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Accuracy of Electronic Pedometers to Assess Body Fatness in Obese Children and Youth

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The purpose of this study was to assess the influence of waist size on the reliability and validity of pedometers to count steps in children and youth. The participants for this study were 20 children and youth, composed of 14 Hispanic and 6 Caucasian children. Ten children and youth had waist circumferences greater than the 85^{th} percentile (Body Mass Index (BMI)=28.91±3.07), and 10 children and youth had waist circumferences smaller than the 50^{th} percentile (BMI=18.05±1.55). To examine pedometer reliability, each child completed 3 ascent and descent trials up a set of 15 stairs while wearing a Yamax SW-701 pedometer. The main effect of trials was not statistically significant for the stair ascent trials $F (2, 36)=2.575$ or for the descent trials $F (2, 36)=0.235$. The trial by group interaction was also not statistically significant. To examine the influence of waist circumference on the validity of the pedometer in counting walking steps at a self-selected walking pace, the children and youth in the two groups completed a 400-m course. The main effect on the groups was statistically significant, $F (1, 18)=7.489$. The main effect of counting techniques was not statistically significant, $F (1, 18)=2.983$ (hand-counted vs. pedometer counted). Overall, the trial and trial by group interaction comparisons for the 400-m walk were not statistically significant, suggesting that the pedometer was equally valid as a tool for assessing walking steps in high waist circumference (HWC) and low waist circumference (LWC) in children and youth.

Key words : Body fat, step counter, physical activity, pedometer, accuracy

Introduction

The prevalence of childhood obesity has increased over the past 20-25 years [19], and there is some supporting evidence indicating that during this same time period the physical activity level of children has decreased [5]. Consequently, there is considerable interest in strategies for using increased levels of physical activity as part of the treatment for childhood obesity [9,13]. As children grow and mature, they change in height and weight as well as body composition.

Therefore reference standards must take such changes into account, as well as the trend for American children to mature earlier. Because percentile norm tables for the Body Mass Index (BMI) of children have been periodically compiled by age and gender from national data, BMI percentiles, rather than absolute BMI values, have served as a relevant reference standard for obesity and overweight status for research and epidemiological purposes. Specifically, BMI values between the $85\text{-}95^{th}$ percentiles are interpreted as being indicative of a child being overweight while BMI values > 95% are indicative of childhood obesity [12].

One of the hypothesized factors contributing to the rapid rise in childhood obesity has been the change in the physical activity behaviors of children. Simply stated, children no longer play the way that they used to play. Therefore it is assumed that children are no longer as physically active as they used to be [1].

Although obesity associated morbidities occur most frequently in adults, there are important consequences of excess fat weight for overweight children and adolescents. The clearest factor being that increased body fat, particularly in select depots, contributes to increased risk of type 2 diabetes in children and adolescents [4,19].

Pedometers are advantageous for assessing physical activity in pediatric populations for several reasons. Pedometers are objective instruments and require less cognitive recall ability than self-reported logs and questionnaires [3]. Pedometers are also relatively less expensive than other motion sensors (e.g., accelerometers) and are less obtrusive to the participant than heart rate monitors [3,6,13]. Pedometers have demonstrated acceptable levels of validity at measuring physical activity with adult populations and some groups of children [3,22]. Therefore, ped-

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ometers are becoming increasingly popular in physical activity research involving clinical interventions, community-wide physical activity interventions, physical activity surveillance, and international comparisons of physical activity levels.

Although pedometers are currently used in a variety of field and research settings to assess and promote physical activity, some researchers have observed that pedometers are less reliable and valid when used with overweight participants [14,17]. Others have suggested that obesity does not influence pedometer validity and reliability [21]. Therefore, the primary aim of this study was to assess the influence of waist circumference on the reliability and validity of pedometers to count steps by having children with high and low waist circumferences walk up and down stairs and complete a 400 m course. It was hypothesized that pedometers would be less reliable and less valid in counting steps in the high waist circumference (HWC) group than the low waist circumference (LWC) group of children.

Materials and Methods

Subjects

The participants for this study were 20 children and youth (14 Hispanic, 6 Caucasian) aged from 10 to 15 years. To examine the possible influence of waist fatness on pedometer reliability and validity, waist circumference was used to quantify waist fatness. Therefore, the participants for this study were selected on the basis of their waist circumference. The participants for a high waist circumference (HWC) group were recruited first and then each HWC child was matched with a low waist circumference (LWC) child. The matching was completed on the basis of age (within±6 months of child in HWC group), height (within 5% of the child in the HWC group), sex, and race. The matching criteria were selected to nullify differences in waist fat distribution due to developmental, racial, and sex-related factors and to account for potential stride length differences due to height. Those children who had waist circumferences greater than the 85th percentile relative to age and gender standards/norms according to the 1988-1994 CDC-NHANES were recruited for the HWC. The LWC group consisted of children matched by sex, age, height and race to a HWC child and whose waists were less than the 50th percentile, relative to age and sex according to the 1988-1994 CDC-NHANES standards.

Anthropometry

Each participant's height was measured to the nearest 0.1 cm twice using a stadiometer (Perspective Enterprises Inc, USA) and the mean of the two recordings was calculated. Body mass was measured to the nearest 0.1 kg twice using a Halverson Scale (IQ 700 IP Rice Lake Weighing System) and the mean of the two recordings was calculated. Waist, hip, and abdominal circumferences were measured according to the NIH [10], the 1988-1994 CDC-NHANES standards and the Anthropometric Standardization Reference Manual [7] respectively. All circumference measurements were taken at the end of a normal expiration (Retractable tape PM-8761). Waist-hip ratio (WHR) was calculated by dividing the average waist circumference (cm) by the average hip circumference (cm). BMI was determined by dividing weight (in kilograms) by height (in meters) squared. (BMI ($kg \cdot m^{-2}$)=Weight (kg) / Height $(m)^2$. Sagittal abdominal diameter was measured with the participant lying supine on a table [11]. A sliding-beam anthropometer was used to measure the vertical distance between the top of the table and the abdomen at the level of the umbilicus. The measurement was repeated two times and recorded to the nearest 0.1 cm.

Procedures

A flight of 15 stairs was used as a course to evaluate the influence of waist fatness on pedometer precision. The participant was instructed to walk at his or her normal walking pace up the stairs. The step count was recorded. Immediately before the descent of the stairs began, the pedometer was reset to zero and checked for proper fit and function. The participant descended the flight of 15 stairs. The step counts for the pedometer were recorded as previously described. The above procedures were repeated three times for three bouts of stair ascent and three bouts of stairs descent.

The participants then walked on a predetermined 400-m course in a gymnasium to assess the accuracy of the pedometers. They were instructed to walk at his or her normal walking pace.

To ascertain the actual number of steps taken during the 400-meter walk, the investigator or assistant followed the participant and counted each heel strike for the right foot. Following the walk, the number of right-foot strides counted was multiplied by two. The average walking velocity ($m \cdot min^{-1}$) for the 400-m course could be calculated by dividing time recorded for the walk by 400-m. These procedures to quantify walking speed were followed because pedometers are known to be less accurate at relatively slow walking speeds [2,18]. If the study participants self-selected a walking speed that previous research has shown to be a speed that is too slow for accurate pedometer function, the potential confounding variable of walking speed could be identified.

Data analysis

Descriptive statistics were used to present the demographic characteristics of the study participants. Independent *t*-tests were used to compare the anthropometric characteristics for the HWC and the LWC. A mixed factor analysis of variance (ANOVA) with repeated measures was used to examine the influence of waist fatness on pedometer precision during both the stair ascent and descent trials. Intraclass correlation coefficients and standard error of measurement values also were used to provide insight into the possible influence of waist fatness on pedometer precision. A mixed-factor ANOVA with repeated measures also was used to examine pedometer accuracy during the 400-m walk. All statistical tests used an alpha level set at $p<0.05$. Statistical analyses were carried out using the Statistical Package for Social Sciences (SPSS) version 14.0 for Windows (SPSS Inc., Chicago, IL).

Results

Descriptive results

A complete description of demographic characteristics of the study participants can be found in Tables 1 and 2. Twenty children (10 HWC and 10 LWC) participated in the study. The HWC group had a significantly higher mean weight and mean BMI than the LWC group. There were no other significant differences between groups.

The summary of the mean values for the various measures of waist fatness is presented in Table 2. For all of indices of waist fatness, the HWC group values were significantly larger than the LWC group. Waist circumference ($p<0.05$) and hip circumference ($p<0.05$) were significantly different for the HWC group and the LWC group. The HWC group had significantly higher waist circumference and hip circumference than the LWC group. The HWC group had significantly higher waist-to-hip ratio than LWC group.

Table 3 shows the mean step counts for each trial. A mixed group factorial ANOVA showed that the HWC group accumulated more step counts than the LWC group, these differences were not statistically significant.

The main effect for group was not statistically significant, F (1, 18)=1.038. The main effect of trials was not statistically significant F, (2, 36)=2.575. There was no interaction between group and trials, F (2, 36)=0.026.

A mixed-groups factorial ANOVA was also conducted to test for significant differences between the waist groups and among the three different descent trials. The main effect for group was not statistically significant, F (1, 18)=3.295. The main effect for trials was also not statistically significant, F (2, 36)=0.235. There was no interaction between group and trials, F (2, 36)=2.113.

Table 1. Descriptive characteristics of the study participants (Means±SD)

Variable	*HWC (*n*=10)	*LWC (*n*=10)	Total (*n*=20)
Race	Hispanic 7	Hispanic 7	Hispanic 14
	Caucasian 3	Caucasian 3	Caucasian 6
Sex	Boys 7	Boys 7	Boys 14
	Girls 3	Girls 3	Girls 6
Age (yr)	12±2	12±1	12±2
Height (cm)	153.6±8.8	152.5±7.9	153.0±8.1
Weight (kg)	68.2±8.8	42.2±6.1*	55.2±15.2
BMI ($kg \cdot m^{-2}$)	28.91±3.07	18.05±1.55*	23.48±6.05

Values are means±*SD*. BMI=body mass index. * $p<0.05$ for HWC and LWC differences. HWC, high waist circumference; LWC, low waist circumference

Table 2. Measures of waist fatness (Means±SD)

Variables	*HWC (*n*=10)	*LWC (*n*=10)
Waist Circumference (cm)	91.2±9.4	62.6±4.7*
Hip Circumference (cm)	101.0±5.3	81.2±5.2*
Abdominal Circumference (cm)	91.3±9.9	64.7±6.2*
Saggittal Abdominal Diameter (cm)	20.8±2.1	13.5±0.9*
WHR	0.9±0.1	0.8±0.1*

Values are means±*SD*. WHR=waist-to-hip ratio. * $p<0.05$ for HWC and LWC differences. HWC, high waist circumference; LWC, low waist circumference

Table 3. Mean step counts for the stair ascents and descents (Means±SD)

	Ascent Trials		
	1st	2nd	3rd
HWC	15±2.5	14±2.5	15±1.2
LWC	14±1.7	14±3.3	15±2.3
	Descent Trials		
	1st	2nd	3rd
HWC	16±1.5	16±0.9	17±1.0
LWC	16±1.3	15±1.7	15±0.8

The 400-m Walk

The mixed-group factorial ANOVA showed that the main effect for groups was statistically significant, F (1, 18)=7.489. The main effect of counting technique was not statistically significant, F (1, 18)=2.983 (hand-counted vs. pedometer counted). There was not a significant interaction between group and step count technique, F (1, 18)=3.404.

There was a statistically significant difference between the HWC group and LWC group walk for time (Table 4). On the basis of time taken to complete the 400-m course walking speed was calculated (Table 4). Therefore, the significant main effect for groups is a reflection of the slower walking speed performed by the HWC children. Since they covered the 400-m at a slower pace, the HWC children also took significantly more steps than the LWC children (Table 5).

In addition to portraying the interaction between trials and groups, Fig. 1 also illustrates that the pedometer step count tended to be higher than the hand-counted steps.

Table 4. Comparison of time and speed between HWC group and LWC group (Means±SD)

400-meter Walk	HWC (n=10)	LWC (n=10)	*t*-value
Time (sec)	318.9±40.1	275.4±29.5	2.76*
Avg. Velocity (m·min^{-1})	76.3±9.2	88.1±9.6	-2.79*

*$p<0.05$ for HWC and LWC differences. HWC, high waist circumference; LWC, low waist circumference

Table 5. Comparison of 400-m walk between the HWC group and the LWC group (Means±SD)

	400-m Walk	
	Hand Counted Steps	Pedometer Steps
HWC	606.6±34.5	652.0±99.4
LWC	560.0±51.9	558.5±50.7

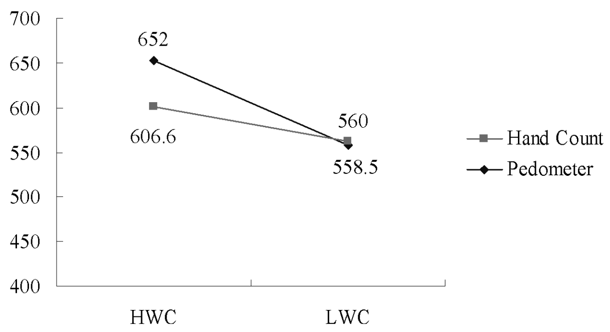

Fig. 1. Interaction of Waist Fat and Pedometer

Disscussion

The advantage of this study is that it was able to assess the influence of waist circumference on the reliability and validity of pedometers to count steps by having children with high and low waist circumferences. The electronic pedometer is a very practical tool for assessing walking and running, important physical activity behaviors for children and adults. Much of the research to determine the reliability and validity of the pedometer as a device for quantifying physical activity has been done with adults and these studies have provided support for the use of the pedometers for physical activity assessment. There are, however, some researchers who have hypothesized that body fatness, particularly fat deposited in the waist area, may detract from the validity and reliability of the pedometer in recording walking steps [15,17,18,20]. A few published studies have investigated the possible influence of obesity, as assessed by BMI, on pedometer reliability, and validity, however, the findings have been conflicting. Furthermore, the use of BMI does not directly test the hypothesis that waist fatness is influencing pedometer function and no studies have specifically focused on the influence of waist fatness in children.

There were no significant differences between the pedometer step counts observed during the ascent or descent trials or between the HWC and LWC groups or for the trial by group comparisons, suggesting that the waist fatness did not influence pedometer reliability. However, the observed power values were low (stair ascent=0.162, stair descent=0.405). Perhaps if there had been more participants, differences in the reliability of the pedometer for HWC and LWC children would have been detected. Adding to the difficulty in concluding that the pedometer is equally reliable for both HWC and LWC children was the observation that the intraclass correlation coefficients for the ascent trials were not very high for either the HWC (α=0.617) or the LWC (α=0.608) group. Lastly, the standard error of measurement (SEM) for the HWC ascent trials was .393 steps, whereas the SEM for the LWC trials was .344 steps. For the descent trials the intraclass correlation coefficients were much more disparate between the groups, with the HWC group exhibiting an α=0.000 and an α=0.851 was observed for the LWC group. Since the intraclass correlation for the LWC group was much higher (α=0.851), it may be that waist circumference causes a change in posture with stair descent or that the waist fatness itself dampens the vertical acceleration force recorded by the pedometer, resulting in undercounting of steps. It is also possible that because of a low number of study participants, individual variability rather than a systematic error due to waist circumference could account for the low intraclass correlation for the descent trials for the HWC group. The relatively large SEM of 0.55 for the HWC descent trials compared to the SEM of 0.135 for the LWC group also suggests a difference in the consistency of the steps counted by the pedometer for the three different descent trials between the groups. This study demonstrated that the electronic pedometer reliably assessed steps taken at ascent and descent trial. However, there were no differences in the mean steps counted for the groups, trials, or group by trials comparisons.

For the 400-m walk, the HWC group self-performed a slower walking pace than the LWC group, which accounts for the significant differences between 76.3 $m \cdot min^{-1}$ for the HWC group and 88.1 $m \cdot min^{-1}$ for the LWC group. These walking speeds were significantly different and explain the significant difference for the group step count comparison on the mixed-factor repeated measures ANOVA. In other words, because the HWC group walked more slowly, with shorter strides, they took more steps to cover the 400-m course. Although the HWC children walked slower than the LWC children, their pace (76.3 $m \cdot min^{-1}$) was within the range of walking speeds previously associated with accurate pedometer step counting [8]. Therefore, walking speed should not have influenced the validity of the pedometer for these children. It has been suggested that the pedometers were not as accurate in step counting at slower speeds. This results from the fact that excess adipose tissue may dampen the vertical acceleration of the waist thereby causing pedometer recording errors at slow walking speeds [2,18]. Although the current study did not use the speeds reported by Swartz et al. [18] the speeds were 80, 94, and 107 $m \cdot min^{-1}$ in individuals with a normal classification of BMI. However, the data presented also supports previous findings of Shepherd et al. [17] who found larger errors with a slower walking pace.

Most pedometer literature indicates that pedometers undercount steps rather than overcounting steps [16,17]. Similarly, for those studies that reported that body fatness influences pedometer reliability and accuracy, researchers observed that the pedometer undercounted steps. For the present study, the pedometer undercounted steps for 1 of the 10 HWC children and overcounted steps for 7 of the 10 HWC children. The influence of waist circumference on the reliability and validity of the pedometer as a tool for counting steps in a sample of children is unclear. However, our results showed no differences in the reliability and validity of the pedometer for the HWC and LWC children.

Additionally, this study established that the electronic pedometer was valid in the assessment of steps taken at self-performed walking pace a 400-m course. There was not a significant difference between the pedometer counted and the hand counted steps, nor was there a significant interaction effect.

The electronic pedometer may be an objective instrument that is robust enough to assess walking steps in obese children with large waist circumferences. However, the low intraclass correlations coefficients are indicative of poor reliability on the stair ascent and stair descent bouts for HWC group and LWC group. Furthermore, because of the low observed power values (stair ascent=0.162, stair descent=0.405), the possibility that the lack of significant differences between the step counts recorded for the stair ascent and descent trials is a function of low power can not be ruled out.

Similarly, for the 400-m walk, the low observed power values rather than the validity of the pedometer may explain the lack of significance observed for the repeated measure ANOVAs. The over-counting of steps for the HWC group also makes interpretation of the results from this study difficult. Further studies are clearly required to test these preliminary finding using a greater number of subjects and several different age groups, and especially to examine the possible influence of pedometer positioning relative to waist circumference.

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초록 : 비만 어린이와 청소년들의 체지방 평가를 위한 electronic pedometer 의 정확성 분석

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본 연구는 미국 유타주에 거주하는 10-15세 어린이와 청소년들의 허리둘레가 electronic pedometer (전자 보수계)의 타당성과 신뢰성에 미치는 영향을 분석하기 위하여 비만집단 10명(HWC, BMI 28.91±3.07)과 일반집단 10명(LWC, BMI 18.05±1.55)으로 총 20명(14 Hispanic and 6 Caucasian)의 어린이와 청소년들을 대상으로 실시하였다. Electronic pedometer 의 신뢰성을 측정하기 위하여 각 어린이는 Yamax SW-701 electronic pedometer 를 허리에 차고 15계단 오르기와 15계단 내리기를 3 sets 실시한 결과, HWC 집단이 LWC 집단보다 더 많은 보수를 기록했으나 오르기와 내르기 시행의 주 효과는 유의한 차이가 없었고, 또 두 집단간의 상호작용에도 유의한 차이가 없었다. 보수를 측정하여 pedometer의 타당성에 허리둘레가 미치는 영향을 분석하기 위하여 각자의 보행 속도에 따라 400 m를 걷게 한 결과 주 효과는 두 집단 간에 유의한 차이가 있었으나 counting technique (hand-counted vs. pedometer counted)의 주 효과는 유의한 차이가 없었으며, 또 400 m 걷기의 시기와 group별 시기의 상호작용도 유의한 차이가 없었다. 이러한 결과는 pedometer가 walking steps 측정에 HWC 집단과 LWC 집단에 동일하게 타당도가 있음을 나타내고 있다. 추후의 연구에서는 어린이들의 walking speed, pedometer tilt angle, leg length, 및 stride length 등을 고려한 연구가 필요하다고 사료된다.