

# Pedometer Accuracy for Children: Can We Recommend Them for Our Obese Population?

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## What's Known on This Subject

Obesity has reached epidemic proportions. The decline in physical activity has contributed to the obesity epidemic. One approach to increase physical activity has been the use of pedometers; however, commercially available pedometers lack accuracy.

## What This Study Adds

Commercially available pedometers are inaccurate for children, especially in the overweight or obese group. They are poor tools for monitoring physical activity and require caution in their use. The AS is a good alternative.

## ABSTRACT

**OBJECTIVE.** In this study, we investigated the accuracy of measuring walking steps with commercially available pedometers and an accelerometer-based step-counter in normal and overweight children. Our primary hypothesis was that commercially available pedometers are not an accurate measure of walking steps in normal and overweight children while walking. Our secondary hypothesis was that the accelerometer-based step-counter provides an accurate measure of walking steps in normal and overweight children.

**METHODS.** Thirteen boys ( $11 \pm 1$  years) and 14 girls ( $11 \pm 1$  years) who ranged in BMI from 15 to 27 kg/m<sup>2</sup> (16 normal and 11 overweight or obese) were recruited. Each child wore 4 pedometers at the waist and 1 accelerometer-based step-counter on each ankle. Steps were manually counted and energy expenditure was measured while the child walked on the treadmill at 0.5, 1.0, 1.5, and 2.0 mph, each for 5 minutes. The step-counting devices were also validated while children walked on level ground at a self-selected pace.

**RESULTS.** For the commercially available pedometers at the lowest speed of 0.5 mph, the percentage error approximated 100% for both of the pedometers. At the fastest speed of 2.0 mph, the percentage error approximated 60%. Conversely the accelerometer-based step-counter showed a percentage error of  $24\% \pm 22\%$  (mean  $\pm$  SD) at 0.5 mph; however, as walking speed increased, the error declined to  $5\% \pm 8\%$  at 1.0 mph,  $4\% \pm 5\%$  at 1.5 mph, and  $2\% \pm 2\%$  at 2.0 mph. The relationship between steps counted and walking energy expenditure showed good linear correlation.

**CONCLUSIONS.** Commercially available pedometers are less accurate for measuring walking and require discretion in their use for children. The accuracy of the accelerometer-based step-counter enables it to be used as a tool to assess and potentially promote physical activity in normal and overweight children. *Pediatrics* 2009;123:e127–e131

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### Key Words

pedometers, obesity, energy expenditure, children, walking, physical activity

### Abbreviations

AS—accelerometer-based step-counter  
EE—energy expenditure  
OM—Ommron  
YX200—Yamax Digiwalker  
REE—resting energy expenditure

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**C**HILDHOOD OBESITY HAS reached epidemic proportions globally.<sup>1</sup> In the past 30 years, 17% of the child population aged 2 to 19 years in the United States have become obese.<sup>2</sup> There is supporting evidence that the steady decline in physical activity and our current diet and have a major role in the development of the obesity epidemic.<sup>3,4</sup>

The question about how best to assess and promote active children remains uncertain. One approach has been through using pedometers.<sup>5</sup> These step-counting devices are readily available and inexpensive and can be used to monitor walking or monitoring an exercise treatment.<sup>6</sup> Early studies suggested that pedometers may be inaccurate for step-counting for children.<sup>7</sup> The accuracy of these devices in the normal and obese population has not been studied in detail, so we should be cautious when recommending them.

In this study, we investigated the accuracy of step-counting of commercially available pedometers in normal and overweight children compared with a gold standard of manual step-counting. We also examined an accelerometer-based step-counter (AS). Our primary hypothesis was that commercially available pedometers are inaccurate for measuring walking steps in normal and overweight children during low walking speeds. Our secondary hypothesis was that the AS is accurate for measuring walking step counts in normal and overweight children. To evaluate the relevance of these instruments for energy balance, we also examined the predictive power of the devices with respect to energy expenditure (EE).

**TABLE 1** Characteristics of Normal and Overweight Study Participants and Mean EE During Various Speeds

Characteristic	Group (n = 27)	Normal (n = 16)	Overweight (n = 11)
Age, mean ± SD, y	11.0 ± 1.0	10.9 ± 1.4	10.8 ± 1.2
Height, mean ± SD, cm	145.0 ± 22.0	146.2 ± 11.1	142.8 ± 33.3
Gender, male/female, n	13/14	6/10	7/4
Weight, mean ± SD, kg	47.0 ± 24.0	36.4 ± 7.6	62.9 ± 29.9
BMI, mean ± SD, kg/m <sup>2</sup>	19.0 ± 4.0	16.8 ± 1.7	22.9 ± 2.8
BMI, mean ± SD, percentile	61 ± 32	41 ± 23	92 ± 4
BMI z score, mean ± SD	0.50 ± 1.00	−0.28 ± 0.67	1.50 ± 0.34
Fat mass, mean ± SD, kg	12.5 ± 8.4	7.5 ± 4.2	19.8 ± 7.6
EE, mean ± SD, kcal/h			
REE	60.5 ± 11.3	54.7 ± 10.4	69.0 ± 6.2
0.5 mph	127.8 ± 25.5	117.1 ± 21.6	143.4 ± 23.0
1.0 mph	139.5 ± 28.8	128.2 ± 25.5	156.0 ± 25.9
1.5 mph	155.4 ± 29.9	143.1 ± 26.2	173.4 ± 26.5
2.0 mph	171.6 ± 37.8	151.7 ± 28.5	200.6 ± 30.8

Fat mass by dual-energy radiograph absorptiometry, EE by indirect calorimeter.

## METHODS

### Subjects

Twenty-seven healthy children of varying ages (8–12 years), 13 boys (11 ± 1 years) and 14 girls (11 ± 1 year) who ranged in BMI from 15 to 27 kg/m<sup>2</sup>, were recruited through local advertisement (Table 1). Sixteen children (6 boys and 10 girls) were considered normal according to their BMI (BMI >5th percentile and <85th percentile for age and gender), and 11 (7 boys and 4 girls) were considered overweight or obese (BMI ≥85th percentile for age and gender).

### Pedometers and AS

Two popular pedometers, a piezoelectric (Omron HJ-105 [OM; Kyoto, Japan]) and a spring-levered (Yamax Digi-Walker SW-200 [YX200; Lees Summit, Missouri]) and an ankle-worn dual-axis accelerometer (AS; Stepwatch [OrthoCare Innovations, Seattle, Washington]) were examined to determine the accuracy of walking steps in normal and overweight children. A total of 4 pedometers were placed on the waistband following manufacturers' recommendations. An OM and a YX200 were placed together on the right and on the left side of the body. Pedometers were proximal to but not touching each other. One AS unit was placed on the inside of the left ankle and another on the outside of the right ankle. The AS was programmed with the child's height by using the manufacturers' software. Thus, each child wore 4 pedometers and 2 ankle-worn stepwatches.

### Energy Expenditure

Measurements of EE were performed by using an indirect calorimeter (Columbus Instruments, Columbus, OH). Expired air was collected by using a dilution face mask that covered the entire face. A primary gas standard (0.5% CO<sub>2</sub>, 20.5% O<sub>2</sub>, and balanced N<sub>2</sub>) was used for gas calibrations. Data were collected every 30 seconds and stored on a personal computer. Weekly alcohol burn experiments showed CO<sub>2</sub> and O<sub>2</sub> recoveries of ≥99%.

### Body Composition

Height and weight were measured without shoes and with children wearing light clothing by using a calibrated stadiometer scale (Seca 644 hand-rail scale, Seca 245 measuring rod [Seca, Hanover, MD]). Dual energy radiograph absorptiometry was performed to assess body composition (GE Medical Systems, Lunar Prodigy, Madison, WI).

### Protocol

The child was instructed to fast (water allowed) for at least 6 hours before arriving at the clinical research unit. All participants wore light clothing and comfortable shoes. The child's height and weight were measured. After the child arrived at the laboratory, the study personnel placed the pedometers and AS on the child as described already. The child rested in a dimly lit quiet room for 30 minutes. Resting EE (REE) was then measured for 20 minutes by using indirect calorimetry as described already. During the REE measurement, the child was awake, semirecumbent (10° head bed tilt), lightly clothed, and in thermal comfort (68–74°F). The child was asked not to talk or move during the REE measurement. The child was allowed to watch age-appropriate videos during the experiment. After REE was measured, the child was given a small snack (eg, crackers and juice). After the snack, the indirect calorimetry mask was then replaced and the child then walked on the calibrated treadmill (True 600 [St Louis, MO]) at 0.5, 1.0, 1.5, and 2.0 mph, each for 5 minutes. Steps were manually counted by the same trained investigator and facilitated by an electronic counter (model 07-905-2 [Fisher Scientific, Pittsburgh, PA]). After all speeds were completed, the indirect calorimetry mask was removed and the child was allowed to rest for 5 minutes. The child was then asked to walk for 230 m on level ground at his or her own pace, followed by the investigator while steps were again counted and the walked was timed. Throughout the study, the 4 pedometers were reset at the beginning and read at the end of each walking period. Time-stamped data from the 2 ASs were downloaded at the end of the study. The testing protocol was approved by the Mayo Clinic's Pediatric and Adolescent Medicine Research Committee and the institutional review board. Informed written assent was obtained from the child, and informed written consent was obtained from the parent.

### Statistical Analyses

Height, weight, age, gender, and BMI were calculated for each participant. BMI percentiles were calculated by using the BMI calculator for child and teen from the Centers for Disease Control and Prevention Web site. The measured height to the nearest 0.1 cm and weight to the nearest 0.1 kg, together with the gender, date of birth, and date of measurement, were entered. To address our primary hypothesis that the commercially available pedometers OM and YX200 are not an accurate measure of walking steps in normal and overweight children during low walking speeds, we compared the steps counted

manually with the steps counted by the pedometers at the 4 speeds. Accuracy was described by the fraction of counts with respect to manual counts. The difference between the pedometers on different sides at each speed was also calculated. The same approach was used to address our secondary hypothesis that the AS is an accurate measure of walking steps in normal and overweight children. Bland Altman plots of the steps reported by the device were graphed against the gold standard (manual counts). To address a subhypothesis that steps counted correlated with EE at the different velocities, we used regression analysis for each child to examine the relationship between AS counts, weight, and walking EE at 0.0 (standing), 0.5, 1.0, 1.5, and 2.0 mph. The analysis was conducted by randomly sampling the entire data set without replacement to generate a data set that consisted of 20 elements (5 observations at 4 speeds) with 0.0 mph speeds included. To address the difference between normal and overweight children, we used analysis of variance and posthoc unpaired *t* test. Statistical analyses were conducted with StatView 5.0 (SAS Institute, Cary, NC). Data are expressed as means  $\pm$  SD unless otherwise stated. Statistical significance was defined at  $P < .05$ .

## RESULTS

The protocol was tolerated well by all children. For the entire group (Table 1), the children ( $11 \pm 1$  years of age; 13 boys and 14 girls) were of mean height ( $145 \pm 22$  cm) and mean weight ( $47 \pm 24$  kg); BMI was  $19 \pm 4$  kg/m<sup>2</sup>. Sixteen of the children were normal according to their BMI (mean BMI percentile:  $41 \pm 23$ ; mean BMI *z* score:  $-0.28 \pm 0.67$ ), and 11 children were obese or overweight (mean BMI percentile:  $92 \pm 4$ ; mean BMI *z* score:  $1.50 \pm 0.34$ ). Twenty-six children were white/not of Hispanic origin, and 1 child was Asian.

Reproducibility of all of the devices (pedometers and AS) was assessed by comparing the steps counted by each device on both sides of the body at all speeds. The mean difference  $\pm$  SEM for the OM was  $10\% \pm 3\%$ , for the YX200 was  $9\% \pm 3\%$ , and for the AS was  $3\% \pm 1\%$ . The total number of steps that were manually counted in the study was 64 011 steps.

To address our primary hypothesis that the commercially available pedometers OM and YX200 are not an accurate measure of walking steps in normal and overweight children during low walking speeds, we compared the accuracy of the commercially available pedometers against the gold standard of manual counting. From Fig 1, it is clear that the pedometers were inaccurate. The percentage error for both pedometers decreased with each increase in speed. At the lower speed of 0.5 mph, the error was close to 100% for both pedometers; however, at the fastest speed of 2.0 mph, the error was  $\sim 60\%$ . The errors were 92% from underreporting and close to 8% for overreporting.

Overall, for the normal children, the pedometers showed a lower percentage error compared with the overweight children (OM:  $P < .0001$ ; YX200:  $P = .0002$ ; Fig 2). This was true for all speeds studied. Across all

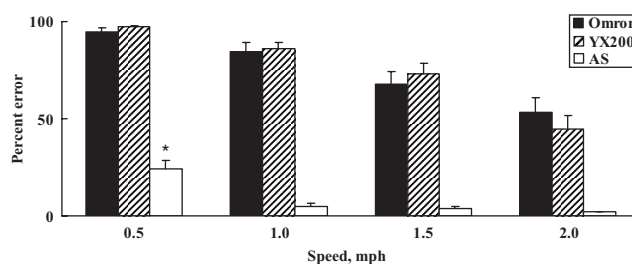


FIGURE 1

Pedometer error at the 4 walking speeds. Steps were manually counted for all participants ( $n = 27$ ) while children walked at 0.5, 1.0, 1.5, and 2.0 mph. The manual counts were compared with the steps observed on the pedometers and AS during a 5-minute period. Error is the mean  $\pm$  SEM at each speed. <sup>a</sup> Significantly greater error compared with all other speeds,  $P < .0001$ .

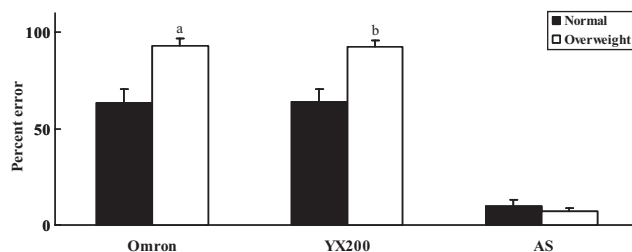


FIGURE 2

Pedometer error by body category. Steps were manually counted for normal ( $n = 16$ ) and overweight ( $n = 11$ ) children. The manual counts were compared with the steps observed on the pedometers and AS during a 5-minute period. Error is the mean  $\pm$  SEM for all speeds, by weight category. <sup>a</sup> Significantly greater error in overweight children compared with normal children,  $P < .0001$ . <sup>b</sup> Significantly greater error in overweight children compared with normal children,  $P < .0002$ .

speeds, there were no significant differences in the errors by gender.

To address our secondary hypothesis that the AS is an accurate measure of walking steps in normal and overweight children, we compared the accuracy of the AS against our gold standard of manual counting (Fig 1). The error was  $24 \pm 22\%$  at 0.5 mph. As the speed increased, the error declined to  $5\% \pm 8\%$  at 1.0 mph,  $4\% \pm 5\%$  at 1.5 mph, and  $2\% \pm 2\%$  at 2.0 mph. The difference (analysis of variance) between 0.5 mph and the other speeds was significantly greater ( $P < .0001$ ). Overall, for the AS, the percentage error between the normal and overweight children was not significantly different (Fig 2). The AS accuracy did not differ by gender.

When children walked at their own pace, the average speed was  $2.5 \pm 0.3$  mph. When this was compared with the 2.0-mph walk on the treadmill (Fig 1), it was seen that the percentage error improved somewhat for the commercially available pedometer. For the OM, the error was  $36\% \pm 8\%$  and for the YX200 was  $21\% \pm 6\%$ . The AS performed well on the treadmill and at the free-living walking ( $5.0\% \pm 0.6\%$ ).

To examine whether walking step rates correlate with walking EE at the various velocities, we used linear regression analysis. When comparing the relationship between steps counted and walking EE, there was good linear correlation for step-counting versus velocity for

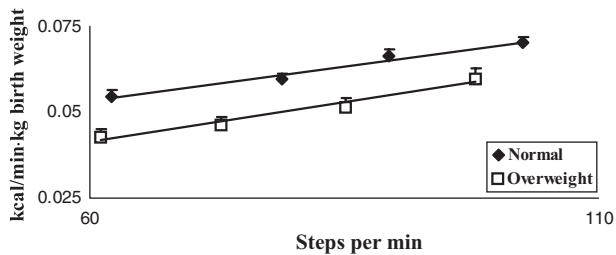


FIGURE 3

Relationship between manual step-counting and EE. Steps were manually counted (steps/min), and EE (kcal/min) was measured by using indirect calorimetry for normal ( $n = 16$ ) and overweight ( $n = 11$ ) children. EE was adjusted for body weight. Data are means  $\pm$  SEM.

walking on the treadmill when corrected for weight and fat-free mass (Fig 3). With progressive increase in velocity, there was progressive increase in EE (Table 1). There was no significant difference in the slope and the intercept of these relationships for the normal and overweight children. The iterated multiple linear regressions with 0.0-mph values included yielded a mean  $r^2$  of 0.86 (max  $r^2 = 0.92$ , min  $r^2 = 0.76$ ) and significant coefficients and regressions in all 50 iterations. A unifying equation for converting steps to EE is  $\ln[\text{EE (kcal/hour)}] = 0.0122 \times \text{weight (kg)} + 0.0073 \times \text{steps/min} + 3.83$ .

## DISCUSSION

One important factor that contributes to the pediatric obesity epidemic is the low levels of physical activity.<sup>3,4</sup> Decreased walking is a major contributing factor.<sup>8</sup> Pedometers may seem like a good option to monitor walking in children; however, many attempts to use them for adults and children have shown that they lack accuracy and precision.<sup>7,9–11</sup> Commercially available pedometers do not correlate well with walking steps, and this may not satisfy expectations, especially when offering them to obese children as tools to assess physical activity. The objective of this study was to examine the accuracy of 2 commercially available pedometers and an AS. We found that the AS was more accurate than the commercially available pedometers that we tested for measuring walking steps of children. Our principal findings are equally true for treadmill and free-living walking.

A likely explanation for the decreased accuracy of the commercially available pedometers is twofold. First, at low speeds, the acceleration and displacement at the hip, especially in children, is insufficient in magnitude to cause the internal mechanism to count a step.<sup>12</sup> Studies have shown that a force of  $\geq 0.35 \times g$  may be needed to register a step.<sup>9</sup> Second, the pedometers have to be worn at the waist in a vertical plane to floor to count a step; however, obese children may wear the pedometer tilted or at an angle as a result of increased waist circumference. This may explain why pedometers perform so poorly, especially in overweight children.

The AS proved to be more accurate. It is accurate for any weight category even at slow walking. This may be because it will respond not only to vertical but also to horizontal acceleration of the ankle.<sup>12</sup> The AS, we sug-

gest, could be an excellent tool for researchers who are interested in monitoring physical activity in high-risk populations, when the impact of a particular exercise treatment needs to be evaluated. Prescribing physical activity to our obese population could be easily facilitated by using such a device, were it less expensive, more readily available, and able to provide direct feedback to the patient.

We recognize that the study has limitations. First, the experiment was conducted in a laboratory and not in the free-living state. Second, our study was relatively small, although it was conducted meticulously, so a larger study would be unlikely to alter the primary findings. Third, we did not include children with extremely high BMI, and we were limited to a particular prepubertal group. Fourth, we examined speeds of  $\leq 2.0$  mph. This was done for safety reasons and because we know from previous studies that children tend to walk 77% of the time at a low level of intensity. They engage in very short bursts of intense physical activity interspersed with varying intervals of activity of low and moderate intensity.<sup>13</sup> Finally, the measurements were done only once on each participant. Overall, we think that the limitations of our study did not invalidate our results.

## CONCLUSIONS

Lack of physical activity is a major contributing factor to the obesity epidemic. The solution to how best to assess and promote physical activity in children remains uncertain. Pedometers are readily available and inexpensive and are often used to monitor physical activity or to prescribe exercise. These data, however, suggest that commercially available pedometers are less accurate for measuring lower levels of activity in normal and overweight children and thus require discretion in their use. Conversely, the accuracy of the AS allows it to be considered as an alternative to assess physical activity of children, especially for researchers.

Practitioners who care for overweight and obese children should be aware of the disadvantages of commercially available pedometers. For the time being, while other devices are being evaluated as intervention tools for obesity prevention and treatment, other, traditional ways for weight management such as lifestyle modifications focused on healthy diet and exercise<sup>14</sup> should be sought for this population.

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