Physical Activity, Sedentary Time, and Obesity in an International Sample of Children

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ABSTRACT

KATZMARZYK, P. T., T. V. BARREIRA, S. T. BROYLES, C. M. CHAMPAGNE, J.-P. CHAPUT, M. FOGELHOLM, G. HU, W. D. JOHNSON, R. KURIYAN, A. KURPAD, E. V. LAMBERT, C. MAHER, J. MAIA, V. MATSUDO, T. OLDS, V. ONYWERA, O. L. SARMIENTO, M. STANDAGE, M. S. TREMBLAY, C. TUDOR-LOCKE, P. ZHAO, and T. S. CHURCH. Physical Activity, Sedentary Time, and Obesity in an International Sample of Children. *Med. Sci. Sports Exerc.*, Vol. 47, No. 10, pp. 2062–2069, 2015. **Purpose**: To determine the relationships between moderate-to-vigorous physical activity (MVPA), vigorous physical activity (VPA), sedentary time, and obesity in children from 12 countries representing a wide range of human development. **Methods**: The sample included 6539 children age 9–11 yr. Times in MVPA, VPA, and sedentary behaviors were assessed by accelerometry. The body mass index (BMI; kg·m^{-2}) was used to classify children as obese based on *z*-scores (> +2 SD) from World Health Organization reference data. **Results**: The mean (SD) times spent in MVPA, VPA, and sedentary behavior were 60 (25) min·d^{-1}, 18 (11) min·d^{-1}, and 513 (69) min·d^{-1}, respectively. The overall proportion of the sample that was obese ranged from 5.2% to 24.6% across sites. The odds ratios for obesity were significant for MVPA (0.49; 95% CI, 0.44–0.55), VPA (0.41; 0.37–0.46), and sedentary time (1.19; 1.08–1.30) in the overall sample. The associations of MVPA and VPA with obesity were significant in all 12 sites, whereas the association between sedentary time and obesity was significant in five of the 12 sites. There was a significant difference in BMI *z*-scores across tertiles of MVPA (P < 0.001) but not across tertiles of sedentary time in a mutually adjusted model. The results of receiver operating characteristic curve analyses for obesity indicated that the optimal thresholds for MVPA (area under the curve [AUC], 0.64), VPA (AUC, 0.67) and sedentary behavior (AUC, 0.57) were 55 (95% CI, 50–64) min·d^{-1}, 14 (11–16) min·d^{-1}, and 482 (455–535) min·d^{-1}, respectively. **Conclusions**: Greater MVPA and VPA were both associated with lower odds of obesity independent of sedentary behavior. Sedentary time was positively associated with obesity, but not independent of MVPA. Attaining at least 55 min·d^{-1} of MVPA is associated with lower obesity in this multinational sample of children, which supports current guidelines. **Key Words:** OVERWEIGHT, PEDIATRICS, EPIDEMIOLOGY, LIFESTYLE, INTERNATIONAL

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Global physical activity guidelines as well as those for the United States call for a minimum of 60 min·d^{-1} of moderate-to-vigorous physical activity (MVPA) for health benefits in school-age children (32,33). These guidelines are largely based on evidence linking physical activity and outcomes such as physical fitness, bone health, and markers of cardiovascular and metabolic health in childhood (32,33). Recent reviews indicate that the cross-sectional association between physical activity and adiposity is modest in children (11,22) and that further research is required to determine the amount of physical activity needed to prevent the development of excess adiposity during childhood (22).

In addition to the health-enhancing effects of physical activity, recent studies have shown a negative association between sedentary behaviors (sitting, TV viewing, etc.) and health outcomes in adults (9,25). The available evidence

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Submitted for publication December 2014.
Accepted for publication February 2015.

0195-9131/15/4710-2062/0
MEDICINE & SCIENCE IN SPORTS & EXERCISE®

DOI: 10.1249/MSS.0000000000000649

also indicates an association between sedentary behavior, especially TV viewing, and health in children and youth (18,26). Given that only a weak association exists between MVPA and sedentary behavior (20), it is important to better understand the independent effects of these behaviors on obesity in children.

Most existing evidence on associations between physical activity, sedentary behavior, and health in children has relied on subjective (self-reported) measures of the exposure variable (11). Although largely limited to North America and Europe, the objective assessment of physical activity and sedentary behavior using accelerometry has recently allowed for large-scale studies to examine associations with health status in children (1,6).

Given the lack of comparative objective data on the relationship between physical activity, sedentary behavior and obesity in international samples, the purpose of this study was to examine the associations of MVPA, vigorous physical activity (VPA) and sedentary behavior with obesity in 9- to 11-yr-old children from countries that differ in stages of epidemiologic transition, and to identify the optimal thresholds of MVPA, VPA and sedentary time that are associated with obesity.

METHODS

Study design. The International Study of Childhood Obesity, Lifestyle and the Environment (ISCOLE) is a cross-sectional, multinational study designed to determine the relationships between lifestyle behaviors and obesity in children in 12 study sites located in Australia, Brazil, Canada, China, Colombia, Finland, India, Kenya, Portugal, South Africa, United Kingdom, and the United States. These countries represent a range of economic development (low to high income) and human development index (0.509 in Kenya to 0.929 in Australia) (12). The institutional review board at the Pennington Biomedical Research Center (coordinating center) approved the overarching protocol, and the institutional/ethical review boards at each participating institution also approved the local protocol. Written informed consent was obtained from parents or legal guardians, and child assent was also obtained as required by local institutional/ethical review boards before participation in the study.

The standardization of the study protocol across sites, a rigorous system of training and certification of study personnel, the use of a Web-based data entry system, and centralized data management and analysis at the coordinating center ensured the quality of data collected (12). Data were collected from September 2011 through December 2013.

Participants. The ISCOLE study includes 7372 children age 9–11 yr. However, a total of 31 participants were missing data on body mass index (BMI) and a further 802 participants were missing data from accelerometry, resulting in an analytic sample size of 6539. Participants with missing BMI or accelerometry data did not differ in age from the analytic sample, but those missing accelerometry had a higher mean BMI *z*-score (0.62) compared to the analytic sample (0.46).

The primary sampling frame was schools, and this sampling frame was typically stratified by an indicator of socioeconomic status to maximize variability within sites (12). By design, the within-site samples were not intended to be nationally representative.

Measurements. Times spent in MVPA, VPA, and sedentary behavior were obtained from 24-h waist-worn accelerometry. An Actigraph GT3X+ accelerometer (Pensacola, FL, USA) was worn at the waist on an elasticized belt on the right mid-axillary line. Participants were encouraged to wear the accelerometer 24 $h \cdot d^{-1}$ (removing only for water-related activities) for at least 7 d (plus an initial familiarization day and the morning of the final day), including weekend days. We have previously shown that this protocol increases wear-time compliance compared to previous studies; and overall, the mean wear time at the US ISCOLE site was 22.6 $h \cdot d^{-1}$ (30). The minimal amount of accelerometer data that was considered acceptable for inclusion in the sample was 4 d with at least 10 h of waking wear time per day, including at least one weekend day. After exclusion of the total sleep episode time (2,29) and nonwear time (any sequence of at least 20 consecutive minutes of zero activity counts) (16), MVPA was defined as all activity 574 or more counts per 15 s, VPA was defined as activity 1003 or more counts per 15 s, and sedentary time was defined as all movement 25 or less counts per 15 s (8,28).

Body height and body mass were measured using standard procedures across all study sites. Body height was measured without shoes using a Seca 213 portable stadiometer (Hamburg, Germany), with the head in the Frankfurt Plane. Body mass was determined with a portable Tanita SC-240 scale (Arlington Heights, IL, USA), after all outer clothing and shoes were removed. Each measurement was repeated, and the average was used for analysis (a third measurement was obtained if the first two measurements were greater than 0.5 cm or 0.5 kg apart for height and body mass, respectively, and the average of the two closest measurements was used in analyses). Body mass index ($kg \cdot m^{-2}$) was calculated, and BMI *z*-scores were computed using age- and sex-specific reference data from the World Health Organization (4). Participants were classified as obese (BMI *z*-score > +2 SD) or nonobese (BMI *z*-score ≤ +2 SD).

Statistical analysis. Means and SD were computed for variables by study site and by sex for participants with complete measurements. Differences between boys and girls were determined using unpaired *t*-tests for continuous variables. Associations between MVPA, VPA, sedentary time, and obesity (0, no; 1, yes) were assessed in odds ratios calculated using generalized linear mixed models (SAS version 9.3, PROC GLMMIX). Study sites were considered to have fixed effects, and schools nested within study sites were viewed as having random effects. The denominator degrees of freedom for statistical tests pertaining to fixed effects

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were calculated using the Kenward and Roger approximation (13). Times in MVPA, VPA, and sedentary time were standardized, such that odds ratios are expressed per SD of each variable (MVPA, 25 min; VPA, 10 min; sedentary time, 70 min). Mean daily waking wear time was included as a covariate in all models, and in all models that included both boys and girls, sex was also included as a covariate. A subsequent linear mixed model (PROC MIXED) was used to examine the combined effects of MVPA and sedentary time on BMI *z*-scores, with both MVPA and sedentary time categorized into sex-specific tertiles.

Receiver operating characteristic (ROC) curves were used to select thresholds of MVPA, VPA, and sedentary time associated with obesity. The area under the curve (AUC) is considered a measure of the use of the predictor variable and represents the trade-off between the correct identification of high-risk (obese) individuals (sensitivity) and the correct identification of low-risk (nonobese) individuals (specificity). An AUC of 1 indicates the ability to perfectly distinguish between obese and nonobese participants, whereas an AUC of 0.5 indicates no greater predictive ability than chance alone.

The optimal threshold was determined from the Youden index (21), which is the maximum value of *J*:

$$J = \text{sensitivity} + \text{specificity} - 1$$

Statistical significance of differences in AUCs between MVPA, VPA, and sedentary time was assessed by using the nonparametric approach of DeLong et al. (5).

In addition to the primary analyses, two sets of sensitivity analyses were conducted. First, the associations were reanalyzed using the MVPA threshold of Treuth et al. (27) (3000 counts per minute) rather than the Evenson et al. (8) threshold used in the primary analysis. Previous work has shown that the prevalence of obesity is similar among children when comparing the WHO growth reference versus the US Centers for Disease Control and Prevention (CDC) cut points (24). However, as an additional sensitivity analysis, the associations in the present study were re-analyzed after reclassifying participants as obese and nonobese using the CDC age- and sex-specific BMI thresholds (≥95th percentile) (14).

Data management and calculations for statistical inferences were conducted using SAS version 9.3 (SAS Institute, Cary, NC). The ROC analyses and comparisons of ROC curves were performed using MedCalc Statistical Software version 13 (MedCalc Software bvba, Ostend, Belgium). The level of significance was set at $P < 0.05$.

RESULTS

The mean (SD) waking wear time in the sample was 14.8 (0.9) $h \cdot d^{-1}$, which ranged from 14.1 to 15.2 $h \cdot d^{-1}$ across the 12 sites. The descriptive characteristics of the study sample are provided in Table 1, stratified by study site. The mean (SD) age of the total sample was 10.4 (0.6) yr, and the mean (SD) times spent in MVPA, VPA, and sedentary behavior were 60 (25) $min \cdot d^{-1}$, 18 (11) $min \cdot d^{-1}$, and 513 (69) $min \cdot d^{-1}$, respectively. The mean MVPA time ranged from 45 $min \cdot d^{-1}$ in China to 71 $min \cdot d^{-1}$ in Kenya and Finland, the mean VPA time ranged from 13 $min \cdot d^{-1}$ in India and China to 23 $min \cdot d^{-1}$ in Finland, and the mean sedentary time ranged from 477 $min \cdot d^{-1}$ in Australia to 565 $min \cdot d^{-1}$ in China. The overall proportion of obese participants was 12.4% and ranged from 5.2% to 24.6% across the sites. Table 2 presents descriptive characteristics of boys and girls. Overall, boys and girls did not significantly differ in mean height, body mass, or BMI; however, BMI *z*-scores were significantly greater in the boys than in the girls. Furthermore, the boys spent significantly more time in MVPA and VPA; whereas the girls spent significantly more time in sedentary behaviors.

Figure 1 presents the combined associations of MVPA and sedentary time with BMI *z*-scores. In both boys and girls, there was a significant decreasing trend for BMI *z*-scores across increasing tertiles of MVPA ($P < 0.001$), but the trend across tertiles of sedentary behavior was not significant. Similar trends in BMI *z*-score were observed across tertiles of VPA and sedentary time (results not shown).

TABLE 1. Descriptive characteristics of participants stratified by study site (n = 6539).

	No. of Participants		Mean (SD)							
Country (site)	Boys	Girls	Age (yr)	Height (cm)	Mass (kg)	BMI ($kg \cdot m^{-2}$)	Sedentary Time ($min \cdot d^{-1}$)	MVPA ($min \cdot d^{-1}$)	VPA ($min \cdot d^{-1}$)	Obesity[a] (%)
Australia (Adelaide)	225	266	10.7 (0.4)	144.7 (7.2)	39.8 (9.3)	18.8 (3.3)	477 (60)	65 (23)	22 (12)	10.2
Brazil (Sao Paulo)	241	252	10.5 (0.5)	143.7 (7.3)	41.1 (11.9)	19.7 (4.4)	500 (69)	59 (26)	18 (11)	21.9
Canada (Ottawa)	216	306	10.5 (0.4)	143.7 (7.1)	38.1 (9.2)	18.3 (3.3)	511 (63)	59 (19)	17 (8)	12.1
China (Tianjin)	261	240	9.9 (0.5)	141.3 (7.1)	38.2 (11.0)	18.9 (4.2)	565 (68)	45 (16)	13 (6.7)	24.6
Colombia (Bogota)	422	435	10.5 (0.6)	137.7 (7.0)	33.6 (7.0)	17.6 (2.5)	500 (67)	68 (25)	18 (10)	5.7
Finland (Helsinki, Espoo, and Vantaa)	231	269	10.5 (0.4)	144.2 (6.6)	37.1 (7.3)	17.7 (2.6)	531 (68)	71 (26)	23 (13)	5.2
India (Bangalore)	254	299	10.4 (0.5)	141.2 (6.8)	36.1 (8.5)	18.0 (3.3)	516 (67)	49 (21)	13 (8)	10.9
Kenya (Nairobi)	232	267	10.2 (0.7)	139.1 (7.4)	33.7 (8.3)	17.2 (3.1)	495 (66)	71 (31)	22 (13)	6.6
Portugal (Porto)	305	381	10.4 (0.3)	143.5 (6.8)	40.4 (9.2)	19.5 (3.4)	551 (62)	56 (22)	17 (10)	17.2
South Africa (Cape Town)	184	284	10.3 (0.7)	138.2 (7.4)	34.7 (9.0)	18.0 (3.6)	487 (65)	65 (26)	18 (11)	11.1
United Kingdom (Bath and NE Somerset)	211	267	10.9 (0.5)	145.0 (7.2)	39.2 (8.6)	18.5 (3.0)	497 (60)	63 (22)	20 (11)	9.2
United States (Baton Rouge)	203	288	9.9 (0.6)	140.9 (7.5)	37.9 (10.3)	18.9 (3.9)	521 (62)	50 (19)	15 (9)	17.7

Data are shown as mean (SD).
Sedentary time, MVPA, and VPA were measured with accelerometry and were defined as time spent at ≤25 counts/15 s, ≥574 counts/15 s, and ≥1003 counts/15 s, respectively.
[a]Obesity defined as BMI *z*-score > +2 from the WHO reference (4).

TABLE 2. Descriptive characteristics of participants stratified by sex (n = 6539).

	Boys (n = 2985)	Girls (n = 3554)	P^a
Age, yr	10.4 (0.6)	10.4 (0.6)	<0.001
Body height, cm	141.6 (7.3)	141.8 (7.7)	0.29
Body mass, kg	37.4 (9.5)	37.3 (9.4)	0.87
BMI, kg·m^{-2}	18.4 (3.5)	18.4 (3.5)	0.47
BMI z-score^b	0.55 (1.31)	0.39 (1.21)	<0.001
Obesity, %^{c}	15.5	9.9	<0.001
MVPA, min·d^{-1}	70 (26)	52 (21)	<0.001
VPA, min·d^{-1}	22 (12)	15 (9)	<0.001
Sedentary time, min·d^{-1}	504 (70)	521 (68)	<0.001

Data are shown as mean (SD) unless otherwise stated. Sedentary time, MVPA, and VPA were measured with accelerometry and were defined as time spent at ≤25 counts/15 s, ≥574 counts/15 s, and ≥1003 counts/15 s, respectively.
[a] P value for differences between sexes (unpaired t-test for continuous variables, chi-square for obesity).
[b] BMI z-score computed from WHO growth reference (4).
[c] Obesity defined as BMI z-score > +2 from WHO reference (4).

Figure 2 shows odds ratios for assessing the associations of MVPA and sedentary behavior with obesity across the study sites. The odds ratios for obesity were significant for MVPA (0.49; 95% CI, 0.44–0.55), VPA (0.41; 95% CI, 0.37–0.46), and sedentary time (1.19; 95% CI, 1.08–1.30) in the overall sample. The negative associations of MVPA and VPA with obesity were significant in all of the 12 study sites, whereas the positive association between sedentary time and obesity was significant in only five (Australia, Canada, Colombia, South Africa, and the United States) of the 12 study sites.

The results of the ROC curve analyses are presented in Table 3. In the total sample and in both boys and girls, the AUC for sedentary behavior was significantly lower than the AUC for both MVPA and VPA (P < 0.001), and the AUC for MVPA was significantly lower than the AUC for VPA (P < 0.001). The overall threshold for MVPA was 55 min·d^{-1} (95% CI, 50–64), and the threshold was higher in the boys (65 min·d^{-1}; 95% CI, 55–75) compared to the girls (49 min·d^{-1}; 95% CI, 43–62). The overall threshold for VPA was 14 min·d^{-1} (95% CI, 11–16), and the threshold was higher in the boys (20 min·d^{-1}; 95% CI, 16–22) compared to the girls (11 min·d^{-1}; 95% CI, 9–13). The overall threshold for sedentary time was 482 min·d^{-1} (95% CI, 455–535) and was similar in the girls (497 min·d^{-1}; 95% CI, 449–534) and boys (482 min·d^{-1}; 95% CI, 455–554). In country-specific analyses (results not shown), the thresholds ranged from 39 to 72 min·d^{-1} for MVPA in 10 sites where the AUC was significant; from 8 to 22 min·d^{-1} for VPA in the 12 sites where the AUC was significant; and from 475 to 609 min·d^{-1} for sedentary behavior in 8 sites where the AUC was significant.

In sensitivity analyses conducted using the Treuth et al. (27) thresholds for MVPA, the associations between MVPA and obesity were similar. The odds ratio for obesity was similar (0.27; 95% CI, 0.23–0.33), and the association between MVPA and obesity remained significant in all 12 study sites. The AUC for the ROC curve analysis was also significant when using the Treuth et al. (27) MVPA threshold (AUC, 0.66; 95% CI, 0.65–0.67). The associations observed when using the WHO BMI thresholds (4) were also maintained when using the CDC BMI thresholds (14). For example, the odds ratios (per SD) for obesity were similar for MVPA (0.47; 95% CI, 0.42–0.53), VPA (0.38; 95% CI, 0.34–0.43), and sedentary time (1.18; 95% CI, 1.07–1.32) in the overall sample when applying the CDC thresholds. Furthermore, the associations of MVPA and VPA with obesity remained significant in all 12 sites, and the association between sedentary time and obesity remained significant in four of the 12 sites, respectively.

DISCUSSION

Time spent in MVPA and VPA was consistently associated with obesity in this multinational sample of children, and the optimal threshold of 55 min·d^{-1} of MVPA supports global recommendations, which call for 60 min·d^{-1} of physical activity for children and youth (33). The robust, standardized data collection procedures used across all world regions in this study and the consistency of the relationship across countries at different stages of economic and epidemiologic transition strongly indicate that physical activity is a robust correlate of obesity across different cultures, races, and geographical settings. The relationship between sedentary time and obesity is weaker, not independent of MVPA, and less consistent across the study sites.

The results support the conclusion of the *2008 Physical Activity Recommendations for Americans* that "Regular physical activity in children and adolescents promotes a healthy body weight and body composition" (32). Indeed, results from the National Institute of Child Health and Human Development Study of Early Child Care and Youth Development demonstrated that time spent in MVPA was negatively associated with changes in BMI from 9 to 15 yr of age (19). The results of the present study confirm the association between MVPA and obesity in US children and extend the results to other world regions. Accelerometers are now ubiquitous in physical activity research as well as in "real-world" settings, as smart phones and other

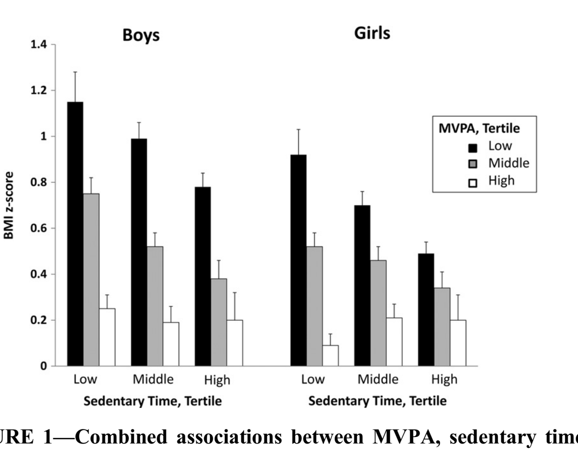

FIGURE 1—Combined associations between MVPA, sedentary time, and BMI z-scores in 2985 boys and 3554 girls. P < 0.001 for differences across tertiles of MVPA in both boys and girls and P = 0.20 in boys and P = 0.73 in girls for differences across tertiles of sedentary time. The results are from multilevel mixed models including both variables simultaneously. Error bars represent standard errors.

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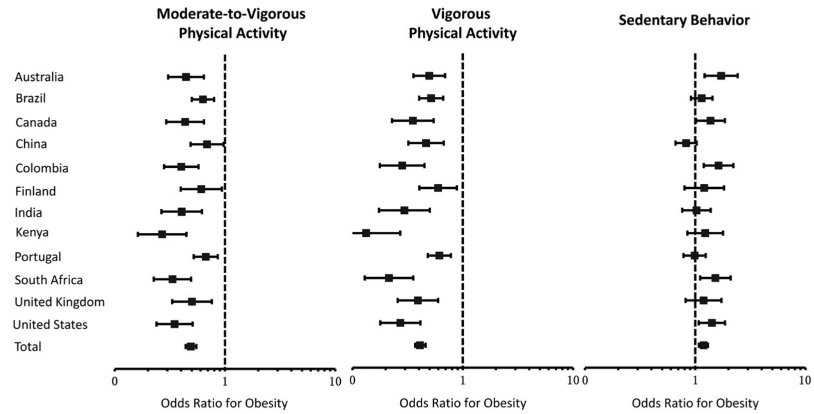

FIGURE 2—Associations between MVPA, VPA, sedentary time, and obesity in 6539 9- to 11-yr-old children from 12 study sites around the world. Odds ratios are expressed per 25 minutes of daily MVPA, 10 min of daily VPA, and 70 min of sedentary behavior, adjusted for sex and waking wear time. Error bars represent 95% CI.

commercial devices such as wrist band physical activity monitors have proliferated in the marketplace (15). Whereas current physical activity recommendations were largely informed by studies relying on self-reported measures of physical activity, objective data such as those reported in the present study have the potential to inform future physical activity guidelines with real-world significance. However, there is a need for independent validation of new devices as they come into the market to ensure they are measuring what they purport to measure.

The results of the present study also support data from regional multinational studies that have objectively measured physical activity by accelerometry. Although limited to European children, time spent in MVPA was significantly inversely associated with body fatness (sum of skinfolds) in 1292 nine- to 10-yr-old children from four countries in the European Youth Heart Study.(7) Results of cluster analyses among 766 10- to 12-yr-old European children participating in the ENERGY study indicated that both higher MVPA and lower sedentary time in girls was associated with lower BMI; however, MVPA was the dominant correlate in boys (3). Furthermore, ROC curve analyses among 2094 adolescents from the HELENA study in Europe identified an optimal threshold of 55 min·d^{-1} for differentiating obese from normal weight youth, and their thresholds were similarly higher in the boys (56 min·d^{-1}) compared to the girls (49 min·d^{-1}) (17). This sex difference in physical activity levels associated with obesity has also been reported when using steps per day as a metric (31). The underlying mechanism for this sex difference is not understood; however, girls tend to have higher levels of percent body fat for a given BMI percentile (10), which could influence the associations with physical activity. The results of the present multinational study extend those of these smaller studies that were limited to European context and confirm that MVPA is a robust correlate of obesity in multiple economic and geographic settings.

The finding in the present study that time spent in MVPA was more consistently related to obesity than time spent in sedentary behavior supports results from the International Children's Accelerometry Database (ICAD; n = 20,871), which indicated that MVPA, but not sedentary time, was associated with cardiometabolic risk factors, including waist circumference (6). The ICAD analysis provides a wealth of important information, although it is limited to data from studies conducted in the United States, Europe, and Brazil using different protocols (6). The present study expands upon these data by the use of a standardized protocol across the 12 sites from five different world regions and confirms that MVPA is more strongly related to obesity than sedentary behavior among 9- to 11-yr-old children. The reason for the lack of association between sedentary time and obesity

TABLE 3. Results of ROC curve analyses for the associations among MVPA, VPA, sedentary time, and obesity in 6539 9- to 11-yr-old children.

	AUC (95% CI)[a]	Youden Index	Threshold, min·d^{-1} (95% CI)	Sensitivity (%)	Specificity (%)
MVPA					
Boys (n = 2985)	0.68 (0.67–0.70)	0.267	65 (55–75)	70	57
Girls (n = 3554)	0.66 (0.64–0.68)	0.246	49 (43–62)	70	55
Total (n = 6539)	0.64 (0.63–0.65)	0.207	55 (50–64)	65	55
VPA					
Boys (n = 2985)	0.72 (0.70–0.73)	0.327	20 (16–22)	80	52
Girls (n = 3554)	0.68 (0.67–0.70)	0.280	11 (9–13)	62	66
Total (n = 6539)	0.67 (0.66–0.68)	0.247	14 (11–16)	63	62
Sedentary time					
Boys (n = 2985)	0.58 (0.56–0.60)	0.126	482 (455–554)	72	41
Girls (n = 3554)	0.57 (0.56–0.59)	0.113	497 (449–534)	74	38
Total (n = 6539)	0.57 (0.56–0.58)	0.101	482 (455–535)	75	35

[a]AUC significantly lower for sedentary time versus both VPA and MVPA, and AUC significantly lower MVPA versus vigorous physical activity in boys, girls, and the total sample (all $P < 0.001$). Comparison of ROC curves following the methods of DeLong et al. (5).

in some countries is not known. Television viewing is one type of sedentary behavior that has been more strongly associated with obesity in children than global measures of overall sedentary time (26). Television viewing may be a more prominent activity in the developed countries, where an association was found (Australia, Canada, Colombia, South Africa, and the United States), which may partially explain the greater associations observed in these countries. However, more research is required to better understand associations among indicators of specific sedentary behaviors and health outcomes such as obesity.

The results of the sensitivity analyses indicate that similar associations with obesity are obtained when using different MVPA thresholds or different definitions of obesity. We chose to use the Evenson et al. (8) MVPA threshold for our primary analysis, as a 15-s epoch may be more appropriate than a 60-s epoch to capture the sporadic nature of children's activity, and it provides the best classification accuracy among the currently available thresholds for sedentary, light-, moderate-, and vigorous-intensity activity in children and adolescents (28). Furthermore, we chose to use the WHO BMI thresholds given that this is an international study of children from five world regions. However, the consistency of the results when using the CDC BMI thresholds is encouraging and suggests that our results may be comparable to other studies that have used the CDC thresholds.

This study has several strengths and limitations that warrant discussion. A marked strength is the large diverse sample of children from study sites from every world region, which varied in their prevalence of obesity, MVPA, VPA, and sedentary behavior. This served to increase the variability among the dependent and independent variables and increased the generalizability of the results. Hence, the results strongly indicate that the associations seen between physical activity and obesity are robust and not related to certain types of cultures, races, or geographical settings. An additional strength is the rigorous standardization of the protocol across all study sites, which included the use of the same anthropometric equipment and the same model of accelerometer to objectively monitor physical activity and sedentary behavior at all study sites. Furthermore, all data management and analysis were centrally conducted at the coordinating center, which assured consistency in data handling and interpretation.

The cross-sectional design of this study limits conclusions regarding cause-and-effect relationships and the direction of the associations observed. Furthermore, we cannot exclude the possibility that unmeasured confounding variables may explain some of the observed relationships. The results for MVPA and VPA were very consistent across the study sites, but it is not known whether lower levels of physical activity are the cause or the consequence of obesity in this sample of children. We objectively assessed physical activity and sedentary behavior using accelerometry; however, a limitation of this approach is the inability to quantify some physical activities such as cycling and swimming. It should be noted that the optimal threshold (identified as 55 min·d^{-1} MVPA in this study) may vary according to the method and algorithm used in classifying physical activity intensity and hence the threshold should be regarded as showing the approximate magnitude rather than an exact value. Finally, we used a threshold of 25 or less counts per 15 s to quantify time spent in sedentary behavior. Although this is commonly used threshold that is related to sitting in children during school hours (23), it does not measure "sitting" *per se* nor time spent in specific sedentary behaviors such as TV viewing; rather, it captures nonmovement and time spent in low-intensity movements. Further research using devices that capture posture in addition to intensity is required to better quantify sedentary behavior in children.

In conclusion, higher levels of MVPA and VPA were associated with lower odds of obesity in this multinational sample of children, independent of sedentary behavior. Attaining at least 55 min·d^{-1} of MVPA seems to be associated with lower obesity, which supports guidelines that call for 60 min·d^{-1} of MVPA in childhood. The implementation of a standardized protocol across countries that vary widely in economic and epidemiologic transition highlights the robustness of the relationship between physical activity and obesity in children.

Funding/Support: ISCOLE was funded by The Coca-Cola Company. The funder had no role in the design and conduct of the study; collection, management, analysis, and interpretation of the data; and preparation, review, or approval of the manuscript.

The authors thank the ISCOLE External Advisory Board and the ISCOLE participants and their families who made this study possible. The ISCOLE Research Group includes the following: *Coordinating Center*, Pennington Biomedical Research Center: Peter T. Katzmarzyk, PhD (co-PI), Timothy S. Church, MD, PhD (co-PI), Denise G. Lambert, RN (Project Manager), Tiago Barreira, PhD, Stephanie Broyles, PhD, Ben Butitta, BS, Catherine Champagne, PhD, RD, Shannon Cocreham, MBA, Kara Dentro, MPH, Katy Drazba, MPH, Deirdre Harrington, PhD, William Johnson, PhD, Dione Milauskas, MS, Emily Mire, MS, Allison Tohme, MPH, Ruben Rodarte MS, MBA; *Data Management Center, Wake Forest University*: Bobby Amoroso, BS, John Luopa, BS, Rebecca Neiberg, MS, Scott Rushing, BS; *Australia, University of South Australia*: Timothy Olds, PhD (site co-PI), Carol Maher, PhD (site co-PI), Lucy Lewis, PhD, Katia Ferrar, B Physiol (Hon), Effie Georgiadis, BPsych, Rebecca Stanley, BAppSc (OT) Hon; *Brazil, Centro de Estudos do Laboratório de Aptidão Física de São Caetano do Sul (CELAFISCS)*: Victor Keihan Rodrigues Matsudo, MD, PhD (site PI), Sandra Matsudo, MD, PhD, Timoteo Araujo, MSc, Luis Carlos de Oliveira, MSc, Leandro Rezende, BSc, Luis Fabiano, BSc, Diogo Bezerra, BSc, Gerson Ferrari, MSc; *Canada, Children's Hospital of Eastern Ontario Research Institute*: Mark S. Tremblay, PhD (site co-PI), Jean-Philippe Chaput, PhD (site co-PI), Priscilla Bélanger, MA, Mike Borghese, MSc, Charles Boyer, MA, Allana LeBlanc, MSc, Claire Francis, MSc, Geneviève Leduc, PhD; *China, Tianjin Women's and Children's Health Center*: Pei Zhao, MD (site co-PI), Gang Hu, MD, PhD (site co-PI), Chengming Diao, MD, Wei Li, MD, Weiqin Li, MSc, Enqing Liu, MD, Gongshu Liu, MD, Hongyan Liu, MSc, Jian Ma, MD, Yijuan Qiao, MSc, Huiguang Tian, PhD, Yue Wang, MD, Tao Zhang, MSc, Fuxia Zhang, MD; *Colombia, Universidad de los Andes*: Olga Sarmiento, MD, PhD (site PI), Julio Acosta, Yalta Alvira, BS, Maria Paula Diaz, Rocio Gamez, BS, Maria Paula Garcia, Luis Guillermo Gómez, Lisseth Gonzalez, Silvia Gonzalez, RD, Carlos Grijalba, MD, Leidys Gutierrez, David Leal, Nicolas Lemus, Etelvina Mahecha, BS, Maria Paula Mahecha, Rosalba Mahecha, BS, Andrea Ramirez, MD, Paola Rios, MD, Andres Suarez, Camilo Triana; *Finland, University of*

Helsinki: Mikael Fogelholm, ScD (site PI), Elli Hovi, BS, Jemina Kivelä, Sari Räsänen, BS, Sanna Roito, BS, Taru Saloheimo, MS, Leena Valta; *India, St. Johns Research Institute*: Anura Kurpad, MD, PhD (site co-PI), Rebecca Kuriyan, PhD (site co-PI), Deepa P. Lokesh, BSc, Michelle Stephanie D'Almeida, BSc, Annie Mattilda R, MSc, Lygia Correa, BSc, Vijay D, BSc; *Kenya, Kenyatta University*: Vincent Onywera, PhD (site co-PI), Mark S. Tremblay, PhD (site Co-PI), Lucy-Joy Wachira, PhD, Stella Muthuri, PhD; *Portugal, University of Porto*: Jose Maia, PhD (site PI), Alessandra da Silva Borges, BA, Sofia Oliveira Sá Cachada, Msc, Raquel Nichele de Chaves, MSc, Thayse Natacha Queiroz Ferreira Gomes, MSc, Sara Isabel Sampaio Pereira, BA, Daniel Monteiro de Vilhena e Santos, PhD, Fernanda Karina dos Santos, MSc, Pedro Gil Rodrigues da Silva, BA, Michele Caroline de Souza, MSc; *South Africa, University of Cape Town*: Vicki Lambert, PhD (site PI), Matthew April, BSc (Hons), Monika Uys, BSc (Hons), Nirmala Naidoo, MSc, Nandi Synyanya, Madelaine Carstens, BSc(Hons); *United Kingdom, University of Bath*: Martyn Standage, PhD (site PI), Sean Cumming, PhD, Clemens Drenowatz, PhD, Lydia Emm, MSc, Fiona Gillison, PhD, Julia Zakrzewski, PhD; *United States, Pennington Biomedical Research Center*: Catrine Tudor-Locke, PhD (site PI), Ashley Braud, Sheletta Donatto, MS, LDN, RD, Corbin Lemon, BS, Ana Jackson, BA, Ashunti Pearson, MS, Gina Pennington, BS, LDN, RD, Daniel Ragus, BS, Ryan Roubion, John Schuna, Jr., PhD; Derek Wiltz. *The ISCOLE External Advisory Board* includes Alan Batterham, PhD, Teesside University, Jacqueline Kerr, PhD, University of California, San Diego; Michael Pratt, MD, Centers for Disease Control and Prevention; Angelo Pietrobelli, MD, Verona University Medical School.

Dr. Church receives honoraria for lectures from scientific, educational, and lay groups. Dr. Church has a book entitled *Move Yourself: The Cooper Clinic Medical Director's Guide to All the Healing Benefits of Exercise*. Dr. Church is a member of the Jenny Craig/Curves Medical Advisory Board as well as the Utilifit/FIX Corporate advisory board. Dr. Church has consulted for Medscape, Vivus, and Takada, and he serves as the Senior Medical Advisor for Catapult Health and the Chief Medical Officer at ACAP health. Dr. Fogelholm has received a research grant from Fazer Finland. Dr. Kurpad is a member of the Advisory Board of McCain Foods. Dr. Matsudo is a member of the Scientific Advisory Board of Actigraph. The authors report no other potential conflicts of interest. The results of the present study do not constitute endorsement by the American College of Sports Medicine.

The International Study of Childhood Obesity, Lifestyle and the Environment (ISCOLE) is registered at ClinicalTrials.gov (Identifier NCT01722500).

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