Abstract  Pedometers are used in many studies because physical activities can be simply assessed using them. In addition to the spring-levered type, piezo-electric pedometers have recently been used. However, their accuracy in children has not been investigated in previous studies. In this study, we investigated the accuracy of spring-levered pedometer and piezo-electric pedometer step counts in comparison with hand-tallied step counts with children during self-paced walking. First to 6th-grade primary school children (394 subjects; 201 boys and 193 girls) walked with pedometers on an outdoor 50-m course, and the measured values were compared with actual steps at 3 speeds: normal, slow, and fast paces. The counts obtained by the spring-levered pedometer were significantly lower than the actual steps in most grades at all walking paces. In the normal- and fast-pace walking, the counts by spring-levered pedometer were significantly lower than the actual steps in all grades excluding the 5th grade. Moreover, the spring-levered pedometer underestimated by 25% or more in all grades at slow pace. The percent error of the counts by the piezo-electric pedometers at normal pace were mostly within ±3%, confirming their high accuracy. Based on these findings, spring-levered pedometers are not appropriate for children, whereas piezo-electric pedometers are useful for investigation of the physical activity of children. J Physiol Anthropol 27(5): 233–239, 2008 http://www.jstage.jst.go.jp/browse/jpa2 [DOI: 10.2114/jpa2.27.233]

Keywords: measurement, physical activity, accelerometer, youth, steps

Introduction

Assessment of physical activity in free-living conditions is important to researchers and practitioners interested in surveillance, screening, program evaluation, and intervention. Self-report methods have been traditionally used to quantify physical activity. However, it has been recognized that such methods may not be appropriate with children due to the limitations include recall bias, floor effects (the lowest score available is too high for some respondents), social desirability, and the inability of children to distinguish between physical activity and non-physical activity behaviors (Ainsworth et al., 1998; Sallis and Sallens, 2000; Trost et al., 2000; Tudor-Locke and Myers, 2001). Additionally, there has been a lack of sensitivity to activities that are low to moderate, such as ambulatory activity or walking (Ainsworth et al., 1993; Bassett et al., 2000).

Physical activity has recently been presented as the number of “steps per day.” For evaluation of physical activity of children, assessment of the total daily volume of physical activity (e.g., min/24h or steps per day) is recommended (Corbin et al., 1994). ‘Steps per day’ is a very familiar physical activity index for not only researchers but also the general public, and appropriate for feedback because it can be evaluated as a continuous variable. Moderate to high correlations of the pedometer method with various objective indices of physical activity have been reported, and its objectivity and usefulness as a scientific method is well recognized (Tudor-Locke et al., 2002b; Tudor-Locke et al., 2004). Furthermore, pedometers are small, light-weight, unobtrusive instruments that are typically worn comfortably at the waist and count movement. Thus, to objectively monitor the physical activity of children, it is better to use a pedometer.

Although there have been many reports on the accuracy of pedometers, most studies were performed on adults aged 18 years or older (Bassett et al., 1996; Crouter et al., 2003; Crouter et al., 2005; Cyarto et al., 2004; Le Masurier and Tudor-Locke, 2003; Le Masurier et al., 2004; Schneider et al., 2003), and only 2 studies on accuracy in children have been reported (Beets et al., 2005; Ramirez-Marrero et al., 2002), in which the actual steps counted using a hand-tally counter and values obtained by pedometers were compared, and a large
Piezo-electric pedometers typically contain a horizontal movement in one plane (uni-axial, typically the vertical plane). (OM) were used. Piezo-electric pedometers can detect pedometer, the Kenz Lifecorder (KZ) and Omron HJ-700IT recorded (Bassett et al., 1996). For the piezo-electric lever arm makes an electrical contact, and one event is ECG-200 (YX) was used. Spring-levered pedometers operate on a piezo-electric cantilevered beam with a weight on the end, which compresses a piezo-electric crystal when subjected to acceleration. In addition, OM has two internal strain gauges intended to let the user place the pedometer either normally on the waist (OMW) or carry it in the pocket (OMP). Previous investigations demonstrated that these pedometer brands have superior accuracy under controlled and free-living conditions compared with other brands (Consumers Union of U.S., 2004; Crouter et al., 2003; Melanson et al., 2004; Schneider et al., 2003; Tudor-Locke and Myers, 2001b; Tudor-Locke et al., 2002a). All the pedometers used in this study were made in Japan.

**METHODS**

Participants

The subjects were 394 children (201 boys and 193 girls aged 7–12 years). For height (to the nearest 0.1 cm) and body weight (to the nearest 0.1 kg) of the subjects, the data of somatometry were obtained in September 2004. The primary school of the subjects has been performing cooperative studies with a university as an experimental and verification school, and participation in such studies are periodically performed by their school were used. The physical characteristics of the subjects are shown in Table 1.

The primary school of the subjects has been performing cooperative studies with a university as an experimental and verification school, and participation in such studies are acknowledged by children and their parents. This study was approved by the Ethical Committee of the Graduate School of Education, Hokkaido University. The study was performed in September and October 2004, and the physical characteristic data were obtained in September 2004.

**Instruments**

For the spring-levered pedometer, the Yamax My-Calory EC-200 (YX) was used. Spring-levered pedometers operate on a horizontal, spring-suspended lever arm that moves up and down with vertical accelerations of the hip. With each step, the lever arm makes an electrical contact, and one event is recorded (Bassett et al., 1996). For the piezo-electric pedometer, the Kenz Lifecorder (KZ) and Omron HJ-700IT (OM) were used. Piezo-electric pedometers can detect movement in one plane (uni-axial, typically the vertical plane). Piezo-electric pedometers typically contain a horizontal

### Table 1  Physical characteristics of the subjects

<table>
<thead>
<tr>
<th>Grade</th>
<th>N</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>66</td>
<td>120.1±0.5</td>
<td>22.7±0.4</td>
</tr>
<tr>
<td>1</td>
<td>38</td>
<td>119.6±0.6</td>
<td>22.8±0.6</td>
</tr>
<tr>
<td>Boys</td>
<td></td>
<td>120.7±0.9</td>
<td>22.6±0.5</td>
</tr>
<tr>
<td>Girls</td>
<td>28</td>
<td>126.1±0.5</td>
<td>25.8±0.6</td>
</tr>
<tr>
<td>Total</td>
<td>68</td>
<td>126.4±0.7</td>
<td>26.3±0.9</td>
</tr>
<tr>
<td>2</td>
<td>31</td>
<td>125.9±0.7</td>
<td>25.7±0.9</td>
</tr>
<tr>
<td>Girls</td>
<td>37</td>
<td>130.6±0.8</td>
<td>28.1±0.6</td>
</tr>
<tr>
<td>Total</td>
<td>75</td>
<td>131.6±1.0</td>
<td>29.1±0.8</td>
</tr>
<tr>
<td>3</td>
<td>40</td>
<td>130.3±1.2</td>
<td>26.9±0.9</td>
</tr>
<tr>
<td>Boys</td>
<td></td>
<td>139.4±0.8</td>
<td>33.6±0.9</td>
</tr>
<tr>
<td>Girls</td>
<td>35</td>
<td>138.8±1.1</td>
<td>35.3±1.5</td>
</tr>
<tr>
<td>Total</td>
<td>63</td>
<td>140.0±1.1</td>
<td>32.1±1.0</td>
</tr>
<tr>
<td>4</td>
<td>30</td>
<td>143.9±0.9</td>
<td>38.1±1.0</td>
</tr>
<tr>
<td>Boys</td>
<td></td>
<td>144.1±1.2</td>
<td>39.1±1.5</td>
</tr>
<tr>
<td>Girls</td>
<td>24</td>
<td>143.5±1.3</td>
<td>36.9±1.4</td>
</tr>
<tr>
<td>Total</td>
<td>54</td>
<td>150.9±0.8</td>
<td>41.0±0.9</td>
</tr>
<tr>
<td>5</td>
<td>32</td>
<td>150.2±1.2</td>
<td>39.4±1.1</td>
</tr>
<tr>
<td>Boys</td>
<td></td>
<td>151.6±1.1</td>
<td>42.4±1.3</td>
</tr>
<tr>
<td>Girls</td>
<td>36</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Mean± standard error

cantilevered beam with a weight on the end, which compresses a piezo-electric crystal when subjected to acceleration. In addition, OM has two internal strain gauges intended to let the user place the pedometer either normally on the waist (OMW) or carry it in the pocket (OMP). Previous investigations demonstrated that these pedometer brands have superior accuracy under controlled and free-living conditions compared with other brands (Consumers Union of U.S., 2004; Crouter et al., 2003; Melanson et al., 2004; Schneider et al., 2003; Tudor-Locke and Myers, 2001b; Tudor-Locke et al., 2002a). All the pedometers used in this study were made in Japan.

**Procedure**

A 50-m distance was measured on an outdoor athletic ground. All participants performed one walking trial of the course with pedometers at three different self-paced speeds: normal, slow, and fast. Specifically, participants were instructed to walk one length of the course, accordingly: 1) walk at a normal pace, neither fast nor slow; 2) walk rather slowly; and 3) walk rather fast but without running and overexerting yourself. The number of pedometer-detected steps was recorded at the end of each trial. Actual steps taken were determined by a researcher using a hand-tally counter. The researchers walked behind the subject to avoid influencing the subject’s pace. Because several studies (Crouter et al., 2003; Schneider et al., 2003) indicate that placement of pedometer (right vs left) has no effect on step count accuracy, we chose left-side placement of the pedometer. Pedometers were attached to a belt or waistband and were placed approximately in line with the middle of the thigh, which was consistent with the manufacturer’s instructions. Although these three pedometers can assess the calorie expenditure and the walking distance, the present investigation examined only the accuracy variation was noted in slow-pace walking, but not in normal- and fast-pace walking. Although the subject age range was wide in these studies (5–11 and 7–12 years, respectively), the number of subjects was small (n=20 and 31, respectively, only 3–5 subjects per age group). In children in the growth period, age greatly affects physical development, and parameters related to walking (e.g., velocity, cadence) markedly vary depending on age (Beck et al., 1981; Noguchi, 1986), suggesting that generalization of the above reports is difficult. The accuracy should be investigated in more homogeneous populations (e.g., each school grade). Moreover, only the accuracy of spring-levered pedometers was described in their reports (Beets et al., 2005; Ramirez-Marrero et al., 2002). In addition to the spring-levered type, piezo-electric pedometers have recently been attracting attention (Westerterp, 1999), and deviation of counts by piezo-electric pedometers from the actual steps has been reported to be smaller than that of spring-levered pedometers in adults (Crouter et al., 2003; Melanson et al., 2004; Schneider et al., 2003). Although piezo-electric pedometers are more accurate, these devices are more expensive, and spring-levered pedometer are often used in large scale surveillance and intervention. Therefore, the purpose of this study was to determine the accuracy of spring-levered pedometer and piezo-electric pedometer step counts in comparison with hand-talled step counts with children during self-paced walking (SPW).
of the number of steps.

Statistical analysis

Statistical analyses were carried out using SPSS version 11.0 (SPSS Ins., Chicago, IL). For all analyses, an alpha 0.05 was used to indicate statistical significance. All values are reported as mean±standard error. Percent error ((pedometer steps−actual steps)/actual steps×100) was computed to determine the over-/underestimation. A positive value indicated overestimation (extra steps detected), and a negative value indicated underestimation of the pedometer (missed steps). Values close to zero indicated more accurate pedometer results. In addition, values in the pedometer steps were compared with actual steps in each trial by Dunnett’s test.

Bland-Altman (Bland and Altman, 1986) plots were constructed to show the dispersion of the individual pedometer error scores around zero. This is a widely accepted technique to show the accuracy of biomedical devices. In this manner, the mean error score can be illustrated, and the 95% prediction interval (i.e., 95% confidence interval for the individual observations) can also be shown. Individual error scores that have a close prediction interval around zero signify a more accurate device.

RESULTS

The steps counted by the pedometers and their errors (%) from the actual steps at each walking pace are shown in Fig. 1. In the normal-pace walking (Fig. 1-A), the count by YX was significantly lower than the actual steps in all grades excluding

![Fig. 1 Errors of pedometer counts from the actual steps at 3 walking paces.](image)

The graphs present the percent errors of the pedometer counts from the actual steps at (A) normal, (B) slow, and (C) fast paces.

- #, ## YX significantly underestimated the number of steps (# p<0.05, ## p<0.01)
- †, †† KZ significantly underestimated the number of steps († p<0.05, †† p<0.01)
- †, †† OMW significantly underestimated the number of steps († p<0.05, †† p<0.01)
- †, ** OMP significantly underestimated the number of steps (* p<0.05, ** p<0.01)
the 5th grade \( (p<0.01) \). The counts by KZ, OMW, or OMP were not significantly different from the actual steps, and the errors of the piezo-electric pedometers were \(-4.2 \sim -0.2\%\) of the actual steps.

In the slow-pace walking (Fig. 1-B), the counts by YX and KZ were significantly lower than the actual steps in all grades \( (p<0.01) \), and particularly, YX underestimated by 25\% or more in all grades. The counts by OMW and OMP were significantly lower than the actual steps in the 1st–4th and 1st–3rd grades, respectively \( (p<0.05 \text{ and } p<0.01, \text{ respectively}) \).

Fig. 2  Errors of pedometer counts from the actual steps at normal pace in height and weight. 
\# YX significantly underestimated the number of steps \( (\# p<0.01) \)

Fig. 3  Bland-Altman plots (normal pace) of the pedometer counts of all subjects. 
The graphs present the Bland-Altman plots of the counts of (A) YX, (B) KZ, (C) OMW, and (D) OMP. 
Solid horizontal line = mean error score. 
Dashed lines = 95\% prediction intervals (i.e., 95\% confidence intervals of the individual observations).
In the fast-pace walking (Fig. 1-C), the counts by YX were significantly lower than the actual steps in all grades excluding the 5th grade ($p<0.05$), as in the normal-pace walking. No significant differences from the actual steps were noted in the piezo-electric pedometer counts in the 5th and older grades.

The steps counted by the pedometers and their errors (%) from the actual steps at normal walking pace in height and weight are shown in Fig. 2. The height is distinguished by less than 119.9 cm ($n=43$), 120 cm~129.9 cm ($n=109$), 130 cm~139.9 cm ($n=106$), 140 cm~149.9 cm ($n=87$), and more than 150 cm ($n=49$). The weight is distinguished by less than 24.9 kg ($n=121$), 25 kg~29.9 kg ($n=80$), 30 kg~34.9 kg ($n=75$), 35 kg~39.9 kg ($n=47$), and more than 40 kg ($n=71$). The counts by YX was significantly lower than the actual steps in all heights and weights ($p<0.01$). In contrast, the counts by the piezo-electric pedometers were not significantly different from the actual steps. In the slow and the fast pace, the accuracy of pedometer according to height and weight are similar to grade distinction (data not shown).

Figure 3 shows the Bland-Altman plots of the pedometers in all subjects. The mean errors (solid lines) from the actual steps of the piezo-electric pedometers were close to 0 (Fig. 3-B, C, D), but the spring-levered pedometer markedly underestimated steps, and the width of the 95% prediction interval (dotted lines) was markedly large. The mean errors of the counts by OMW (Fig. 3-C) and OMP (Fig. 3-D) were similar, but the 95% prediction interval of OMP was larger.

**Discussion**

This study clarified that spring-levered pedometers (YX) are not suitable for the physical activity assessment of children, and the piezo-electric pedometers (KZ, OM) are better (Figs. 1, 2). The accuracy of spring-levered and piezo-electric pedometer according to height and weight are similar to age distinction. Taking account of the surveillance, screening, program evaluation or intervention in children, it is thought that classification by school year is adequate, and we discuss the results according to grade hereinafter. YX significantly underestimated the actual steps in all grades and at all paces excluding the 5th grade at normal and fast pace (Fig. 1). Errors reduced as the pace increased in all grades. Simulation of the normal-pace walking of children may have been insufficient for YX to count steps, and the ground reaction force may have increased as the walking speed increased. Spring-levered pedometers, such as YX, sense the vertical acceleration (shock acceleration) of ground reactions conducted to the lumbar region via joints including the knee upon the landing of the foot, i.e., the frequency of vibration of the lumbar region with walking are counted as steps. The threshold of vibration sensed by spring-levered pedometers are typically set to 0.35~0.50 G ($G=9.8 \text{ m/} \text{s}^2$) (Hatano, 1997; Le Masurier and Tudor-Locke, 2003; Tudor-Locke et al., 2002a). Ohtsuka et al. (1992) reported that the shock acceleration was less than the threshold in adults in a slow-pace walking at about 50 m/min. Kato et al. (1981) found a significant positive correlation between the shock acceleration and walking velocity ($r=0.756, p<0.01$), suggesting that the steps of children may be accurately counted by setting the threshold of pedometer to a low level. However, setting a low threshold for children leads to counting daily non-walking movements and vibrations of vehicles (Hatano, 1997; Le Masurier and Tudor-Locke, 2003; Tudor-Locke et al., 2002a). For example, pedometers counted sitting on a chair in a running bus (0.32 G) and movement from the standing position to sitting on a chair (0.35 G) (Hatano, 1997), suggesting that it may overestimate steps, resulting in inaccurate assessment of children’s physical activity. The accuracy of the Japanese pedometers has been identified in the manufacturing process, according to the Japanese Industrial Standards (JIS). Briefly, in the JIS, the error of step counts must be below ±3%. Although there was no significant difference, the YX error in the 5th grade at normal pace was −5.6%, and this error did not meet the JIS criterion. Therefore, spring-levered pedometers may be inappropriate for counting steps in children.

However, our results of the accuracy of spring-levered pedometers in children were not consistent with that reported by Beets et al. (2005) and Ramirez-Marrero et al. (2002). Errors in spring-levered pedometers were within the acceptable range in both treadmill walking and SPW in the study reported by Beets et al. (2005) and treadmill walking in the study reported by Ramirez-Marrero et al. (2002). In the study by Ramirez-Marrero et al. (2002), the step count of treadmill walking by a spring-levered pedometer (Yamax SW-200) was not significantly different from the actual steps (error: −4.7%, calculated by ourselves) at 4.2 km/h (=70 m/min) or faster, but significantly lower at 3.5 km/h (approximately 58 m/min) ($p<0.05$, error: −12.9%, calculated by ourself). Beets et al. (2005) also reported that the error increased as the treadmill walking speed decreased, but the error of SPW in children was within 1%. In their study, the mean value of SPW was about 77 m/min in 5- to 11-year-old subjects, which was similar to the mean walking speed (about 77.4 m/min, $n=151$) of 6th-grade children (11–12 years of age) (Stansfield et al., 2001). Japanese children are generally shorter than European and American children, and their legs are also shorter. In humans, the free walking speed increases with development (Noguchi, 1986; Tanaka and Okuzumi, 1996), and this may be mainly due to an increase in the ratio of the leg length to the height (Sinclair and Dangerfield, 1978). An increase in the leg length may extend the step length, increasing the walking speed. This remains to be clarified because we did not measure the walking speed, but the speed may have been slower than that in the previous reports (Beets et al., 2005; Ramirez-Marrero et al., 2002), resulting in larger errors of the spring-levered pedometer. In addition, differences in the step length and frequency between walking on a treadmill and level ground (Nishida et al., 1998; Okada et al., 2004; Pearce et al., 1983; Stolze et al., 1997) may also have been a reason for the low accuracy of the spring-levered pedometer. In the Bland-Altman
plots (Fig. 3), the mean value deviated markedly from 0 (Fig. 3-A), and the 95% prediction interval of the counts by the spring-levered pedometer was larger than that of the counts of the other pedometers, showing that spring-levered pedometers are not suitable for the physical activity assessment of children.

OM and KZ are piezo-electric pedometers. No significant differences from the actual steps were noted in the counts of normal-pace walking by KZ, OMW or OMP in any grade, and the errors were $-3.2 \sim -0.7\%$, $-3.2 \sim -1.8\%$, and $-4.2 \sim -0.6\%$, respectively. Since these values mostly met the JIS specification for pedometers (within $\pm 3\%$), assessment of physical activity accurately in children can be expected. However, significantly lower counts than the actual steps were obtained in many items in slow-paced walking. Many studies reported that the pedometer underestimated the actual steps when the walking speed was slow (Crouter et al., 2003; Melanson et al., 2004; Ohtsuka, 1992). Crouter et al. (2003) performed an experiment in adults, and found that the error of KZ was within $\pm 1\%$ at a walking speed of 80–107 m/min, but underestimated the actual steps by 10% or more at 54 m/min. Although discussion is not possible because we did not measure the walking speed, children walk more slowly than adults, and thus, the large error in slow-pace walking may have been due to SPW slower than 54 m/min. According to Melanson et al. (2004), the accuracy of a piezo-electric pedometer (Omron HF-100) was higher than that of spring-levered pedometers (Walk-4-Life LS-2500 and Step Keeper HSB-SKM) at a slow walking speed, suggesting the usefulness of piezo-electric pedometers for slow walkers (e.g., elderly individuals). The Omron HF-100 is no longer available, but the HJ-700IT (HJ-112 in Europe and America) used is its successor model.

The accuracy of OM attached to the waist (OMW) and carried in a pocket (OMP) was also investigated. The error from the actual steps was similar at the 2 sites (Fig. 1), and the 95% prediction interval representing the variation was larger in OMP (Fig. 3-C, D). Since OM is equipped with accelerometers on 2 axes, it can count steps even when the pedometer is not kept vertical to the ground, such as when it is carried in a pocket, but it does not mean that 2 axes simultaneously operate. Only one of the 2 axes senses vertical acceleration. In addition, OM has a random-motion filter function which does not count steps unless walking continues for at least 4 seconds. If the walk lasts only three consecutive seconds, with a pause in between the third and fourth seconds, the pedometer will register zero, indicating a shift to another axis for some reason (e.g., movement of the pedometer in a pocket with walking), so it requires at least 4 seconds of walking to start counting. When OM is carried in the pocket, the pedometer is not immobilized, and the axis sensing vertical accelerations changes with movement of the pedometer. Namely, since this event repeats within 4 seconds, the steps are not counted during this period making a larger error than that of OMW.

In conclusion, spring-levered pedometers (YX) are not suitable for counting steps in children, and it is better to use piezo-electric pedometers (KZ and OM). Although this study was a relatively large-scale experiment, all subjects were Japanese, which may have been a factor reducing the accuracy of YX. It should be considered that racial differences in the walking pattern may have affected the accuracy of the pedometer. The distance for the self-paced walk test in the present study should also be considered. Several studies (Beets et al., 2005; Schneider et al., 2003) had their subjects walk 400m on a track test. In short walking trials, miscounting the first and last steps may also increase error because, unlike a mid-walk step, both the swing phase and weight transfer are shorter and produce less movement of the hip (Shepherd et al., 1999). Although the present study has these limitations, researchers and practitioners need to take this information into consideration when choosing a pedometer for children.

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