BMI-referenced cut-points for recommended daily pedometer-determined steps in Australian school-aged children and adolescents

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Pedometers capture objective physical activity data and are used in interventions designed to promote physical activity participation among children and adolescents (Butcher, Fairclough, Stratton, & Richardson, 2007; Pangrazi, Beighle, Vehige, & Vack, 2003). Research establishing and/or evaluating pedometer-based recommendations for children and adolescents is in its infancy (Duncan, Schofield, & Duncan, 2007; Eisenmann, Laurson, Wickel, Gentile, & Walsh, 2007; Laurson et al., 2008; Tudor-Locke et al., 2004). To date the contrasting-groups method (Duncan et al., 2007; Tudor-Locke et al., 2004) receiver operating curves (ROC: Laurson et al., 2008) and norm-referenced approaches (Vincent & Pangrazi, 2002b) have been used to estimate pedometer-determined cut-points among youth.

Tudor-Locke et al. (2004) used the contrasting-groups method to calculate age by sex-specific BMI-referenced pedometer-determined cut-points among 6-12 year old children and found 15000 steps/day for boys and 12000 steps/day for girls to be the median optimal cut-points discriminating between healthy weight and overweight. Using the same technique, Duncan et al. (2007) found somewhat higher cut-points among boys (i.e., 16000 steps/day) and girls (i.e., 13000 steps/day) using percentage of body fat to define overweight (i.e. >85th percentile). Lower BMI-referenced cut-points among 6-12 year old boys (13666 steps/day) and girls (9983 steps/day) using ROCs have also been reported (Laurson et al., 2008). While previously estimated cut-points are within the normal range of daily pedometer-determined physical activity undertaken by youth (Tudor-Locke, McClain, Hart, Sisson, & Washington, 2009), a recent study found that the original Tudor-Locke et al. (2004) cut-points could not differentiate among U.S. youth classified as healthy weight or overweight (Beets et al., 2008).

Given that pedometer-determined cut-points have been estimated using different body composition measures via several statistical techniques, in populations where general physical activity levels and the prevalence of unhealthy weight usually differ (e.g., U.S.A versus New Zealand), a single recommendation may not be suitable for all populations and therefore population-specific pedometer-determined guidelines may be needed (Beets et al., 2008; Duncan et al., 2007). The purpose of this study was to determine the criterion-referenced standards for pedometer-determined physical activity related to BMI-defined weight status (i.e., healthy weight vs. overweight/obese) for youth 7-16 years of age, using a Western Australian sample. Because the primary purpose of the study was to empirically select optimal pedometer-derived step counts per day, the well-used contrasting-groups validation method was used in place of ROCs. The contrasting-groups method analyzes validation samples of healthy weight and overweight/obese youth in order to maximize the probability of selecting the most appropriate criterion-referenced, sex-specific standard.

Method

Sample recruitment

The current analysis included data collected from the Western Australian Children and Adolescent Physical Activity and Nutrition Survey (CAPANS: Hands, Parker, Glasson, Brinkman, & Read, 2004). Briefly, CAPANS was undertaken during August-December 2003 to monitor levels of physical activity and nutrition behaviour among Western Australian school children and adolescents in Grades 3, 5-7, and 8-11 (n=2275). The sampling frame for schools included all government and non-government primary and secondary schools. Schools with less than 90 students across the three grade groups, education support and hospital schools, and schools located in the Cocos and Christmas Islands, and schools drawn for the Australian Adolescent Health Monitoring Survey were excluded.

Initially thirty-two schools (metropolitan/primary n=12, metropolitan/secondary n=12, non-metropolitan/primary n=4, non-metropolitan/secondary n=4) were randomly selected. Schools refusing to participate were replaced with a school of the same type and location. Thirtysix schools (n=17 primary and n=19 secondary) agreed to participate in the survey (response rate=60%). To increase school buy-in and compliance with the survey, schools were responsible for recruiting students (Hands et al., 2004). Parental and student informed written consent were obtained from 2274 students (response rate=55.8%), of which 1835 also consented to anthropometric data collection (Hands et al., 2004). The data were collected within the schools by a team of investigators from the University of Notre Dame Australia. University of Notre Dame Ethics Committee provided ethics approval for the survey.

Data collection

Anthropometry

Height was measured using a portable stadiometer (Mentone Educational Portable Height Scale) and body mass measured using an electronic scale (A&D Personal Precision Scale UC-321). Body mass and height were measured with shoes, heavy clothing, and jewelry removed. Height was measured twice (three times if the difference between the first two measurements was >0.5cm) and averaged. Body mass was measured once only.

Pedometer-assessed physical activity

Yamax Digiwalker SW-700 pedometers were used to record step counts. High agreement between actual steps and pedometer counted steps, at self-paced and controlled speeds has been reported for children wearing Yamax pedometers (Beets, Patton, & Edwards, 2005). Students were asked to wear pedometers at all times during a seven-day period, except while sleeping, swimming, bathing, or showering. Methods were taken to reduce potential behavior modification and accidental resetting (Tudor-Locke & Myers, 2001). Pedometer count recording procedures differed between primary and secondary schools. In primary schools, the teacher or teaching assistant read, reset, and resealed pedometers each morning at school. Weekend pedometer counts were recorded in class on the next school day. This approach was intended to improve the quality of pedometer data recorded, particularly among the grade 3 students. Rowe et al. (2004) reported fewer missing data among teacher- versus student-recorded pedometer counts for children aged 10-14 years. Secondary schools students recorded steps, reset and resealed the pedometer each night before retiring to bed, including on weekends. Primary and secondary school students completed a daily diary recording activities and times when the pedometer was not worn.

Statistical analysis

Data treatment

Using measured height and weight , BMI was calculated (kg/m^2) and participants were dichotomized into healthy weight versus overweight/obese based on cut-points established for sex and age (Cole, Bellizzi, Flegal, & Dietz, 2000). Step counts <1000 and >30000 (0.7-6.6% of daily counts) were removed (Rowe et al., 2004). Students with steps recorded for at least four days including weekday and weekend data only, were retained in the analysis (Strycker, Duncan, Chaumeton, Duncan, & Toobert, 2007; Vincent & Pangrazi, 2002a). Average steps per day was computed and smoothed to 1000 steps/day increments because of the inability of smaller increments to discriminate cut-points at this level of precision (Tudor-Locke et al., 2004). Complete gender, age, BMI, and pedometer data were available for 1403 students. Students with complete data were slightly younger (11.7±2.5 vs. 11.4±3.6 years, $p<.05$), took more average daily steps (11811±3587 vs. 10796±4190 steps/day, $p<.05$), and had a higher BMI (19.7±3.6 vs. 19.0±3.3 kg/m^2, $p<.05$) than those with incomplete data. Overall prevalence of overweight/obesity was 23.5% (range=17.2-37.0%) for boys and 27.6% (range=16.0-37.2%) for girls (Table 1).

Data analysis

The current analysis sought to establish BMI-referenced pedometer-determined cut-points among children based on sex, in part replicating methods used in previous studies (Tudor-

Locke et al., 2004). We did not examine age-specific cut-points because the purpose of this study was to develop a single recommendation that could be easily communicated across Western Australia. The analytical sample included all overweight/obese students (boys=169 and girls=189) and a randomly drawn sample of healthy weight students (boys=170 and girls=190). To establish criterion-referenced cut-points, the contrasting-groups method was used (Safrit, 1986). This method is based on the existence of dichotomous groups with respect to the criterion. To test this assumption, a two-tailed independent samples t test was used to examine the differences in steps/day between the healthy weight and overweight groups for boys and girls. The contrasting-groups method includes computation of several statistical indices including: probability of correct decisions; misclassification of errors; validity coefficient; and; utility analysis (Berk, 1976; Safrit, 1986). A high *probability of correct decisions index, validity coefficient index, and utility analysis index* and a low *misclassification errors index* are used to identify optimal sex-specific cut-points. A detailed explanation of the contrasting-groups method is presented elsewhere (Tudor-Locke et al., 2008; Tudor-Locke et al., 2004).

Results

The mean age of the healthy weight and overweight/obese participants were similar among boys (11.2±2.7 vs. 11.3±2.7 years, p=.98) and girls (11.3±2.6 vs. 11.3±2.6 years, p=.98). Compared with healthy weight boys and girls, mean steps/day were significantly lower among overweight/obese boys (14413±3187 vs. 12088±3927, p<.001) and girls (12562±2688 vs. 10114±2897, p<.001), respectively.

Table 2 presents a summary of the statistical indices calculated as part of the contrasting-groups procedure. The cut-point of 8000 steps/day was the most accurate estimate for correctly classifying weight status for both boys (.93) and girls (.89). The misclassification of boys (.07) and girls (.11) as overweight/obese when they were healthy weight was also 8000 steps/day. However, the likelihood of incorrectly classifying boys as healthy weight when they were overweight/obesity was lowest for the cut-point of 17000 steps/day (.08). The lowest likelihood of incorrectly classifying girls as overweight/obese as being healthy weight was at cut-points of 16000 and 17000 steps/day (.01). Both provided the lowest likelihood of incorrectly classifying those overweight as being healthy weight. Although relatively low, the validity coefficients, indicated that the cut-point of 16000 steps/day provided the most accurate measure of weight status for boys (Φ = .08) and girls (Φ = .18). For boys the expected maximum utility was equal across all cut-points (.01), but for girls the lowest expected maximum utility was for the 17000 steps/day. When all indices were considered simultaneously, the optimal criterion-referenced cut-point was 16000 steps/day for both boys and girls.

Discussion

This study provides preliminary BMI-referenced pedometer-determined recommendations specific to Western Australian boys and girls aged 7-16 years. Overweight/obese boys and girls took significantly fewer steps than their healthy weight counterparts, supporting previous evidence of a relationship between physical activity and body composition (Trost, Kerr, Ward, & Pate, 2001). Western Australian children and adolescents undertaking fewer than 16000 steps/day were more likely to be classified as overweight/obese. Noteworthy, was that both boys and girls had the same BMI-referenced cut-point—inconsistent with previous findings (Duncan et al., 2007; Laurson et al., 2008; Tudor-Locke et al., 2004) where BMI-referenced pedometer-determined recommendations have typically been higher for boys than girls. Pedometer-determined cut-points for overweight range between 13000-16000 steps/day for boys and between 9900-13000 steps/day for girls (Duncan et al., 2007; Laurson et al., 2008; Tudor-Locke et al., 2004).

The cut-point for boys in the current study was similar to that reported by Duncan et al.(2007) although different measures of overweight were used in these two studies (i.e., BMI vs. percent body fat). Tudor-Locke et al. (2004) examining sex by age cut-points found a lower median optimal pedometer-determined cut-point to be approximately 1000 steps/day for boys and 3000 steps/day for girls lower than those found here. Differences in study design, local conditions, sample demographic characteristics, diet, physical activity and prevalence of overweight and obesity may explain disparities among these findings. Specifically, Tudor-Locke et al. (2004) included pedometer and BMI data from Australian children and adolescents residing in a different Australian state (i.e., Queensland); however, cut-points were calculated based on aggregated data from Australia, Sweden and the United States and specific sex and age groups. Our sample was also predominantly white while others have included significant proportions of non-white populations (i.e., Hispanic, Polynesian, and Asian) (Duncan et al., 2007; Tudor-Locke et al., 2004). Differences in weight among children and youth are associated with ethnicity (Delva, O'Malley, & Johnston, 2006).

Our study included data from children and adolescents aged 7-16 years. Previous studies have established BMI-referenced pedometer-determined cut-points with younger children (i.e., 6-12 years) (Laurson et al., 2008; Tudor-Locke et al., 2004). Thus, a larger proportion of children in this sample were at a more advanced stage of physical maturity compared with children included in previous studies. Pubescent changes contribute to increases in BMI (Lee et al., 2007), therefore more daily pedometer-determined steps might be required to achieve a healthy weight among older children and adolescents. This might also explain why BMI-referenced pedometer-determined cut-points were much higher for girls in the current study compared with those found previously. Separate BMI-referenced recommendations for younger and older children might be necessary and should be investigated in future studies, particularly as variations in energy cost of physical activity related to body size, stride length, and types of activities, differ with age. Nevertheless, the promotion of a single BMI-referenced recommendation, rather than age-related recommendations, may aid its delivery, acceptance, and compliance among the Western Australian population.

Overweight and obese children were combined into a single group for the current analysis, which might explain the higher than expected pedometer-determined cut-point in this study. Nevertheless, reducing the prevalence of pre-obese overweight children and adolescents is also important because weight status tracks into adulthood (Magarey, Daniels, Boulton, & Cockington, 2003). Future studies should test the utility of the BMI-referenced pedometer-determined cut-points using prospective study designs to establish causality between pedometer-determined physical activity and body composition. These studies may also want to examine whether achieving these cut-points have other health benefits (Beighle & Beets, 2007). Moreover, given the specificity of our sample—Western Australian children aged 7-16 years—future studies might want to validate our cut-points in other Australian samples. The exact BMI-referenced pedometer-determined cut-point for youth is yet to be established and it is likely that a single, exact cut-point may not be suitable for all populations (Beets et al., 2008). Nevertheless, the relative magnitude of the range of steps required has been consistently high (i.e., 13000 to 16000 steps/day) and could be used to guide interventions targeting weight loss among children and adolescents or as a behavioral criterion in population-based surveys.

Author's Notes

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Table 1. Weight status by gender & age for the sample providing complete data (n=1403)

	Boys			Girls		
Age (yrs)	**N**	**Healthy weight (%)**	**Overweight (%)**	**N**	**Healthy weight (%)**	**Overweight (%)**
7	38	73.7	26.3	37	64.9	35.1
8	110	75.5	24.5	98	77.6	22.4
9	34	70.6	29.4	43	62.8	37.2
10	126	71.4	28.6	120	71.7	28.3
11	31	80.6	19.4	29	69.0	31.0
12	122	82.8	17.2	119	71.4	28.6
13	104	81.7	18.3	76	73.7	26.3
14	27	63.0	37.0	34	79.4	20.6
15	63	71.4	28.6	79	67.1	32.9
16	63	80.9	19.1	50	84.0	16.0
Total	718	76.5	23.5	685	72.4	27.6

Table 2. Summary of the analytical process undertake to evaluate cut pedometer cut-points in boys & girls 7-16 years

Steps/day	Probability of correct decisions	Misclassification error type I/type II (false overweight/false healthy weight)	Validity coefficient	Utility analysis		
				Expected utility	Expected disutility	Expected maximum utility
Boys						
8000	.93	.07/.43	-.24	.50	-.93	-.001
9000	.90	.09/.41	-.21	.50	-.91	-.001
10000	.81	.14/.36	-.16	.50	-.86	-.001
11000	.73	.20/.30	-.14	.50	-.80	-.001
12000	.63	.26/.24	-.08	.50	-.74	-.001
13000	.50	.32/.18	-.002	.50	-.68	-.001
14000	.41	.35/.15	.04	.50	-.65	-.001
15000	.31	.39/.11	.07	.50	-.61	-.001
16000*	**.21**	**.42/.08**	**.08**	**.50**	**-.58**	**-.001**
17000	.15	.44/.06	.07	.50	-.56	-.001
Girls						
8000	.89	.11/.39	-.28	.50	-.89	-.001
9000	.78	.19/.31	-.22	.50	-.81	-.001
10000	.65	.27/.23	-.14	.50	-.73	-.001
11000	.51	.33/.17	-.007	.50	-.67	-.0005
12000	.38	.37/.13	.06	.50	-.63	-.0003
13000	.27	.41/.09	.09	.50	-.59	-.0002
14000	.17	.46/.04	.15	.50	-.54	-.0001
15000	.12	.48/.02	.17	.50	-.52	-.00006
16000*	**.08**	**.49/.01**	**.18**	**.50**	**-.51**	**-.00003**
17000	.05	.49/.01	.15	.50	-.51	-.00002

* Optimal cut-point