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Pedometer-Determined Physical Activity, BMI, and Waist Girth in 7- to 16-Year-Old Children and Adolescents

Beth Hands and Helen Parker

Background: Different approaches to measuring physical activity and fatness in youth have resulted in studies reporting relationships ranging from very strong to nonexistent. ***Methods:*** The sample comprised 787 boys and 752 girls between the ages of 7 and 16 years. Pedometer-determined physical activity, height, weight, and waist girth measures were taken. ***Results:*** Significant differences were found in activity level between body mass index–determined weight categories for the girls ($F_{1,742}$ = 9.07, P = .003) but not for the boys ($F_{1,777}$ = 3.59, P = .06) and between truncal adiposity groupings for the boys ($F_{1,777}$ = 4.69, P = .03) and the girls ($F_{1,742}$ = 13.56, P = .000). ***Conclusions:*** The relationship between physical activity and body fatness differs according to the measure used and between boys and girls. Factors contributing to body fatness such as eating behaviors or sedentary activities might be more important among boys than girls.

Keywords: overweight, obesity, physical activity, body mass index

Studies over the last 20 years have shown an increasing trend in the prevalence of children and adolescents who are overweight and obese in Australia.[1] In 2003, Australian children were on average 5.1 kg heavier than in 1985, with 21.7% of boys and 27.8% of girls classified as overweight or obese.[2] Obese children have a greater risk of developing cardiovascular disease, insulin resistance and type 2 diabetes, dislipidemia, atherosclerosis, and other adverse health conditions.[3,4] Because overweight or obese children are more likely to be overweight when they become adults,[5] many studies investigating this worrying trend have been undertaken. However, surprisingly little is known, yet much is assumed, about factors contributing to obesity. Physical inactivity or reduced energy expenditure without a concomitant reduction in energy or fat intake is often considered to increase the likelihood of obesity.[6]

It is widely assumed that there is an inverse relationship between physical activity level and overweight; however, despite numerous studies and several review papers,[7,8] this assumption remains contentious for a number of reasons.[9] Among children and adolescents, this might be a result of the wide age range of participants

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in a study, differences between sexes, or the chosen method for measuring physical activity or determining body fatness.

Age

It is likely that the relationship between activity level and weight becomes stronger with age. Among children under 7 years old, most researchers have not found a significant relationship,[9-13] although some have.[14] DuRant et al[13] reported that 5- and 6-year-old children who watched more television were overall less active; this, however, did not result in increased adiposity. Among Chilean preschoolers, both obese and nonobese groups spent similar amounts of time watching television; sleeping; and engaging in sedentary, moderate, and intense activities.[12] On the other hand, the Framingham Children's Study found that preschool inactive children gained more subcutaneous body fat over 12 months than active children,[15] although leaner inactive children were less likely to accumulate body fat.

Among older children, studies more consistently report significant relationships between physical activity measures and overweight.[6,7,16] Rowlands, Eston, and Ingledew[17] found significant negative correlations between physical activity (measured by accelerometer and pedometer) and fatness (measured by body mass index [BMI]) for thirty four 8- to 10-year-old children but not for boys or girls alone. Gillis and colleagues[18] found that obese children between the ages of 4 and 16 years spent less time engaged in moderate and vigorous activity than acceptable-weight children. Other studies, however, have failed to identify a relationship. For example, Marti and Vartianen[19] found no relationship between physical activity and obesity measures among 1142 fifteen-year-olds.

Gender

The relationship between activity and weight differs for boys and girls. Some studies have reported a significant difference in overall daily physical activity between acceptable and overweight girls but not boys,[20] and others have found the reverse relationship in children age 5 years,[21] 6 to 9 years,[22] and adolescents.[23] These differences might relate to lower activity levels in girls.[24] Boreham et al,[23] however, found that activity level was more likely to affect obesity in girls than boys age 12 to 15 years. Other possible determinants of obesity might be more influential than physical activity with girls. For example, Dowda et al[25] found that 4 hours or more of television watching was related to overweight in 14- to 16-year-old girls but not boys. Overweight adolescent girls perceived more barriers, had less peer support, had fewer activity choices, had less athletic coordination, and enjoyed physical activity less than acceptable-weight girls.[20] This was not the case for same-aged boys.

Physical Activity Measure

Sallis and colleagues[26] found an inverse correlation between BMI and vigorous physical activity among younger boys (but not girls) when measured by accelerometer but not when measured by parent-reported physical activity. Such results suggest that the variety of methods and protocols used to measure physical activity might cloud the picture because comparability is difficult.[17,27] In a meta-analysis

of studies investigating the relationship between physical activity and body fat in children, Rowlands et al[27] found a small-to-moderate relationship that varied depending on the physical activity measure, but no effect was evident for gender or age group. They concluded that direct observation or motion counters such as accelerometers or pedometers were preferred methods of measuring physical activity and that duration of measurement was important. The longer the motion counters were worn, the stronger the relationship between activity level and weight. More indirect measures of physical activity such as self-report questionnaires or diaries might result in biased associations with weight.

In recent years, pedometers have been increasingly used to measure daily physical activity.[28,29] Step counts are highly correlated with physical activity[30] and have been validated against accelerometers (r = .99)[30] and (r = .90),[29] heart-rate monitors (r = .78),[31] and direct observation (r = .96)[30] for children age 7 years and older. Most studies that have used pedometers to investigate the relationship between weight and physical activity have not reported a significant relationship.[17,28,32,33]

Body-Fat Measure

There are many ways to measure and report on body fatness. As noted above, many studies using BMI as the measure of body fatness found no significant correlations with physical activity measured by pedometer. BMI, the most commonly used measure, is a weight-based index that cannot account for variations in the distribution of body fat, body somatotype, or differences in fat-free mass (bone, muscle) and fat.[34] More-valid measures of fatness might be more closely related to physical activity levels. Rowlands and colleagues[17] reported a significant negative correlation between pedometer step counts and skinfold measures for 8- to 10-year-old children (r = –.42, P = .025) but not for girls (r = –.49) or boys (r = –.22) alone. Recently, Duncan, Schofield, and Duncan reported a stronger association between physical activity measured by pedometers and percentage body fatness than BMI.[35] Klein-Platat and colleagues[36] found that structured physical activity was negatively associated with BMI in 12-year-old girls but not boys, and it was not associated with waist circumference for either sex. Waist girth has been validated as a simple and sensitive measure of truncal adiposity in children and adolescents.[32] Central body fat carries an increased risk of metabolic complications; therefore, this latter measure might be more valuable in identifying overweight children.[37]

Given the inconsistent results reported across age, gender, physical activity, and body fatness measures, the purpose of this article is to clarify the relationship between physical activity measured by pedometer and 2 fatness measures, BMI and waist circumference, among children and adolescents between 7 and 16 years of age.

Method

Participants

Overall, 2275 students (1133 boys and 1142 girls) attending 17 secondary schools and 19 primary schools throughout the state of Western Australia participated in a survey of physical activity (WA Child and Adolescent Physical Activity and

Nutrition Survey 2003). A 2-stage, stratified sample design was used to obtain proportional representation of the state's population. The Australian Centre for Education Research selected the sample through systematic random sampling from the total West Australian school population, inclusive of government and nongovernment schools. The sampling frame was divided into primary metropolitan and nonmetropolitan schools and secondary metropolitan and nonmetropolitan schools. The requirement of 30 students from each year group automatically excluded remote schools. Consent to participate was received from all parents and participants. Although all students were provided with a pedometer and diary, not all complied with the protocol. The results reported are for the 67.6% of the students who recorded step counts for at least 4 days,[38] and for whom height, weight, and waist-girth measures were taken. This subsample comprised 1539 participants (boys = 787, girls = 752) and is described in Tables 1 and 2. To examine whether this smaller sample was significantly different from the larger sample, which would bias the results, a logistic regression was conducted using gender and waist girth as independent variables for the 2 groups. There were no significant differences for either measure.

Table 1 Characteristics of the Sample (Mean ± SD)

	Boys (N = 787)	Girls (N = 752)
Age (y)	11.4 ± 2.6	11.36 ± 2.6
Height (cm)	151.3 ± 16.6[a]	149.6 ± 14.3[a]
Weight (kg)	45.9 ± 16.1	45.4 ± 14.3
Body mass index (kg/m^2)	19.4 ± 3.5	19.8 ± 3.6
Waist girth (cm)	67.0 ± 9.6[a]	65.9 ± 9.1[a]
Mean daily step count	13,194.3 ± 4130.8[a]	11,102.7 ± 3653.6[a]

[a] $P < .001$.

Table 2 Pedometer-Determined Physical Activity for Boys and Girls (Mean Daily Step Counts)

	Boys		Girls	
	N	Mean ± SD	N	Mean ± SD
Total[a]	787	13,194 ± 7131	752	11,103 ± 3654
Age (y)				
7–8[a]	158	11,544 ± 3737	150	10,031 ± 3172
9–10[a]	191	12,502 ± 3932	197	10,942 ± 3318
11–12[a]	175	13,529 ± 4020	159	11,282 ± 3145
13–14[a]	132	14,609 ± 3791	113	12,198 ± 3983
15–16[a]	131	14,320 ± 4486	133	11,404 ± 4520
Body mass index (kg · m^{-2})				
acceptable[a]	504	13,563 ± 4004	523	11,153 ± 3769
overweight/obese[a]	164	12,920 ± 4285	205	10,217 ± 3264
Waist girth				
normal fat[a]	642	13,331 ± 4145	618	11,314 ± 3622
high trunk fat[a]	145	12,587 ± 4027	134	10,129 ± 3656

[a] $P < .001$.

Data Collection

The data were collected during spring and early summer months, between late August and December.

Measures

Pedometers. A Yamax Digi-Walker SW-700 pedometer was used to count daily steps over 8 days and was worn on the right hip above the right foot. Except for the first day, the step count was recorded daily and the pedometer reset and resealed with a small adhesive sticker.[39]

Pedometer Diaries. The participants recorded their daily step counts, physical activities undertaken during each school day and weekend, and mode of transport to and from school in a simple diary. Students between 9 and 16 years of age also recorded the time spent in each activity to the nearest 15 minutes. The information was used to explain unusual step counts or to apply an estimation algorithm for step counts of activities during which it was not possible to wear a pedometer. Examples included swimming, surfing, and beach activities or sports involving body contact such as rugby.

Anthropometric Measures. Height was measured using a portable stadiometer. Two measurements to the nearest 0.1 cm in bare feet were taken. Actual height value was recorded as the average of the 2 measurements taken. Weight was measured using a portable precision digital scale and recorded to the nearest 0.1 kg. Weight values were adjusted after preliminary data entry for the wearing of heavy clothing according to a clothing code. Waist girth was taken using a steel measurement tape midway between the 10th rib and iliac crest.[40] Two measurements were recorded to the nearest 0.1 cm. The value was the average of the 2 measurements.

Data Analysis

The data for the pedometer counts were examined, and outliers of less than 1000 and more than 40,000 steps were removed. The validity of other high values was examined against the pedometer diary information. Step-count estimates were made for activities reported in the pedometer diaries during which the wearing of the pedometer was not possible or inadvisable based on the following rules. All conversions were based on reported activity duration (minutes) $\times$ 120 steps.[41] For surfing, swimming, or beach activities, a maximum of 3 hours (or 21,600 steps) was allowed. Sedentary activities such as reading or watching television were not included. Consistent with current adult physical activity guidelines for accumulating activity, only activity bouts of 10 minutes or more were included. The data for participants with less than 4 days of step counts were deleted.

The BMI for each student was calculated based on height/weight^2, and participants were classified as acceptable weight, overweight, or obese using the internationally accepted cut points according to age and sex for children and adolescents.[42] Participants were classified for high trunk-fat mass based on their waist-girth measures using the 80th percentile cut-offs calculated for same age and sex New Zealand children.[43]

Associations between all primary variables were examined using Pearson product-moment correlations. For these calculations, BMI as a continuous variable rather than weight category was used. Differences in step counts between boys and girls were calculated using a *t* test. The data were then analyzed for boys and girls separately using ANOVA. The null hypothesis was assumed and probability values of $P \leq .05$ were used to determine significance, unless otherwise noted.

Statement of Ethics

We certify that all applicable institutional and government regulations concerning the ethical use of human volunteers were followed during this research. Approval was granted by the Ethics Committee of the University of Notre Dame Australia.

Results

The descriptive statistics for the sample by sex are reported in Table 1. There were significant differences between boys and girls for height, waist girth, and mean daily step counts. The mean daily step counts for boys and girls by age group and body-fatness measure are reported in Tables 2, 3, and 4. Based on the international BMI cut-off points, 22.5% of the boys and 27.5% of girls were classified as overweight or obese. When grouped according to waist circumference standards,[43] however, only 18.4% of boys and 17.8% of girls were considered to have high truncal adiposity. In Table 5, the percentage of agreement between the measures is presented. Overall, 90.1% of the students were classified as either overweight or acceptable weight for both measures. However, 8.4% of students were classified as overweight based on BMI only, and 1.6% were overweight based on waist girth only.

Independent-sample *t* tests explored differences between male and female mean daily step counts according to age, waist-girth category, and BMI category. There was a significant difference in scores between boys and girls for all measures; subsequently, all further analyses were undertaken separately for each sex. The relationships between mean daily step counts measured by pedometer, BMI, and waist girth for boys and girls were investigated using Pearson product-moment correlation coefficients (Table 6). There was a significant correlation between waist girth and BMI for boy and girls. There was, however, no relationship between BMI and mean daily step count for either boys or girls and only a small but significant relationship between waist girth and physical activity for boys.

An analysis of variance investigated the effect of age and fatness classification based on BMI on activity level. There were statistical differences in step counts between ages for boys ($F_{4,777} = 11.84$, $P = .000$) and girls ($F_{4,742} = 5.14$, $P = .000$). The differences in step counts between weight groupings were approaching significance for boys ($F_{1,777} = 3.59$, $P = .06$) and were significant for girls ($F_{1,742} = 9.07$, $P = .003$). The interactions between age and weight categories were not significant for boys or girls. Participants were also dichotomized as normal and high trunk mass according to the waist circumference cut points proposed by Taylor et al.[43] Once again, there were statistical differences in step counts between ages for boys ($F_{4,777} = 7.84$, $P = .000$) and girls ($F_{4,742} = 6.13$, $P = .000$). There were also significant differences in step counts between truncal adiposity groupings for boys ($F_{1,777} = 4.69$, $P = .03$) and girls ($F_{1,742} = 13.56$, $P = .000$). These differences were in the predicted

Table 3 Mean Daily Step Counts by Age and Weight Category Based on BMI for Boys and Girls

	Boys				Girls			
Age (y)	n	Acceptable	n	Overweight/Obese	n	Acceptable	n	Overweight/Obese
7–8	122	11,712	36	10,976	111	10,301	39	9261
9–10	141	12,899	50	11,383[a]	139	11,245	58	10,218[a]
11–12	144	13,428	31	13,999	113	11,597	46	10,508[a]
13–14	105	14,802	27	13,860	85	12,423	28	11,517
15–16	98	14,487	33	13,827	97	11,529	36	11,066
Total	610	13,369	177	12,592	545	11,360	207	10,425

Abbreviation: BMI, body mass index.

[a] $P < .05$.

Table 4 Mean Daily Step Counts by Age and Body Fatness Based on Waist Girth for Boys and Girls

	Boys				Girls			
Age (y)	n	Normal trunk mass	n	High trunk mass	n	Normal trunk mass	n	High trunk mass
7–8	133	11,621	25	11,130	131	10,315	19	8075[a]
9–10	149	12,707	42	11,775	159	11,210	38	9823[a]
11–12	146	13,407	29	14,141	130	11,645	29	9655[a]
13–14	108	15,006	24	12,824	90	12,338	23	11,651
15–16	106	14,543	25	13,376[a]	108	11,426	25	11,306
Total	642	13,331	145	12,587	618	11,314	134	10,129

[a] $P < .05$.

Table 5 Percentage of Agreement Between Weight Categories for BMI and Waist-Girth Measures

	Waist girth	
BMI	**Normal, N (%)**	**High trunk mass, N (%)**
Acceptable	1131 (73.5)	24 (1.6)
Overweight/Obese	129 (8.4)	255 (16.6)

Abbreviation: BMI, body mass index.

Table 6 Correlations Between Pedometer-Determined Physical Activity, Body Mass Index, and Waist Girth

	Body mass index	Waist girth
Boys		
mean daily step counts	.05	.10[a]
body mass index		.92[b]
Girls		
mean daily step counts	–.04	–.02
body mass index		.92[b]

[a] $P < .05$.
[b] $P < .01$.

direction—those with greater waist circumferences recorded fewer steps per day than the normal group. The interactions between age and weight categories were not significant for either boys or girls. Independent *t* tests (Tables 3 and 4) indicated less difference in mean daily step counts between each fatness category with increasing age. This is most evident for the waist-girth measures for girls.

Discussion

This study examined the relationship between physical activity and 2 measures of body fatness. The results did not provide strong evidence of a relationship; sex, however, appeared to be an important factor. Physical activity outcomes were consistent with previous findings in that the boys in the sample took more steps per day.[35] The mean daily steps per day of 13,194 for boys and 11,103 for girls are similar to another Australian study involving 6- to 12-year-olds that reported a range of 13,864 to 15,023 steps for boys and 11,221 to 12,322 for girls on weekdays.[32] Mean daily step counts for children vary around the world, generally ranging between 12,000 and 18,000.[17,32,35,39,44] It is unclear to what extent these differences can be attributed to variations in measurement protocol or actual activity level. Further research is needed to establish whether there are cultural differences in pedometer-based activity levels.

The mean value of BMI was similar for boys and girls, at 19.4 and 19.8, respectively. The high percentage of overweight/obese participants identified using BMI (22.5% of boys, 27.5% of girls), however, is surprising, particularly as one might

expect some reduced incidence given that the students could refuse to have height, weight, and waist-girth measures taken. These results, however, are similar to those being reported elsewhere.[45] Fewer participants were classified as high in body fatness based on waist girth, but the percentage of 11- to 16-year-olds with high truncal fat (21.7% of boys, 23.5% of girls) was less than McCarthy et al[37] reported among British youth (28% of boys, 38% of girls) of the same age in 1997.

As shown in Tables 3 and 4, overall, the steps per day for participants categorized as overweight and obese (boys = 12,592, girls = 10,425) or with high trunk mass (boys = 12,587, girls = 10,129) were fewer than the acceptable-weight groups. Tudor Locke et al[28] estimated that for children between 6 and 12 years of age, girls who took less than 12,000 steps per day and boys who took less than 15,000 steps per day were more likely to be overweight or obese. Based on the overall mean daily steps for boys and girls, this current study supports these estimates.

The age of participants ranged between 7 and 15 years. When grouped into 2-year age bands, it was possible to identify trends in the measures. The difference in physical activity level between the participants grouped according to body fatness was greater among the younger children, particularly for girls (Tables 3 and 4). This finding is the reverse of trends found in other studies in which the relationship strengthened with age.[7] This suggests that the measure used to categorize fatness affects the strength of the relationship. It is also valuable to consider the directional nature of the relationship between physical activity and fatness. If there is a relationship, does low physical activity precede body fat or does high body fat precede inactivity? Studies of young children have demonstrated a link between low activity at 3 and 4 years of age and overweight at 8 years,[46] yet Li et al[47] reported lower activity levels at 12 months of age if overweight at 6 and 9 months of age. Further studies are required.

When categorized by weight, based on BMI, analyses of variance found significant differences in physical activity between weight categories for girls but not boys. Mota and colleagues used BMI to categorize weight and accelerometer data over 3 consecutive days to determine physical activity.[49] They also found significant differences in moderate and vigorous activity between acceptable-weight and overweight/obese girls but not boys. When categorized according to waist circumference, the results were more supportive of a consistent relationship between activity and body fatness. On average, boys and girls with high trunk mass reported significantly fewer steps per day than those with normal trunk mass. Although the overweight groupings based on waist girth included fewer children overall (279 compared with 384), it might be a more valid proxy measure of fatness that also has more health consequences than overall body mass, as in the BMI measure. These results highlight the discrepant findings when using different measures of fatness and might indicate that the measures identify different groupings when used with boys than with girls.

There are several possible explanations for the gender differences. Overweight and obesity might be linked to physical activity participation in younger girls, but other determinants such as eating behaviors or sedentary activities might be more influential for boys. Although it is well established that boys are more active than girls from a very early age, girls become even less active once reaching adolescence.[48] The variety of physical activity measures used in studies exploring this topic should also be considered. Rowlands, Ingledew, and Eston[27] reported stronger

relationships between body fat and physical activity level when observation or activity monitors were used rather than questionnaires. Self-report measures are more likely to include (and be affected by) behavioral aspects of physical activity, whereas objective measures relate more closely to energy expenditure. It is difficult to determine which aspects of physical activity are most important in weight regulation because our understanding of the etiology of obesity is limited. A reduction in physical activity and a related increase in sedentary behaviors, such as watching television, are commonly cited as key contributors to increasing levels of overweight and obesity.[28] Intervention studies reversing this pattern, that is, increasing physical activity and reducing television watching, have successfully reduced BMI, particularly among overweight children.[50] A recent meta-analysis of 52 studies examining media use and body fatness, however, found the relationship to be nonexistent among 0- to 6-year-olds and small among 7- to 18-year-olds.[9]

In conclusion, overweight and obesity is not the result of reduced physical activity alone but is most probably the result of a combination of factors. The effects of lifestyle, environmental factors, maturation, heredity, and diet are important. The relative importance of each might change with age and gender. This probably accounts for the failure of many exercise programs to alone reduce obesity in the long term, although some encouraging results have been reported, particularly related to reducing inactivity.[51,52] Enhanced physical activity should be included in multidisciplinary approaches to obesity reduction and prevention with independent considerations made for boys and girls. It is important, however, not to lose sight of the many other reasons for people to be physically active such as fun, social opportunity, and personal challenge. Finally, the use of BMI as a measure of adiposity should be questioned.

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