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Evaluation of youth pedometer-determined physical activity guidelines using receiver operator characteristic curves

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Abstract

Objective. Evidence-based pedometer guidelines have not been sufficiently validated in youth. The purpose of this paper was to evaluate the utility of current pedometer-determined physical activity guidelines for youth.

Methods. Participants ($n=812$, mean age 9.7 years) were from two Midwestern communities during Fall 2005. Participants completed 7 days of pedometer monitoring using a Digiwalker 200-SW. ROC analyses were utilized to assess the utility of the cutpoints in reference to weight status. The percentage of subjects meeting physical activity recommendations (steps/day) was determined using two published recommendations.

Results. The mean (SD) steps/day for boys, girls, and sexes combined were 12,709 (3,384), 10,834 (2562), and 11,665 (3028), respectively. Depending on the recommendation, approximately 55–75% of children did not meet the recommended number of steps/day. Sensitivity was high and specificity was low for both current guidelines evaluated. The ROC analysis indicated that lowering the steps/day cutpoint for boys and girls may increase accuracy.

Conclusions. This study demonstrates that a large percentage of children from two Midwestern communities do not meet current pedometer-based physical activity recommendations. Because the percentage of children categorized as active or inactive depends on the criteria that are employed, it is recommended that researchers select cutpoints based on the preferred context of application.
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Introduction

The pedometer has become a popular physical activity assessment tool since it provides an inexpensive way to objectively measure the volume of physical activity (Tudor-Locke and Bassett, 2004; Tudor-Locke et al., 2004b; Tudor-Locke et al., 2002). They are particularly well suited for use in children because they are easy to use, and produce valid (Eston et al., 1998), easily interpretable data. Pedometers have been endorsed by the American Academy of Pediatrics for monitoring physical activity (Council on Sports Medicine and Fitness and Council on School Health, 2006) and form the basis for promotional programs by leading school physical education programs (e.g. *FITNESSGRAM* and the Presidential Active Lifestyle Award [President's Council on Physical Fitness and Sport, 2001]).

Despite their widespread use, there is currently no consensus on pedometer (steps/day) recommendations for children. Initial pedometer recommendations for youth (13,000 steps/day for boys and 11,000 steps/day for girls) were established based on a normative approach — mean values of U.S. children (Vincent and Pangrazi, 2002). A subsequent study using a sample of children from the U.S., Sweden and Australia, employed the contrasting groups methodology to establish standards referenced to overweight status (Tudor-Locke et al., 2004a). This study recommended daily step counts of 15,000 for boys and 12,000 for girls. While this approach can be criterion-based, the guidelines utilized pooled data from multiple countries. This

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approach assumes a consistent relationship between the BMI and pedometer-based activity between countries and similar influence from potential confounders (e.g. socio-economic status, intensity of physical activity, diet, etc…) so further evaluation is needed. Another limitation of current guidelines is that neither the norm-referenced or criterion-referenced cutpoints included weekend pedometer data, which has been shown to be significantly different from weekday pedometer activity (Duncan et al., 2006).

Receiver-operating characteristic analysis, or ROC, is another tool that can be used to determine cutpoints. ROC has been utilized in medical decision-making since the 1960′s (Zweig and Campbell, 1993) and is often used to analyze the global and local performance of diagnostic tests by describing the clinical utility and accuracy of those tests to classify subjects into clinically relevant sub-groups. Besides evaluating diagnostic tests, this technique lends to creating new clinical cutpoints and evaluating existing cutpoints. Previous researchers (Jago et al., 2007; Welk, 2005) have proposed ROC approaches for determining appropriate activity monitor cutpoints but this approach has not been conducted with pedometers. An advantage is that ROC analysis is that it facilitates comparisons of the relative sensitivity (Se) and the specificity (Sp) of a cutpoint or recommendation. As applied to pedometer cutpoints (using overweight as the outcome), Se is the probability that an overweight/obese child does not meet the pedometer cutpoint while Sp is the probability that a normal weight child does meet the pedometer cutpoint. Recommendations for pedometer-determined physical activity should be based on a cutpoint that minimizes misclassification error and maximizes Se and Sp.

Since there is no universal pedometer guideline in children, the purpose of this research was to create ROC-derived cutpoints (i.e., recommendations) and evaluate these concurrently with previously available pedometer guidelines. A secondary aim was to report the prevalence of pedometer-determined physical activity in US children.

Methods

The subjects ($n=1370$) were from two Midwestern communities (Lakeville, MN, USA and Cedar Rapids, IA, USA) and all data were collected during Fall 2005. The subjects in Lakeville, MN were from four elementary schools and those in Cedar Rapids were from six elementary schools (age range=6–12 years, grades 3–6). The participants were primarily White (92.5%). Written assent from each subject and consent from the primary caregiver was obtained prior to participation. The study protocol was approved by the University of Minnesota Human Subjects Review Board and is in accordance with the Declaration of Helsinki.

Anthropometry

Stature and body mass were measured by school nurses according to standard procedures (Malina, 1995). Stature was measured using a portable stadiometer (Seca Road Rod). Body mass was measured using a strain gauge scale (Lifesource MD). The body mass index (BMI, kg/m^2) was calculated from stature and body mass. Overweight and obesity were determined based on age- and sex-specific reference values developed by the International Obesity Task Force (Cole et al., 2000).

Habitual physical activity

Habitual, free-living physical activity was assessed by a pedometer (Digiwalker SW-200). This pedometer has been found suitable for research purposes (Schneider et al., 2004). Accuracy of the pedometers was assessed by the research team prior to distribution using the shaker test and the 10-step test. The subjects were given instructions on wearing the pedometer during the school day and participants recorded the time the pedometer was worn and the number of steps accumulated each day over a 7-day period. Previous research supports a 4-day monitoring period to determine habitual physical activity (Trost et al., 2000). In addition, it is necessary to account for potential bias between weekend and weekday step counts (Duncan et al., 2006). For these reasons, participants were included in the analysis only if they had at least 4 days (3 weekdays and 1 weekend) when the pedometer was worn for at least 10 h. From the total sample of subjects, 812 children (59%) met the inclusion criteria while having complete anthropometric data. Missing activity data due to noncompliance were random, with no trends by gender, age, or BMI. The percentage of youth achieving the recommended steps/day were computed using both the norm-referenced criterion suggested by Vincent and Pangrazi (2002) [VP cutpoint] and the criterion-referenced cutpoint recommended by Tudor-Locke et al. (2004a) [TL cutpoint].

Statistical analysis

Descriptive statistics were calculated by sex, location, and for the total sample. ROC analysis was utilized to identify and evaluate pedometer steps/day cutoff values in reference to childhood weight status based on the BMI. ROC analysis involves the plotting of a curve representing the Se (true positive rate) and 1 — Sp (false-positive rate) across a wide range of pedometer steps/day values. The area under this curve can be used as a measure of the global accuracy of a cutoff value (Greiner et al., 2000). In this analysis, AUC can be considered equivalent to the probability that a randomly drawn individual from the overweight/obese reference sample takes less steps/day than a child randomly drawn from the normal weight sample. Values for AUC range from 0.5 (noninformative) to 1.0 (perfect cutpoint).

Using pedometer steps/day as the threshold value and weight status (normal weight, overweight, obese) as the outcome, ROC analysis was completed using 3 different groupings of weight status. The first grouping used ROC to identify

Table 1
Descriptive characteristics of children in the ROC analysis; Lakeville, MN and Cedar Rapids, IA in 2005

Variable[a]	Lakeville, MN			Cedar Rapid, IA			Sites combined		
	Boys ($n=201$)	Girls ($n=249$)	Total ($n=450$)	Boys ($n=157$)	Girls ($n=205$)	Total ($n=362$)	Boys ($n=358$)	Girls ($n=454$)	Total ($n=812$)
Age (years)	9.7 (0.9)	9.7 (0.9)	9.7 (0.9)	9.7 (0.9)	9.6 (0.9)	9.7 (0.9)	9.7 (0.9)	9.6 (0.9)	9.7 (0.9)
Height (cm)	138.5 (6.9)	138.0 (7.8)	138.2 (7.4)	138.6 (7.2)	138.1 (8.6)	138.3 (8.0)	138.5 (7.0)	138.0 (8.1)	138.3 (7.7)
Weight (kg)	34.6 (7.2)	34.5 (8.9)	34.5 (8.2)	36.5 (9.6)	36.9 (10.5)	36.7 (10.1)	35.4 (8.4)	35.6 (9.7)	35.5 (9.2)
Body Mass Index (kg/m^2)	17.9 (2.7)	17.9 (3.2)	17.9 (3.0)	18.8 (3.6)	19.1 (3.9)	19.0 (3.8)	18.3 (3.2)	18.4 (3.6)	18.4 (3.4)
Overweight (%)	16.9%	17.3%	17.1%	21.0%	24.9%	23.2%	18.7%	20.7%	19.8%
Obese (%)	3.5%	6.0%	4.9%	8.3%	11.7%	10.2%	5.6%	8.6%	7.3%
Pedometer steps/d	12,816 (3094)	11,068 (2647)	11,849 (2982)	12,633 (3772)	10,589 (2379)	11,476 (3221)	12,736 (3404)	10,852 (2538)	11,682 (3094)

[a] Mean (SD), all such values.

cutpoints between the steps/day of normal weight and overweight/obese children. The second grouping excluded the overweight sample ($n=161$) to more precisely refine activity cutpoints between normal weight and obese children. By removing those children with a weight status that was intermediate to normal weight and obese, it was hypothesized that fewer misclassifications and a larger AUC would result. The final grouping included the overweight sample summed with the normal weight sample to determine if it was possible to differentiate between the steps/day of overweight and obese children.

Each analysis was completed separately for boys and girls, as well as for the total sample. Using the ROC, a unique pedometer steps/day cutoff point that minimized classification errors and resulted in maximal accuracy (ROC-optimized cutpoint). In addition, the cutpoint that matched Se and Sp was identified for each analysis (Matched cutpoint). For comparative purposes, Se and Sp were estimated for both the aforementioned VP and TL cutpoints, as well as the adult pedometer cutpoint of 10,000 steps/day (Hatano, 1993; Welk et al., 2000). Five cutpoints within each grouping resulted, indicating the direction and extent of misclassification errors. Before considering the samples from Iowa and Minnesota equivalent, ROC analysis was carried out on each independently. The matched cutpoints identified between samples from both locations were considered similar (±400 steps/day), so children from both areas were pooled for analysis.

Results

Descriptive information is shown in Table 1. Approximately 25–30% of children were overweight or obese. There were no significant differences in age, height, body mass, BMI, or the prevalence of overweight or obesity between sexes. The mean (SD) number of steps/day for boys, girls, and sexes combined were 12,736 (3404), 10,852 (2538), and 11,682 (3094), respectively.

The cutpoints derived from the ROC analysis are shown in Table 2. For all ROC analyses, AUC was significantly better than chance with regards to global accuracy ($p<0.001$). The performance of the steps/day cutpoints were greatest with overweight children removed from the sample ($AUC \approx 0.75$). When overweight children were included, AUC was highest when grouped with normal weight children. Furthermore, the resulting cutpoints and AUC were comparable between when identifying a cutpoint referenced to obesity rather than overweight.

Table 2
ROC-defined cutpoints for pedometer steps/day referenced to weight status; Lakeville, MN and Cedar Rapids, IA in 2005

Grouping	Matched cutpoint [a]	Optimized cutpoint [b]	AUC [c]	95% CI
Normal weight vs. Overweight and Obese				
Boys	11,980	13,666	0.67	0.62, 0.72
Girls	10,599	9983	0.65	0.61, 0.70
Combined	11,040	10,832	0.66	0.63, 0.69
Normal weight vs. Obese				
Boys	11,588	10,064	0.73	0.68, 0.78
Girls	10,106	11,150	0.76	0.72, 0.81
Combined	10,631	11,150	0.76	0.72, 0.79
Normal weight and Overweight vs. Obese				
Boys	11,458	10,064	0.71	0.66, 0.75
Girls	10,079	11,150	0.74	0.70, 0.78
Combined	10,480	11,150	0.74	0.70, 0.77

[a] Matched cutpoint determined by matching sensitivity and specificity.
[b] Optimized cutpoint minimizes misclassification error (maximal accuracy).
[c] Area under curve.

Table 3
Performance of pedometer cutpoints identified between normal weight and overweight/obesity; Lakeville, MN and Cedar Rapids, IA in 2005

Pedometer cutpoint	Steps/day	Sensitivity	Specificity
Boys			
Matched cutpoint [a]	11,980	0.60	0.60
ROC optimized [b]	13,666	0.85	0.40
TL [c]	15,000	0.90	0.27
VP [d]	13,000	0.75	0.46
Adult [e]	10,000	0.32	0.84
Girls			
Matched cutpoint [a]	10,599	0.60	0.60
ROC optimized [b]	9983	0.53	0.71
TL [c]	12,000	0.78	0.35
VP [d]	11,000	0.68	0.51
Adult [e]	10,000	0.53	0.70
Combined			
Matched cutpoint [a]	11,040	0.61	0.61
ROC optimized [b]	10,832	0.59	0.65
Adult [e]	10,000	0.45	0.76

[a] Matched cutpoint determined by matching sensitivity and specificity.
[b] Optimized cutpoint minimizes misclassification error (maximal accuracy).
[c] Tudor-Locke et al. (2004a).
[d] Vincent and Pangrazi (2002).
[e] Adult (Hatano, 1993).

Performance of individual pedometer cutpoints are shown in Table 3. The ROC-optimized cutpoint was approximately 13,500 steps/day for boys and 10,000 steps/day for girls. This cutpoint resulted in a low Sp for boys and a low Se for girls. Many normal weight boys did not attain 13,500 steps/day and several overweight or obese girls accumulated more than 10,000 steps/day. The TL and VP cutpoints resulted in high Se and low Sp for

Table 4
Performance of pedometer cutpoints identified between normal weight and obesity; Lakeville, MN and Cedar Rapids, IA in 2005

Pedometer cutpoint	Steps/day	Sensitivity	Specificity
Boys			
Matched cutpoint [a]	11,588	0.65	0.65
ROC optimized [b]	10,064	0.55	0.83
TL [c]	15,000	0.90	0.27
VP [d]	13,000	0.80	0.46
Adult [e]	10,000	0.50	0.84
Girls			
Matched cutpoint [a]	10,106	0.67	0.67
ROC optimized [b]	11,150	0.92	0.49
TL [c]	12,000	0.92	0.35
VP [d]	11,000	0.82	0.51
Adult [e]	10,000	0.64	0.70
Combined			
Matched cutpoint [a]	10,631	0.68	0.67
ROC optimized [b]	11,150	0.81	0.60
Adult [e]	10,000	0.59	0.76

[a] Matched cutpoint determined by matching sensitivity and specificity.
[b] Optimized cutpoint minimizes misclassification error (maximal accuracy).
[c] Tudor-Locke et al. (2004a).
[d] Vincent and Pangrazi (2002).
[e] Adult (Hatano, 1993).

Table 5
Performance of pedometer cutpoints identified between normal/overweight and obesity; Lakeville, MN and Cedar Rapids, IA in 2005

Pedometer cutpoint	Steps/day	Sensitivity	Specificity
Boys			
Matched Cutpoint[a]	11,458	0.65	0.65
ROC optimized[b]	10,064	0.55	0.81
TL[c]	15,000	0.90	0.24
VP[d]	13,000	0.80	0.42
Adult[e]	10,000	0.50	0.82
Girls			
Matched cutpoint[a]	10,079	0.64	0.64
ROC optimized[b]	11,150	0.92	0.46
TL[c]	12,000	0.92	0.34
VP[d]	11,000	0.82	0.48
Adult[e]	10,000	0.64	0.66
Combined			
Matched Cutpoint[a]	10,480	0.66	0.66
ROC optimized[b]	11,150	0.81	0.56
Adult[e]	10,000	0.59	0.73

[a] Matched cutpoint determined by matching sensitivity and specificity.
[b] Optimized cutpoint minimizes misclassification error (maximal accuracy).
[c] Tudor-Locke et al. (2004a).
[d] Vincent and Pangrazi (2002).
[e] Adult (Hatano, 1993).

both boys and girls. This trend was exaggerated using the TL cutpoints, and reversed for the adult cutpoint in boys. The cutpoints matched on Se and Sp were approximately 12,000 steps/day for boys and 10,500 steps/day for girls.

Because the AUC from the ROC analysis was greatest when overweight children were withheld (Table 4), or grouped with normal weight children (Table 5), the Se and Sp of the matched cutpoints were higher compared with values computed with overweight children grouped with obese children (Table 3). This similarity between the groupings indicates that steps/day was more accurate determining a cutpoint for obese children, rather than overweight children. Within these groupings, the ROC-optimized and matched cutpoints were within 1000 steps/day for boys and girls. The matched cutpoint for boys was approximately 11,500 steps/day with a Se/Sp of 0.65. In girls, the matched cutpoint was close to the adult cutpoint of 10,000 steps/day with a Se/Sp, similar to that of the boys' cutpoint. In comparison, the Sp of the TL cutpoint was less than 0.30 for boys and 0.35 for girls.

Depending on the physical activity recommendation, approximately 55–75% of children in the current sample did not meet the existing steps/day cutpoints. For comparative purposes, prevalence of boys and girls meeting the Se/Sp Matched cutpoints (from Tables 4 and 5) in the current study are provided in Table 6.

Discussion

This study is unique in that it implements an objective, biostatistical approach to identifying criterion-referenced physical activity cutpoints. Weight status can be effectively used to create a cutpoint for pedometer-determined physical activity. The AUC for the obesity analysis (≈0.75) is considered to be moderately accurate by available ROC criteria (Swets, 1988). This is an encouraging result considering the multi-factorial nature of obesity (Eisenmann, 2006). However, it should be noted that using weight status is more accurate when identifying a cutpoint referenced to obesity rather than overweight. While pedometer-determined physical activity may not be equivalent between normal weight and overweight children, these two groups are more similar based on pedometer steps/day.

Evaluating Se and Sp of various pedometer guidelines is helpful in characterizing relative utility. In all analyses, the TL cutpoints displayed a high Se (0.78–0.92) and a low Sp (0.24–0.35). Most overweight and obese children did not meet the recommendation; however, nearly 70% of normal weight children also did not meet the recommended number of steps/day. The sample used by Tudor-Locke et al. (2004a) included children from the US, Sweden and Australia, but those from the US had the lowest steps/day (Vincent et al., 2003). The TL cutpoint likely reflects the relatively high pedometer counts of the Swedish and Australian children; hence, it did not perform well in this US sample. In addition, the TL cutpoint was created in reference only to overweight status. When doing so in the current study, this separation was the least accurate and produced the lowest AUC of the three groupings (Table 2).

From a practical standpoint, pedometer cutpoints that have a high Se and low Sp may be frustrating for many normal weight children since they may become discouraged by not meeting recommendations. On the contrary, if cutpoints are too low, overweight/obese children may already meet the standard and lack motivation or encouragement to increase activity. This, however, is not likely because the majority of children in this sample do not meet current recommendations. Although a dose-response relationship between steps/day and BMI has been previously demonstrated (Eisenmann et al., 2007), caution should be taken when prescribing cutpoints to ensure that they are attainable by the target population. If a child is already meeting the recommendation, it seems unlikely that the child would curtail physical activity as a result.

Table 6
Percentage of boys and girls meeting various pedometer cutpoints; Lakeville, MN and Cedar Rapids, IA in 2005

Percentage meeting cutpoint	Boys (n=358)	Girls (n=454)	Combined (n=812)
Matched cutpoint[a]	62.6%	63.2%	62.9%
ROC optimized[b]	80.2%	45.6%	60.8%
TL[c]	23.2%	31.5%	27.8%
VP[d]	41.3%	45.6%	43.7%
Adult[e]	80.2%	63.2%	70.7%

[a] Matched Cutpoint approximated to 11,500 and 10,000 steps/day for boys and girls, respectively.
[b] Optimized Cutpoint approximated to 10,000 and 11,000 steps/day for boys and girls, respectively.
[c] Tudor-Locke et al. (2004a).
[d] Vincent and Pangrazi (2002).
[e] Adult (Hatano, 1993).

The ROC-optimized cutpoints are those which provide maximal accuracy. However, one drawback to these cutpoints is the disparity in the Se and Sp for each. It may be more fitting to utilize the matched cutpoints as guidelines for pedometer-determined physical activity depending on the goal of application. The matched cutpoints between normal weight and obesity are 11,500 steps/day and 10,000 steps/day for boys and girls, respectively. These cutpoints equate to approximately a Se/Sp of 0.65. The matched cutpoints between normal weight and overweight status are 12,000 steps/day for boys and 10,500 steps/day for girls. These result in a slightly lower Se/Sp of approximately 0.60. While a certain degree of error will have to be conceded in any cutpoint, the benefit of using ROC cutpoints is that the direction of the error is known.

To our knowledge, this is the first report to show the percentage of children meeting existing pedometer-based physical activity recommendations. The results indicate that 55–75% of subjects did not meet current recommendations. The mean (SD) number of steps/day for boys, girls, and sexes combined were 12,736 (3404), 10,852 (2538), and 11,682 (3094), respectively. The results here are very similar to children from Arizona (Vincent and Pangrazi, 2002), but suggest that these children take fewer steps/day than children from the UK (Rowlands et al., 1999), Cyprus (Loucaides et al., 2004), France (Romon et al., 2004), New Zealand (Cox et al., 2006), and Sweden and Australia (Vincent et al., 2003). In contrast, boys and girls residing in northern Mexico were found to take about 6500 steps/day, respectively (Ballesteros et al., 2005).

Study strengths and limitations

A strength of the current study is that the sample was from two locations. The ROC analysis indicated cutpoints within 400 steps/day for both the Minnesota and Iowa subjects (data not shown); therefore one can be more confident in the generalizability of the resulting cutpoints for similar groups of US children. Another strength is the use of strict inclusion criteria that required at least 3 weekdays and 1 weekend day of pedometer counts to compute mean step counts. This screening reduced the available sample size but likely contributed to improved precision since there would be reduced measurement error.

A limitation of the current study is the cross-sectional design. It is not possible to discern if pedometer-determined physical activity is the cause or the outcome of weight status. Future studies should examine pedometer recommendations and subsequent health outcomes using a prospective cohort design. Increasing the strength of the criterion measure may be of value as well. Even though the BMI is both a widely accepted diagnostic test for high body fat and increased risk of morbidity (Reilly, 2006), utilizing percent body fat may decrease random noise and increase cutpoint accuracy. However, because there is no clear agreement on a cutpoint to define "overfat" in children (Dwyer and Blizzard, 1996; Taylor et al., 2002; Williams et al., 1992), cross-validation of the cutpoints with a wide range of outcomes, such as cardiovascular disease risk factors, bone integrity, adult health outcomes, and so forth, is likely the best way to determine the optimal recommendation for pedometer steps/day in children.

Conclusions

In summary, a large percentage of the sample did not meet current pedometer recommendations. The ROC analysis indicated that the relationship between steps/day and weight status can be used to accurately identify steps/day cutpoints. The appropriate cutpoint can be selected based on the preferred context of the application. As indicated by the low specificity and high false-positive rate resulting from the ROC analysis, many normal weight children were currently not meeting the TL guidelines. This may be a reflection of protection from overweight through other forms of activity not measurable by pedometry. Caution is warranted when applying these cutpoints to children from different geographical locations or from various ethnicities. The ROC-optimized and matched cutpoints provided are lower, resulting in greater accuracy and may be more attainable goals for overweight or obese children.

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References

Ballesteros, M.N., Cabrera, R.M., Saucedo Mdel, S., et al., 2005. High intake of saturated fat and early occurrence of specific biomarkers may explain the prevalence of chronic disease in northern Mexico. J. Nutr. 135, 70–73.

Cole, T.J., Bellizzi, M.C., Flegal, K.M., Dietz, W.H., 2000. Establishing a standard definition for child overweight and obesity worldwide: international survey. BMJ 320, 1240–1243.

Council on Sports Medicine and Fitness and Council on School Health, 2006. Active healthy living: prevention of childhood obesity through increased physical activity. Pediatrics 17 (5), 1834–1842.

Cox, M., Schofield, G., Greasley, N., Kolt, G.S., 2006. Pedometer steps in primary school-aged children: a comparison of school-based and out-of-school activity. J. Sci. Med. Sport 9, 91–97.

Duncan, J.S., Schofield, G., Duncan, E.K., 2006. Pedometer-determined physical activity and body composition in New Zealand children. Med. Sci. Sports Exerc. 38, 1402–1409.

Dwyer, T., Blizzard, C.L., 1996. Defining obesity in children by biological endpoint rather than population distribution. Int. J. Obes. Relat. Metab. Disord. 20, 472–480.

Eisenmann, J.C., 2006. Insight into the causes of the recent secular trend in pediatric obesity: common sense does not always prevail for complex, multifactorial phenotypes. Prev. Med. 42, 329–335.

Eisenmann, J.C., Laurson, K.R., Wickel, E.E., Gentile, D., Walsh, D., 2007. Utility of pedometer step recommendations for predicting overweight in children. Int. J. Obes. (Lond) 31, 1179–1182.

Eston, R.G., Rowlands, A.V., Ingledew, D.K., 1998. Validity of heart rate, pedometry, and accelerometry for predicting the energy cost of children's activities. J. Appl. Physiol. 84, 362–371.

Greiner, M., Pfeiffer, D., Smith, R.D., 2000. Principles and practical application of the receiver-operating characteristic analysis for diagnostic tests. Prev. Vet. Med. 45, 23–41.

Hatano, Y., 1993. Use of the pedometer for promoting daily walking exercise. Int Council Health, Phys Ed, Rec. 29, 4–8.

Jago, R., Zakeri, I., Baranowski, T., Watson, K., 2007. Decision boundaries and receiver operating characteristic curves: new methods for determining accelerometer cutpoints. J. Sports Sci. 25, 937–944.

Loucaides, C.A., Chedzoy, S.M., Bennett, N., 2004. Differences in physical activity levels between urban and rural school children in Cyprus. Health Educ. Res. 19, 138–147.

Malina, R.M., 1995. Anthropometry. In: Maud, P.J., Foster, C. (Eds.), Physiological Assessment of Human Fitness. Human Kinetics, Champaign, IL, pp. 205–219.

President's Council on Physical Fitness and Sports, 2001. The President's Challenge Physical Activity and Fitness Awards Program. President's Council on Physical Fitness and Sports. U.S. Department of Health and Human Services, Bloomington, IN.

Reilly, J.J., 2006. Diagnostic accuracy of the BMI for age in pediatrics. Int. J. Obes. (Lond) 30, 595–597.

Romon, M., Lafay, L., Bresson, J.L., et al., 2004. Relationships between physical activity and plasma leptin levels in healthy children: the Fleurbaix-Laventie Ville Sante II Study. Int. J. Obes. Relat. Metab. Disord. 28, 1227–1232.

Rowlands, A.V., Eston, R.G., Ingledew, D.K., 1999. Relationship between activity levels, aerobic fitness, and body fat in 8- to 10-yr-old children. J. Appl. Physiol. 86, 1428–1435.

Schneider, P.L., Crouter, S.E., Bassett, D.R., 2004. Pedometer measures of free-living physical activity: comparison of 13 models. Med. Sci. Sports Exerc. 36, 331–335.

Swets, J.A., 1988. Measuring the accuracy of diagnostic systems. Science. 240, 1285–1293.

Taylor, R.W., Jones, I.E., Williams, S.M., Goulding, A., 2002. Body fat percentages measured by dual-energy X-ray absorptiometry corresponding to recently recommended body mass index cutoffs for overweight and obesity in children and adolescents aged 3–18 y. Am. J. Clin. Nutr. 76, 1416–1421.

Trost, S.G., Pate, R.R., Freedson, P.S., Sallis, J.F., Taylor, W.C., 2000. Using objective physical activity measures with youth: how many days of monitoring are needed? Med. Sci. Sports Exerc. 32, 426–431.

Tudor-Locke, C., Bassett, D., 2004. How many steps/day are enough? Preliminary pedometer indices for public health. Sports Med. 34, 1–8.

Tudor-Locke, C., Pangrazi, R.P., Corbin, C.B., et al., 2004a. BMI-referenced standards for recommended pedometer-determined steps/day in children. Prev. Med. 38, 857–864.

Tudor-Locke, C., Williams, J., Reis, J., Pluto, D., 2004b. Utility of pedometers for assessing physical activity: construct validity. Sports Med. 34, 281–291.

Tudor-Locke, C., Williams, J.E., Reis, J.P., Pluto, D., 2002. Utility of pedometers for assessing physical activity: convergent validity. Sports Med. 32, 795–808.

Vincent, S.D., Pangrazi, R.P., 2002. An examination of the activity patterns of elementary school children. Pediatr. Exerc. Sci. 14, 432–441.

Vincent, S.D., Pangrazi, R.P., Raustorp, A., Tomson, L.M., Cuddihy, T.F., 2003. Activity levels and body mass index of children in the United States, Sweden, and Australia. Med. Sci. Sports Exerc. 35, 1367–1373.

Welk, G.J., 2005. Principles of design and analyses for the calibration of accelerometry-based activity monitors. Med. Sci. Sports Exerc. 37, S501–S511.

Welk, G.J., Differding, J.A., Thompson, R.W., et al., 2000. The utility of the Digi-walker step counter to assess daily physical activity patterns. Med. Sci. Sports Exerc. 32 (9 Suppl), S481–S488.

Williams, D.P., Going, S.B., Lohman, T.G., et al., 1992. Body fatness and risk for elevated blood pressure, total cholesterol, and serum lipoproteins ratios in children and adolescents. Am. J. Public Health 82, 358–363.

Zweig, M.H., Campbell, G., 1993. Receiver-operating characteristic (ROC) plots: a fundamental evaluation tool in clinical medicine. Clin. Chem. 39, 561–577.