days and found that adults with intellectual disabilities without DS walked approximately 11,800 steps/day compared with 5,600–8,800 steps/day for adults with DS, indicating a significant difference between subgroups. These findings have not been directly substantiated by subsequent studies. Stanish and Draheim (2005a, 2005b, 2007) reported no statistically significant differences in steps counted between groups, but did show that a greater percentage of participants with DS recorded fewer than 7,500 steps/day. Furthermore, Peterson, Janz and Lowe (2008) reported no substantive or statistical difference in steps recorded between groups. The inconsistencies in statistical differences between adults with and without DS, or at the very least a trend of adults with DS having lower steps counts, could represent differences between unique samples but could also reflect a source of measurement error.

Many previous studies examining physical activity have used pedometers. It is a simple, user-friendly, unobtrusive and relatively inexpensive device (Bassett et al., 1996; Crouter, Schneider, Karabulut, & Bassett, 2003; Le Masurier & Tudor-Locke, 2003; Schneider, Crouter, & Bassett, 2004; Tudor-Locke & Myers, 2001) and may be particularly practical for use among populations with intellectual disabilities. There are three types of pedometers, each utilizing different mechanisms including spring-levered arm, magnetic reed, and piezoelectric crystal. The two most common commercially available pedometer mechanisms are the traditional spring-levered arm and newer piezoelectric pedometers. The spring-suspended level arm mechanism records steps as an internal horizontal lever arm moves up and down from vertical movement at the hip (Crouter et al., 2003; Schneider, Crouter, Lukajic, & Bassett, 2003). The piezoelectric pedometer mechanism is similar to a uni-axial accelerometer that uses a horizontal beam and a piezoelectric crystal to record steps based on the number of zero-crossings of the instantaneous acceleration versus time curve (Crouter et al., 2003; Schneider et al., 2003).

All pedometer types have been extensively validated in the general population, and numerous studies have demonstrated that certain brands and models are more accurate than others (Bassett et al., 1996; Crouter et al., 2003; Schneider et al., 2003, 2004). In general, most pedometers have been found to have acceptable accuracy for measuring steps, and to a lesser degree distance, time, and calories expended; however, the pedometer has undergone less validation within disability populations, particularly individuals with DS. Of the limited evidence available, Stanish (2004) found intraclass correlations for spring-levered arm pedometers for adults with intellectual disabilities to be very high across speed, location, and surface (all above ICC = 0.95). Additional studies have identified unique sources of measurement error, yet provided moderate support for using pedometry to measure physical activity in populations of youth with developmental disabilities, youth with visual impairments, and adults with neurological disabilities (Beets, Combs,
Pitetti, Morgan, Bryan, & Foley, 2007; Beets, Foley, Tindall, & Lieberman, 2007; Manns, Orchard, & Warren, 2007; Pitetti, Beets, & Flaming, 2009). To the best of current knowledge, no known studies have examined accuracy of piezoelectric pedometers for individuals with DS, however.

All of these studies, however, are limited by the lack of stratified analyses that may show important differences between subgroups as opposed to using broadly collected and innately heterogeneous groups. Stratified designs have been recommended to better account for subgroup differences, particularly with samples including individuals with DS (Temple, Frey, & Stanish, 2006). The previously discussed studies all employed “whole group” analyses, which despite moderate to high levels of accuracy, could still miss significant group differences. Furthermore, none of these validation studies employed any control group, so while these studies have provided initial evidence of pedometer accuracy in certain populations, there is no indication on how this level of accuracy compares between adults with and without disabilities. This is important to determine if the body of literature on pedometers in the general population can be generalized to specific disability groups.

In the Stanish (2004) study, the author suggests that while the “validity data on pedometers is likely applicable to adults with MR, it is still important to gather evidence of accuracy when using instruments for research purposes” (p. 168). The same sentiment applies to individuals with Down syndrome, although there are additional reasons why pedometers may not be as accurate in this population. First, individuals with DS typically walk with unique gait pattern, described as a shuffling pattern that includes a wider base and increased medio-lateral variability to overcome joint laxity and muscle hypotonia through muscle cocontractions and stiffness (Agiovlasitis et al., 2009; Kubo & Ulrich, 2006; Smith, Kubo, Black, Holt, & Ulrich, 2007; Smith & Ulrich, 2008; Ulrich, Haehl, Buzzi, Kubo, & Holt, 2004). Gait variability has been identified as a significant source of pedometer error (Manns, Orchard, & Warren, 2007), so this gait pattern could present problems for pedometer measurement. Second, individuals with DS typically walk at slower self-selected speeds, notably under 70 m/min⁻¹ (Smith & Ulrich, 2008; Smith et al., 2007; Ulrich et al., 2004). Pedometers have been shown to become less accurate at speeds less than 80 m/min⁻¹, particularly at 54 m/min⁻¹ (Bassett et al., 1996; Crouter et al., 2003; Le Masurier & Tudor-Locke, 2003; Le Masurier, Lee, & Tudor-Locke, 2004; Melanson et al., 2004; Schneider et al., 2003, 2004). It is certainly possible that walking activity for individuals with DS is being underestimated due to this slower walking speed. Third, individuals with DS have been shown to have a body composition characterized by additional adipose tissue in the torso area, in a pattern that is unique to this population (Roizen, 2002). Studies in the general population have found that pedometer tilt, caused by adipose abdominal tissue in overweight and obese individuals, can cause pedometer error by negatively influencing the devices ability to use its mechanism for measurement (Crouter, Schneider, & Bassett, 2005). The body composition of individuals with DS is conducive with creating pedometer tilt, thus creating a source of pedometer error. Due to these potential sources of error including gait variability, walking speed, and body composition, certain pedometer mechanisms may be more appropriate for adults with DS.

It is necessary to gather empirical evidence on the accuracy and validity of both spring-levered and piezoelectric pedometers for adults with Down syndrome so that the most appropriate instrument can be used for the measurement of
walking activity. Given the common sources of error that have been shown in the general population, the DS population may be prone to producing measurement error. Thus, the purpose of this study was to examine the magnitude of errors and differences in accuracy for spring-levered and piezoelectric pedometers with adults with Down syndrome and adults without a disability. In addition, this study examined the effect of the walking speed traveled and the anthropometric characteristics of the individual on absolute measurement error for the pedometer models and DS groups.

**Method**

**Participants**

Convenience samples of twenty adults with Down syndrome (12 female, 8 male) aged 18–61 years (mean age 29.25 years) and 24 adults without a disability (14 female, 10 male) aged 22–60 years (mean age 32.08 years) participated in the study. All participants were recruited from small cities in the Northwest region of the United States and were independently ambulatory without assistive devices. Age was self-reported by participants, and height, weight, waist, and hip circumferences were measured without shoes in light clothing to the nearest 0.1 cm and 0.1 kg, respectively. The demographic and anthropometric characteristics of participants are included in Table 1. Independent sample $t$ tests showed participants without DS had significantly greater body mass (weight; $p < .05$), and height ($p < .05$). There were no significant differences between participants with and without DS for age, BMI, waist circumference, hip circumference, and waist-to-hip ratio (all $p > .05$).

Written consent was obtained from all participants before participation in the study in accordance with Institutional Review Board approval. Informed consent

| Table 1  Physical Characteristics of Participants: Descriptive Statistics by Group |
|----------------|----------------|----------------|
| Variable        | Down Syndrome ($N = 20$) | Control Group ($N = 24$) |
| Gender (female/male) | 12 / 8 | 14 / 10 |
| Age (yr)        | 29.25 ± 12.45 | 32.08 ± 13.10 |
| Height (cm)*    | 148.96 ± 8.13  | 170.33 ± 8.22  |
| Weight (kg)*    | 64.16 ± 11.59  | 76.15 ± 17.12  |
| BMI (kg·m$^{-2}$) | 29.09 ± 5.76  | 26.14 ± 5.23   |
| Waist circumference (cm) | 87.97 ± 12.86 | 84.93 ± 14.51 |
| Hip circumference (cm) | 103.74 ± 11.39 | 103.60 ± 10.69 |
| Waist-to-hip ratio | 0.85 ± 0.07 | 0.82 ± 0.09 |

*Note. Values are M ± SD. 
*Significant differences between groups, $p < .05$. 
documents for participants that required assistance in completing consent and demographic questionnaire documents were also signed by the assisting parent or legal caregiver. Medical diagnosis of Down syndrome was self reported by participants or reported with assistance of a parent or legal caregiver.

**Instruments**

Omron HJ-112 (Omron Healthcare, Vernon Hills, IL) and Yamax Digiwalker SW-200 (Yamax Inc., Tokyo, Japan) pedometers were used to measure walking steps taken. The Omron HJ-112 pedometer utilizes two piezoelectric sensors that allow the pedometer to be used at multiple locations on the body and measure steps when positioned at greater angles (Hasson, Haller, Pober, Staudenmayer, & Freedson, 2009). This particular brand and model were selected due to established levels of accuracy and validity (Doyle, Green, Corona, Simone, & Dennison, 2007; Hasson et al., 2009; Hasson, Pober, & Freedson, 2004). The Yamax Digiwalker SW-200 is a spring-levered arm pedometer and has been extensively researched. It has been shown to generate both valid and reliable measurement (Bassett et al., 1996; Crouter et al., 2003; Schneider et al., 2003) and has even been used as the criterion from which to validate other pedometers (Schneider et al., 2004). Like many spring-levered arm pedometers, however, it has been shown to be susceptible to measurement error due to slow walking speed and abdominal obesity (Crouter et al., 2005; LeMasurier & TudorLocke, 2003; Melanson et al., 2004; Swartz, Bassett, Moore, Thompson, & Strath, 2003). Since the purpose of this study was not to validate or promote these specific brands and models, each pedometer will be referred to by mechanism (piezoelectric or spring-levered) henceforth.

All instruments were checked for calibration before the start of the study using a 100 count modified version of a “shake test” (Vincent & Sidman, 2003). Pedometers that demonstrated errors of 1% or less were used in the study. During testing, each participant wore four pedometers, two of each model, on the right waistband at the midline of thigh using an elastic belt. All pedometers were positioned as close to manufacturer’s recommendation as was physically possible for the participant. At the start of each trial, all pedometers were reset to zero. At the end of each trial, the number of steps measured was recorded for each instrument.

**Testing Procedures**

The accuracy of pedometers using piezoelectric (Omron HJ-112) and spring-levered arm mechanisms (Yamax Digiwalker SW-200) were tested at three different walking speeds: self-selected, slow, and fast. Each walking trial occurred on a “figure 8” (see Figure 1) walking course and lasted 2 min each. This walking bout is similar to protocols used in previous treadmill based studies (Crouter et al., 2005; Swartz et al., 2003). A shorter walking period was used to maximize participant adherence to testing procedures. Data were collected in three separate sites. Due to physical constraints of the space at each site, the total course walking distance ranged from 38 m to 68 m. All versions of the course had cross tangents of at least 10 m and were on hard indoor gymnasium surfaces. The 10 m cross tangent was marked with two cones on each side.
Throughout the testing procedure, the participant walked with a researcher. During the self-selected pace trial, the researcher walked behind the participants as to not affect the walking pace. The researcher encouraged the participant and gave simple verbal instructions to ensure that the walking course was followed properly. During the slow and fast paced trials, the researcher walked side by side with the participants using a calibrated measuring wheel with an attached CatEye (Kuwazu, Japan) speedometer and encouraged the participant to walk at the paced speed throughout each trial. In addition, a researcher measured the time it took the participant to walk across the marked 10 m cross tangent. The researcher began timing when the first foot of the participant crossed the start line and stopped timing when the first foot crossed the end line. The time required for the participants to walk the 10 m distance was averaged over all measurements within a trial and divided by 10 to determine the walking speed in meters per second. This speed was then converted to miles per hour.

During the slow paced trial, the researcher set a pace of 2 mph. This speed was selected as it was the slowest speed that could be consistently set using the available CatEye technology. At this pace, the average speed walked was 1.97 mph ($SD = 0.45$) for participants with DS and 2.17 mph ($SD = 0.15$) for participants without DS. These slower speeds correspond with the slowest speeds (54 m/min$^{-1}$ and 67 m/min$^{-1}$) used in pedometer studies on treadmills that have been shown to decrease accuracy (Bassett et al., 1996; Crouter et al., 2003, 2005; Le Masurier & Tudor-Locke, 2003; Le Masurier et al., 2004; Swartz et al., 2003).

During the fast paced trial, the researcher set a pace for the participant at the fastest walking speed possible and/or a maximum of 4 mph. This speed differed between individuals to account for different transition speeds from walking to running and ensured that all participants walked the course. On the fast trials, the average walking speeds were 3.49 mph ($SD = 0.67$) and 3.93 mph ($SD = 0.31$) for participants with and without DS, respectively. These faster speeds correspond with the fastest speeds (94 m/min$^{-1}$ and 107 m/min$^{-1}$) used in multiple treadmill based studies (Bassett et al., 1996; Crouter et al., 2003, 2005; Le Masurier & Tudor-Locke, 2003; Le Masurier et al., 2004; Swartz et al., 2003). The average self-paced walking speed for participants with and without Down syndrome were 2.62 mph ($SD = 0.70$) and 3.19 mph (0.41), respectively.

![Figure 1 — Diagram of controlled course layout.](image)
During each walking trial, another researcher observed the participant and recorded the number of steps taken using a hand-held tally counter. The researcher counted the number of foot-strikes by the lead foot. This number was doubled to represent the actual number of steps observed and is used as the criterion step count in all analyses. Each participant repeated one trial for test-retest reliability. Intraclass correlations of pedometer error between trials were high across all speed conditions and models: ICC (2, 2) > 0.89.

**Statistical Analysis**

To examine the accuracy of pedometers, absolute error scores were calculated. Each absolute error score was determined for each pedometer model at three speeds of walking (self-paced, slow and fast paced) by the equation: (Observed steps—Pedometer / Observed steps). This error score is used as the dependent variable in subsequent analyses and represents the absolute degree of error between the pedometer recorded steps and the actual steps taken (Lee, Zhu, Yang, Bendis, & Hernandez, 2007).

In addition, intraclass correlation coefficients (ICC) were calculated to further examine the level of conformity between observed and pedometer recorded steps. Each ICC (2, 2) was calculated for absolute agreement with a two-way random average measures model. Independent t tests were also employed to examine differences in actual steps taken between groups.

A 2 × 2 × 3 (group × model × speed) repeated-measures ANOVAs was used to examine differences in absolute error scores between groups with and without DS, piezoelectric and spring-levered pedometers, and self-selected, slow, and fast paced speeds. Post hoc comparisons to determine significant differences of speed when an interaction was present were examined through one-way (speed) repeated-measures ANOVA for each pedometer model. In addition, a follow-up analysis to determine the influence of waist-to-hip ratio on absolute error was performed using a 2 × 2 × 3 (group × model × speed) repeated measures ANCOVA with the covariate of waist-to-hip ratio. The waist-to-hip ratio (WHR) covariate was treated as a continuous variable with a larger value indicating greater adipose tissue in the abdominal region and pedometer tilt angle. When assumption of sphericity was violated, Huynh-Feldt corrections were employed. Alpha of 0.05 was used to indicate statistical significance.

**Results**

The average steps observed and recorded by pedometers are presented in Table 2. For both participants, with and without DS, the most steps were taken during the fast trial while the fewest steps were taken during the slow trial. Under all three speed conditions, participants with DS walked more steps than participants without DS. During the fast and slow trials, this difference was statistically significant (p < .01).

Absolute percent error across speeds for adults with DS ranged from 11.40% to 22.39% for the spring-levered pedometer and from 7.57% to 8.02% for the piezoelectric. Similarly, absolute percent error for participants without DS ranged from 2.87% to 16.44% for the spring-levered and from 1.06% to 2.96% for the piezoelectric pedometer. The absolute error scores are presented as percentages in Table 3.
Table 2  Average Criterion Hand Counts and Pedometer Measurements at Three Speeds

<table>
<thead>
<tr>
<th></th>
<th>Self Paced Trial</th>
<th>Slow Paced Trial</th>
<th>Fast Paced Trial</th>
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<tbody>
<tr>
<td></td>
<td>Unit 1**</td>
<td>Unit 2</td>
<td>Unit 1</td>
</tr>
<tr>
<td><strong>Down Syndrome</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HC*</td>
<td>234.90 ± 28.05</td>
<td>219.80 ± 18.42†</td>
<td>291.50 ± 32.70†</td>
</tr>
<tr>
<td>SL</td>
<td>217.20 ± 59.69</td>
<td>204.05 ± 58.22</td>
<td>189.50 ± 48.80</td>
</tr>
<tr>
<td>PZ</td>
<td>228.25 ± 56.95</td>
<td>224.60 ± 43.72</td>
<td>206.30 ± 37.46</td>
</tr>
<tr>
<td><strong>Control Group</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HC</td>
<td>230.00 ± 13.64</td>
<td></td>
<td>191.67 ± 11.09</td>
</tr>
<tr>
<td>SL</td>
<td>215.17 ± 50.84</td>
<td>219.63 ± 27.24</td>
<td>174.00 ± 33.14</td>
</tr>
<tr>
<td>PZ</td>
<td>229.25 ± 14.51</td>
<td>230.17 ± 13.32</td>
<td>188.92 ± 10.25</td>
</tr>
</tbody>
</table>

*Note. Values are M ± SD.
Abbreviations: Criterion Hand Count (HC); Spring-levered Pedometer (SL); Piezoelectric Pedometer (PZ)
HC values are two times the counted lead foot strikes.
**Pedometer 1 is placed in lateral position; Pedometer 2 is placed in medial position on right hip.
† Significant differences on HC steps between groups, p < .01.
The 2 × 2 × 3 (group by model by speed) repeated-measures ANOVA on absolute percent error scores revealed there was a significant model by speed interaction, $F(2, 84) = 13.14, p < .001, \eta^2 = 0.24$. For the spring-levered model there was a simple main effect for speed, $F(2, 86) = 14.01, p < .001, \eta^2 = 0.25$. Simple contrasts revealed the absolute error of the spring-levered model at the self-paced and fast speed were significantly different than the slow speed ($p < .001$), but not significantly different from each other ($p > 0.04$). For the piezoelectric model, there was no simple main effect for speed, $F(2, 86) = 0.17, p > 0.8$, indicating absolute error was consistent across walking speeds.

There were also significant group differences on absolute error between participants with and without DS, $F(1, 42) = 9.06, p < .05, \eta^2 = 0.15$. Interactions for model by group, $F(1, 12) = 0.19, p > 0.8$; speed by group, $F(2, 84) = 0.32, p > 0.7$; and model by speed by group, $F(2, 84) = 0.40, p > 0.6$ were not statistically significant.

When the covariate of waist-to-hip ratio was added to the 2 × 2 × 3 (group × model × speed) repeated measures ANCOVA the results change. The group differences between adults with and without DS remained significant, $F(1, 41) = 7.35, p < .05, \eta^2 = 0.15$. However, both the main effects for speed, $F(1.82, 74.75) = 2.93, p > 0.1, \eta^2 = 0.04$ and model, $F(1, 41) = 1.98, p > 0.1, \eta^2 = 0.05$, were not significant. All possible interactions were also not statistically significant ($p > 0.1$).

Finally, Intraclass correlation coefficients are also presented in Table 3. ICC (2, 2) results were variable across model, group, and speed. High ICC levels were observed for the piezoelectric pedometer ranging from 0.89 to 0.97 across all speeds for the control group and from 0.87 to 0.90 for participants with DS at self-paced and slow speeds. However, the piezoelectric pedometer demonstrated moderate ICC of 0.66 for participants with DS at the fast speed. Moderate levels of ICC were observed for the spring-levered pedometer at self-paced and fast speeds for participants in control group (0.67–0.70) and with DS (0.76–0.79). Very low levels were observed for both groups at slow speeds (ICC > 0.52).

### Table 3 Absolute Percent Error and Intraclass Correlation Coefficients at Three Speeds

<table>
<thead>
<tr>
<th></th>
<th>Self Paced Trial</th>
<th>Slow Paced Trial</th>
<th>Fast Paced Trial</th>
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<tbody>
<tr>
<td></td>
<td>$M^*$  $SD$  ICC†</td>
<td>$M$  $SD$  ICC</td>
<td>$M$  $SD$  ICC</td>
</tr>
<tr>
<td>Down Syndrome</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SL</td>
<td>11.40  19.21  0.76</td>
<td>22.39  17.71  0.41</td>
<td>11.89  21.13  0.79</td>
</tr>
<tr>
<td>PZ</td>
<td>7.90   13.08  0.87</td>
<td>7.57    13.76  0.90</td>
<td>8.02    9.03  0.66</td>
</tr>
<tr>
<td>Control Group</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SL</td>
<td>6.49   12.16  0.67</td>
<td>16.44   11.66  0.52</td>
<td>2.87    6.51  0.70</td>
</tr>
<tr>
<td>PZ</td>
<td>1.06   1.47   0.97</td>
<td>2.96    2.94   0.89</td>
<td>1.05    2.17  0.92</td>
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</table>

*Values are mean absolute percent errors: (Observed Steps—Pedometer / Observed Steps × 100), Abbreviations: Spring-levered Pedometer (SL); Piezoelectric Pedometer (PZ)
† ICC (2,2)
Discussion

The pedometer is a widely used measurement tool with many models capable of monitoring the steps an individual takes during daily ambulation in addition to other indices of walking activity including distance walked, time in aerobic walking activity, and calories expended. Pedometers have been used in research to measure walking and physical activity behaviors in the general (Tudor-Locke & Myers, 2001) and disability (Peterson et al., 2008; Stanish, 2004; Stanish & Draheim, 2005a, 2005b, 2007) populations. There are also a growing number of individuals that use pedometers recreationally as part of their own lifestyles.

The study sought to examine if accuracy differed between two types of pedometers and between adults with Down syndrome and with no disability. These differences were addressed at self-paced, slower, and faster speeds as well as controlling for WHR.

The main finding is that pedometers utilizing different mechanisms, particularly spring-levered and piezoelectric pedometers, can have different levels of measurement error. The results indicate that there is a significant main effect related to model. The absolute errors for the spring-levered pedometer ranged from approximately 11–22% for adults with DS and 3–16% for adults in the control group. Absolute error for the piezoelectric model ranged from approximately 7–8% for adults with DS and 1–3% for adults in the control group. The support for wide variability between mechanisms and consumer models has been well documented in the literature. Multiple studies (Bassett et al., 1996; Crouter et al., 2003; Schneider et al., 2003, 2004) have examined numerous models of pedometers under a range of conditions (treadmill, walking track, free-living). The general consensus is that due to the variability among models, not all pedometers are equal. In studies examining numerous models, pedometers using a piezoelectric mechanism were consistently among the most accurate and most reliable (Crouter et al., 2003; Schneider et al., 2003, 2004). Furthermore, when piezoelectric and spring-levered pedometers have been directly compared, the piezoelectric has been found superior, particularly during adverse measurement conditions (Crouter et al., 2005; Melanson et al., 2004). The findings of the current study are in agreement with this previous literature and further demonstrate that piezoelectric pedometers are more accurate than spring-levered models for both adults with and without DS.

A second finding is the significant differences between pedometer models and participant groups, the results also confirm two sources of measurement error. The first source of error is walking speed. The current study provides additional evidence that the accuracy of pedometers for each model is moderated by the speed at which the mover travels. The spring-levered model was more affected by
speed, as demonstrated by additional error reported at the slower walking pace. The piezoelectric pedometer had decreases in accuracy with slower speeds, but this difference was not significantly or substantively different. These results are consistent with much of the recent literature in pedometer accuracy. Melanson et al. (2004) showed that regardless of speed, piezoelectric pedometers were more accurate than spring-levered pedometers, including speeds of 1.0 mph. While the current study used approximately 2.0 mph as the slowest speed, the differences in accuracy for the spring-levered pedometer as opposed to the lack of differences observed in the piezoelectric models represent a comparable and similar trend. This shows that the piezoelectric pedometer is more resistant to speed related errors for both groups.

The remainder of the literature has consistently shown this trend that pedometers become less accurate at speeds under 80 m·min⁻¹ (2.98 mph; Bassett et al., 1996; Crouter et al., 2003; Le Masurier et al., 2004; Le Masurier & Tudor-Locke, 2003; Schneider et al., 2003, 2004). In the current sample, adults without a disability demonstrated the usual pattern of accuracy decreasing with speed. Percent error was under 3% at the fastest speed, under 6.5% at the self-selected speed, and under 16% at the slowest speed for both pedometer models; however, adults with DS showed a slightly different pattern. With the spring-levered pedometer, percent error was under 22% at the slowest speed and under 11.5% at the self-selected speed, but under 12% at the fastest speed. The hypothesis behind walking speed being a cause of error for pedometers is that as speed decreases, there is less vertical movement at the hip for the device to detect (Crouter et al., 2003); however, it appears that this phenomenon is not a strictly linear relationship between speed and accuracy. The slightly higher error rate at the fastest speed could represent a more variable gait pattern for adults with DS as they near the threshold for transition for running (Agiovlasitis, Yun, Pavol, McCubbin, & Kim, 2008). Despite no significant differences between self-paced and fast speeds, as compared with the significant differences between the slow pace and the two faster speeds, the results indicate that not only dampened, but also excessive hip displacement may result in error. Despite these slight fluctuations from the usual trend, the results clearly indicate that at slower speeds, accuracy is compromised.

The second source of measurement error was pedometer tilt caused by increasing WHR. There have been contradicting results related to body composition and pedometers. While some studies have found that BMI has no statistically significant effect on pedometer accuracy (Melanson et al., 2004; Swartz et al., 2003), Crouter et al. (2005) found that higher BMI, waist circumference, and pedometer tilt resulted in lower levels of accuracy. Specifically, pedometer tilt was found to be strongest factor affecting steps counted. The Crouter et al. (2005) study also found that these factors significantly contributed to the major underestimation of steps by the Digiwalker SW-200, while having a nonsignificant effect on the New Lifestyles NL-2000, a piezoelectric pedometer. This study found similar results. WHR was measured to represent the physical conditions that cause pedometer tilt. While using WHR instead of pedometer tilt may be a limitation, an actual measure of pedometer tilt was not used because it is possible that the angle of tilt could change throughout the gait cycle as well as between individual strides. The initial results found an interaction between the two models and the three speed conditions; however, once the covariate of WHR was added, all of these effects became nonsignificant. This indicates that the differences observed on error rate between
the spring-levered and piezoelectric pedometer can be explained by the influence of WHR. This is a particularly important factor for addressing the accuracy of pedometers for individuals with DS, as the population is prone to abdominal obesity (Roizen, 2002). It should be noted however, that in the current sample, there was no statistical difference between groups related to any obesity related measure (WHR, BMI, waist and hip circumferences).

While significant differences between participant groups, pedometer models, and walking speeds are important, the magnitude of error or precision of accuracy must also be taken into account. For adults with DS, the magnitude of pedometer accuracy poses a problem. The spring-levered arm pedometer consistently demonstrated accuracy levels under 90%. Previous studies have deemed “fair” accuracy to be within 10% of actual steps taken (Crouter et al., 2005; Schneider et al., 2004). Furthermore, intraclass correlation coefficients were less than 0.80, making it difficult to associate moderate levels of agreement with observed steps (Baumgartner, Jackson, Mahar, & Rowe, 2007). The piezoelectric pedometer, despite demonstrating more error than in previous studies (Schneider et al., 2004), may still be acceptable for use among adults with DS. Absolute error rates were consistently around 8% and ICC coefficients were greater than 0.80 except for at the fast paced speed demonstrating moderate agreement. Beets, Combs et al. (2007) concluded that a moderate level of agreement was acceptable for pedometers.

An underlying problem still remains, in that the source of error resulting in significant differences among adults with and without Down syndrome has not been precisely identified by this study. The original hypothesis was that pedometers would have more error for individuals with DS due to unique gait patterns, slow walking speed, and stereotypical abdominal obesity. The presence of additional errors has been supported by the results; however, the cause of this error is still unclear. When controlling for the pedometer model, walking speed, and WHR, there remained a significant group difference. There was also no interaction between syndrome group and any other factor, indicating that the influences of model, speed, or body composition are not unique to individuals with or without DS. This signifies that an additional factor(s) specific to individuals with DS, possibly gait pattern, is causing additional pedometer error. There is evidence that gait variability can significantly impact the accuracy of pedometers (Manns, Orchard & Warren, 2007). Individuals with DS have been shown to walk with a gait pattern with increased variability in the medio-lateral direction (Agiovlasitis et al., 2009; Kubo & Ulrich, 2006) which could result in the underestimation of steps. This study did not measure gait characteristics, so this factor cannot be directly addressed.

The results of this study do not completely agree with the previous literature on pedometer accuracy for adults with intellectual disabilities. This may be due to differences between studies in protocol and analysis. In the Stanish (2004) study, the Digiwalker SW-200 was used and demonstrated very high accuracy with intraclass correlations greater than 0.95 across different walking surfaces, speeds, and sides of the body. The present study found wide ranging intraclass correlations for adults with DS, ranging from 0.41 to 0.79 for the spring-levered pedometer and 0.66 to 0.90 for the piezoelectric. The difference in accuracy between studies using the same pedometer model can be explained in two ways. First, the Stanish study included adults with intellectual disabilities with and without DS, while the current study focused on adults with DS. Given the results of a significant difference between
groups, the pedometer error for adults with DS may be systematically different than groups without DS, regardless of ID classification. Second, the experimental conditions were very different between the studies. In the current study, the controlled conditions included a “figure-8” walking course with four discrete turns per lap, whereas Stanish used a 400 m walk with presumably wider turns. The use of turns and changes in direction are more realistic to daily walking patterns, but could also add to pedometer error. Pitetti et al. (2009) found that pedometers were less accurate for youth with intellectual disabilities when used during dynamic movements. Regardless, the established differences between groups of adults with and without DS support the use of stratified sampling designs, unlike the “whole group” analyses used by Stanish (2004) and Beets, Combs et al. (2007). Disability groups that are inherently heterogeneous should be analyzed carefully as within-subjects variability may be very high.

Based on the findings of this study, the authors would recommend that piezoelectric pedometers be used in future research when pedometers are selected as a measurement tool. Researchers intending to measure the walking activity of individuals with DS should strongly consider other modes of physical activity measurement, such as accelerometers, but could use pedometers if the research questions and study conditions (time, budget, sample size) warrant their use. The use of spring-levered pedometers is not advised due to the high levels of error associated with walking speed and pedometer tilt. Despite this recommendation, future research should note that there is still approximately 8% error associated with piezoelectric pedometers and find ways to address and limit these errors in study methodology. It may also be useful to address pedometer data in terms of 95% confidence intervals rather than traditional group averages to better account for variability.

There are several limitations in the current study that should be acknowledged. First, during certain analyses, the between-subjects variance was larger than the within-subjects variance. This is due to the variable nature of a heterogeneous group, such as adults with DS, and is common among disability research but limits the validity of those analyses. Second, the controlled nature in testing conditions of speed pace did not result in a consistent fast speed for all participants. When participants were paced on the fast trial, each participant was limited by their maximum walking speed before transitioning to running. Thus, unlike the slow speed, there were differences between groups on the speed walked during that condition. These differences may have been problematic to the results. Third, the use of 2 min as the walking period for all three trials may have limited results, particularly at the slowest speed. Given the difficulty to pace participants with DS at the fast pace, however, this time period was still appropriate to maximize participant adherence and consistency between trials. Fourth, neither leg length nor gait characteristics were measured in the current study. Thus, there remain unexamined portions of the DS walking pattern that may impact pedometer accuracy. While the step counts in Table 2 clearly show that participants with DS walked more steps and that step patterns were more variable, the cause of these results can only be speculated. Finally, the use of a convenience sample of volunteers may also be a study limitation. The use of volunteers in a population of individuals with intellectual disability may result in a higher functioning group of participants that may not fully represent the true population.
Pedometers are a widely used tool for measuring walking activity. The present study examined the accuracy of spring-levered and piezoelectric pedometers for adults with Down syndrome as well as determined the effects of walking speed and WHR on absolute pedometer error. Results indicate that errors in steps recorded by a pedometer are significantly higher for adults with DS, for models with spring-levered mechanisms, at slower speeds, and with greater WHR. Given these results, it is recommended that research utilizing pedometers use piezoelectric pedometers to minimize the effects of walking speed and body composition on measurement error, particularly for samples of individuals with DS. Future research should further examine the sources of pedometer error for adults with DS to determine if gait characteristics are responsible for unexplained errors.

References


