

*Citation for published version:*

Chaput, J-P, Barnes, JD, Tremblay, MS, Fogelholm, M, Hu, G, Lambert, EV, Maher, C, Maia, J, Olds, T, Onywera, V, Sarmiento, OL, Standage, M, Tudor-Locke, C & Katzmarzyk, PT 2018, 'Thresholds of physical activity associated with obesity by level of sedentary behaviour in children', *Pediatric Obesity*, vol. 13, no. 7, pp. 450-457. <https://doi.org/10.1111/ijpo.12276>

*DOI:*

[10.1111/ijpo.12276](https://doi.org/10.1111/ijpo.12276)

*Publication date:*

2018

*Document Version*

Peer reviewed version

[Link to publication](#)

This is the peer reviewed version of the following article: J.-P. Chaput J. D. Barnes M. S. Tremblay M. Fogelholm G. Hu E. V. Lambert C. Maher J. Maia T. Olds V. Onywera O. L. Sarmiento M. Standage C. Tudor-Locke P. T. Katzmarzyk (2018) Thresholds of physical activity associated with obesity by level of sedentary behaviour in children. *Pediatric Obesity*, 13(7), which has been published in final form at [doi.org/10.1111/ijpo.12276](https://doi.org/10.1111/ijpo.12276). This article may be used for non-commercial purposes in accordance with Wiley Terms and Conditions for Self-Archiving.

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## Thresholds of physical activity associated with obesity by level of sedentary behavior in children

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**Running Title:** Physical activity, sedentary behavior, and obesity

**Keywords:** moderate-to-vigorous physical activity, screen time, sedentary time, guidelines, recommendations, adiposity

**Trial Registration:** ClinicalTrials.gov: Identifier NCT01722500

**Abbreviations:** AUC, area under the curve; BMI, body mass index, CDC, Centers for Disease Control and Prevention; IOTF, International Obesity Task Force; ISCOLE, International Study of Childhood Obesity, Lifestyle and the Environment; MVPA, moderate-to-vigorous physical activity; ROC, receiver operating characteristic; SD, standard deviation; SED, sedentary time; ST, screen time; WHO, World Health Organization

**Word Count:** 2577 words

## **Abstract**

**Background:** It is unknown whether moderate-to-vigorous physical activity (MVPA) thresholds for obesity should be adapted depending on level of sedentary behavior in children.

**Objective:** To determine the MVPA thresholds that best discriminate between obese and non-obese children, by level of screen time and total sedentary time in 12 countries.

**Methods:** This multinational, cross-sectional study included 6522 children 9-11 years of age. MVPA and sedentary time were assessed using waist-worn accelerometry, while screen time was self-reported. Obesity was defined according to the World Health Organization reference data.

**Results:** ROC curve analyses showed that the best thresholds of MVPA to predict obesity ranged from 53.8 to 73.9 min/day in boys and from 41.7 to 58.7 min/day in girls, depending on the level of screen time. The MVPA cut-offs to predict obesity ranged from 37.9 to 75.9 min/day in boys and from 32.5 to 62.7 min/day in girls, depending on the level of sedentary behavior. The areas under the curve (AUC) ranged from 0.57 to 0.73 (“fail” to “fair” accuracy) and most sensitivity and specificity values were below 85%, similar to MVPA alone. Country-specific analyses provided similar findings.

**Conclusions:** The addition of sedentary behavior levels to MVPA did not result in a better predictive ability to classify children as obese/non-obese compared with MVPA alone.

## Introduction

Public health authorities around the world agree that children should accumulate at least 60 minutes of moderate- to vigorous-intensity physical activity (MVPA) daily to accrue optimal health benefits.<sup>1-4</sup> Although the exact amount of MVPA needed for optimal health is still debated, higher MVPA is generally associated with lower adiposity indicators in children.<sup>5</sup> Further to the health-promoting effects of MVPA, recent studies have reported a negative association between sedentary behavior (especially screen time) and health indicators in children.<sup>6</sup> Public health guidelines for sedentary behavior are relatively new, and generally focus on screen time.<sup>7-9</sup> Typically, these guidelines recommend that time spent sedentary be minimized, and time spent in recreational screen time be limited to no more than 2 hours per day for children.<sup>7-9</sup> Given that only a weak association exists between MVPA and sedentary behavior in children ( $r=-0.11$ ),<sup>10</sup> it is important to better understand the joint associations of these behaviors with health indicators such as obesity.

Although a growing body of studies have examined how combinations of physical activity and sedentary behavior are associated with health indicators in children,<sup>11-13</sup> no studies to date have determined whether the optimal thresholds of MVPA vary according to the level of sedentary behavior. For example, we have recently published data showing that 55 min/day was the MVPA threshold that best discriminate between obese and non-obese children.<sup>14</sup> Yet, sedentary behavior level is highly variable between individuals,<sup>9</sup> so it is reasonable to assume that MVPA recommendations should be adapted based on volume of sedentary behavior. This approach is also aligned with recent 24-hour and integrated movement behavior guidelines for health

promotion, shifting the thinking from “isolated movement behaviors” to the concept that “the whole day matters”.<sup>7</sup>

The objective of this study was to determine thresholds of MVPA associated with obesity, by level of screen time and total sedentary time, in children from around the world. We hypothesized that optimal MVPA thresholds would vary depending on volume of sedentary behavior in this multinational study of children.

## **Methods**

### Study Design and Setting

The International Study of Childhood Obesity, Lifestyle and the Environment (ISCOLE) is a cross-sectional, multinational study designed to examine the relationships between lifestyle behaviors and obesity in children from all inhabited continents of the world. ISCOLE included 12 study sites (Australia, Brazil, Canada, China, Colombia, Finland, India, Kenya, Portugal, South Africa, United Kingdom, and United States), representing a wide range of economic development (low to high income), Human Development Index (0.509 in Kenya to 0.929 in Australia), and income inequality (Gini index of 26.9 in Finland to 63.1 in South Africa).<sup>15</sup> Details about ISCOLE have been published elsewhere.<sup>15</sup> By design, the samples were not intended to be nationally representative but comprised children from urban and suburban sites and were stratified by indicators of socioeconomic status to maximize variability within sites. A standardized protocol was followed to collect data across all sites, and study personnel underwent rigorous training and certification to ensure high-quality data. The Pennington Biomedical Research Center Institutional Review Board as well as Institutional/Ethical Review

Boards at each site approved the study. Written informed consent was obtained from parents/legal guardians, and child assent was also obtained as required by local ethics review boards. Data were collected during the school year at each study site and testing occurred between September 2011 and December 2013.

## Participants

ISCOLE included 9- to 11-year-old children at each site. Based on *a priori* sample size and power calculations,<sup>15</sup> a sex-balanced sample of at least 500 children per site were recruited. Of the 7372 children who participated in ISCOLE, a total of 6522 remained in the final analytical sample after excluding participants with missing data on body mass index (BMI), accelerometry and screen time. Except for higher BMI z-scores, children who were excluded for missing data did not significantly differ from those who were included in the present analysis.

## Measurements

### *Physical Activity, Sedentary Time, and Screen Time*

MVPA and total sedentary time were objectively-assessed using 24-h, waist-worn accelerometry.<sup>16</sup> An Actigraph GT3X+ accelerometer (ActiGraph LLC, Pensacola, FL, USA) was worn at the waist on an elasticized belt at the right mid-axillary line. Participants were encouraged to wear the accelerometer 24 h per day (removing only for water-based activities) for at least 7 days, including 2 weekend days. Overall, mean 24-h wear time and wake wear time were 22.6 h/day and 14.9 h/day in ISCOLE, respectively. The minimal amount of daytime data that was considered acceptable for inclusion was at least 4 days with at least 10 h of wake wear

time per day, including at least 1 weekend day. Data were collected at a sampling rate of 80 Hz, downloaded in 1-s epochs with the low-frequency extension filter using the ActiLife software version 5.6 or higher (ActiGraph LLC, Pensacola, FL, USA), and reintegrated to 15-s epochs for analysis. After exclusion of sleep period time<sup>17,18</sup> and awake non-wear time (any sequence of  $\geq 20$  consecutive minutes of zero activity counts), MVPA was defined as all activity  $\geq 574$  counts/15 s and total sedentary time as all movement  $\leq 25$  counts/15 s, consistent with the Evenson cutoffs.<sup>19</sup> Child-reported screen time was assessed using questions from the U.S. Youth Risk Behavior Surveillance System.<sup>20</sup> Children were asked to report how many hours they typically watched TV, and how many hours they played video games and/or used the computer per weekday, and per weekend day. As previously reported,<sup>21</sup> a daily average screen time score was calculated by weighting the responses for each question (2/7 for weekend and 5/7 for weekday). Scores from self-report methods of quantifying screen time have been reported to have acceptable reliability and validity in children.<sup>22,23</sup>

#### *Ascertainment of Obesity*

Body mass was measured with a Tanita SC-240 scale (Arlington Heights, IL, USA), after all outer clothing, heavy pocket items and shoes were removed. Body height was assessed without shoes using a Seca 213 portable stadiometer (Hamburg, Germany). 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 kg or 0.5 cm apart for body mass and body height, respectively, and the average of the two closest measurements was used for analysis). BMI ( $\text{kg}/\text{m}^2$ ) was calculated, and BMI z-scores were computed using age- and sex-specific reference

data from the World Health Organization.<sup>24</sup> Participants were classified as obese (BMI z-score > +2 SD) or non-obese (BMI z-score  $\leq$  +2 SD).<sup>24</sup>

## Statistical Analysis

Descriptive characteristics of participants were computed by study site. Receiver operating characteristic (ROC) curves were used to identify thresholds of MVPA associated with obesity, according to level of sedentary behavior. In the full sample (all sites combined), we used 6 categories of screen time ( $\leq$ 1 h/day, 1.1–2.0 h/day, 2.1–3.0 h/day, 3.1–4.0 h/day, 4.1–5.0 h/day, and  $\geq$ 5.1 h/day) and 6 categories of sedentary behavior (sextiles), based on variability in the data and to examine potential dose-response gradients. In site-stratified analyses, we used 3 categories of screen time ( $\leq$ 2 h/day, 2.1–4.0 h/day, and  $\geq$ 4.1 h/day) and 3 categories of sedentary behavior (tertiles), due to reduced statistical power. The area under the curve (AUC) is considered a measure of the predictive ability of a classifier variable (e.g., obese or non-obese) and represents the relationship between the true positive rate (obese participants classified as obese divided by all obese participants), or sensitivity, and the false positive rate (non-obese participants classified as obese divided all non-obese participants), or 1 – specificity, across all possible classification thresholds. An AUC of 1 indicates the ability to correctly classify obese and non-obese participants across all possible classification thresholds, whereas an AUC of 0.5 indicates no greater predictive ability than by chance alone. The categories used to interpret the AUCs in ROC curve analyses were as follows: “excellent” (0.9–1.0), “good” (0.8–0.9), “fair” (0.7–0.8), “poor” (0.6–0.7) and “fail” (0.5–0.6).<sup>25,26</sup> A test with an AUC  $\geq$ 0.85 is generally considered an accurate test.<sup>26</sup> The optimal thresholds of MVPA were determined from the Youden index,<sup>27</sup>



which is the maximum value of  $J$  ( $J = \text{sensitivity} + \text{specificity} - 1$ ). Statistical significance of differences in AUCs between sites was assessed by using the non-parametric approach of DeLong et al.,<sup>28</sup> and Bonferroni corrections were made to account for multiple group comparisons.

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.<sup>29</sup> (3000 counts per minute) rather than the Evenson et al.<sup>19</sup> threshold. Second, the associations were reanalyzed after reclassifying participants as obese and non-obese using the International Obesity Task Force (IOTF) thresholds<sup>30</sup> as well as the Centers for Disease Control and Prevention (CDC) thresholds.<sup>31</sup> Statistical analyses were performed using R version 3.4.1 (The R Foundation for Statistical Computing, Vienna, Austria) and JMP version 13 (SAS Institute, Cary, NC, USA).

## **Results**

Table 1 presents descriptive characteristics of the sample stratified by study site. The overall prevalence of obesity was 12.2% and ranged from 5.4% (Finland) to 24.4% (China). Kenya (71.7 min/day) and Finland (70.7 min/day) had the highest levels of MVPA among ISCOLE sites. Total sedentary time was highest in China (9.4 h/day) and lowest in Australia (8.0 h/day). Finally, screen time was highest in Brazil (3.9 h/day) and lowest in India (2.0 h/day).

Table 2 shows the results of the ROC curve analyses for the associations between MVPA and obesity, according to the level of screen time in the full study sample (all sites combined). AUC

results ranged from 0.57 (“fail”) to 0.73 (“fair”), and most sensitivity and specificity values were below 85% (range: 53-89%). The MVPA cut-offs for predicting obesity ranged from 53.8 to 73.9 min/day in boys and from 41.7 to 58.7 min/day in girls, depending on the level of screen time. In country-specific analyses (Table S1), AUC values also ranged from “fail” to “fair”, and most sensitivity and specificity values were <85% (i.e., inaccurate test). The MVPA thresholds for predicting obesity ranged from 29.3 min/day (Australia) to 72.5 min/day (Colombia).

Table 3 presents findings of the ROC curve analyses for the associations between MVPA and obesity, according to the level of total sedentary behavior in the full study sample. AUC results also ranged from 0.57 (“fail”) to 0.73 (“fair”), and all sensitivity and specificity values were <85% (range: 49-84%). The MVPA cut-offs for predicting obesity ranged from 37.9 to 75.9 min/day in boys and from 32.5 to 62.7 min/day in girls, depending on the level of sedentary time. In country-specific analyses (Table S2), AUC values also ranged from “fail” to “good”, and most sensitivity and specificity values were <85%. The MVPA threshold for predicting obesity ranged from 27.6 min/day (Brazil) to 85.6 min/day (Finland). Differences between countries were not significant after Bonferroni adjustment.

In sensitivity analyses conducted using the MVPA threshold of Treuth et al.,<sup>29</sup> the findings were very similar (data not shown). Likewise, using the IOTF<sup>30</sup> or the CDC<sup>31</sup> thresholds for obesity resulted in similar findings (data not shown).

## Discussion

Collectively, stratifying by sedentary behavior levels did not result in a better predictive ability of MVPA to classify children as obese/non-obese than with MVPA alone, as reported in a previous paper.<sup>14</sup> These findings reinforce the fact that obesity is a multifactorial condition, and both MVPA and sedentary behavior, alone or in combination, are not able to accurately detect children with obesity. Further studies are needed to replicate these findings, especially with health indicators other than obesity.

The present findings suggest that the current physical activity recommendations (at least 60 minutes of MVPA per day) are aligned with the prediction of obesity in this sample.<sup>1-4</sup> Katzmarzyk et al.<sup>14</sup> reported a MVPA threshold of 55 min/day for predicting obesity, higher in boys (65 min/day) than girls (49 min/day). Data from the HELENA study in Europe also showed an optimal MVPA threshold of 55 min/day for differentiating obese from normal-weight adolescents.<sup>33</sup> The optimal MVPA threshold was also higher in boys (56 min/day) compared to girls (49 min/day). Optimal standards for pedometer-assessed steps/day related to healthy body composition have also been shown to be higher in boys compared to girls.<sup>34</sup> The reasons underlying this sex difference are still debated; however, girls tend to have more adiposity than boys for a given BMI percentile<sup>35</sup> and are also less active,<sup>5</sup> which could influence the reported associations.

The observation that stratification by sedentary or screen time did not provide better predictive ability to classify obesity than MVPA alone suggests that MVPA guidelines may apply broadly

to all children. This finding also supports the study of Ekelund et al.,<sup>13</sup> showing that higher MVPA is associated with better cardio-metabolic risk factors in children (including waist circumference), regardless of the amount of sedentary time. Furthermore, the present findings remind us that obesity is a complex condition with multiple contributors. MVPA is only one of them, and its ability to classify children as obese/non-obese is not very accurate.

Although we observed some variation in the optimal MVPA thresholds by level of sedentary behavior in the present study, the ROC curve data were not better when we added either screen time or total sedentary behavior to MVPA than with the use of MVPA alone.<sup>14</sup> Country-specific analyses, albeit limited due to reduced sample size, also suggest no better accuracy in differentiating obese from normal-weight children with the combination of MVPA/sedentary time than with MVPA alone.<sup>14</sup>

Results of the sensitivity analyses showed that similar findings are obtained when using a different MVPA threshold (Treuth) or different definitions of obesity (IOTF or CDC). This consistency in the findings is encouraging and suggests that the results may be comparable to other studies that have used other thresholds. We used the MVPA threshold of Evenson et al.<sup>19</sup> in our primary analysis, because a 15-s epoch is more appropriate than a 60-s epoch to capture the sporadic nature of children's physical activity, and was shown to be the best accelerometer cut-point for predicting MVPA in children.<sup>32</sup> Moreover, we used the WHO definition of obesity in our primary analysis given that this is the one preferred in international studies of children.

This study has several strengths and limitations. An important strength is the multinational sample of children from low- to high-income countries across several regions of the world, with marked variability in MVPA and obesity data. We also used a highly standardized measurement protocol and a rigorous quality control program to ensure consistency and high-quality data across all sites.<sup>15</sup> MVPA and sedentary time were accelerometer-determined and we also used objective measures of BMI. However, our results need to be interpreted with the following limitations. First, the cross-sectional nature of the data precludes inferences about causality and directionality in the observed associations. Second, self-reported measures of screen time were used, which are prone to social desirability responding and recall bias. Third, ISCOLE was not designed to provide nationally representative data, thereby limiting generalizability of the findings. Fourth, the narrow age range limits our ability to extrapolate our results to other age groups. Finally, replication studies using outcome measures other than obesity are needed to determine whether or not including the amount of sedentary behavior to MVPA can provide an added value to its ability to predict health indicators of interest.

## **Conclusions**

Findings from this multinational study showed that stratification by sedentary behavior levels did not lead to a better predictive ability for discriminating between obese and non-obese children than with MVPA alone. These novel findings suggest that current MVPA guidelines may apply broadly to all children, regardless of their level of sedentary behavior. Future studies should conduct similar ROC curve analyses with outcomes other than obesity.

## **Conflicts of Interest Statement**

The authors have indicated they have no conflicts of interest to disclose.

## **Acknowledgements**

We wish to thank the ISCOLE External Advisory Board, ISCOLE participants and their families, and the ISCOLE Research Group. ISCOLE was funded by The Coca-Cola Company. With the exception of requiring that the study be global in nature, the funder had no role in the design and conduct of the study; collection, management, analysis, and interpretation of the data; preparation, review, or approval of the manuscript; and decision to submit the manuscript for publication.

J.-P.C. conceptualized and designed the study, carried out the statistical analyses, drafted the manuscript, and critically revised the manuscript. J.D.B. carried out the statistical analyses and critically revised the manuscript. M.S.T., M.F., G.H., E.V.L., C.M., J.M., T.O., V.O., O.L.S., M.S. and C.T.-L. conceptualized and designed the study, and critically revised the manuscript. P.T.K. obtained funding, conceptualized and designed the study, and critically revised the manuscript. All authors approved the final manuscript as submitted and agree to be accountable for all aspects of the work.

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**Table 1.** Descriptive characteristics of participants stratified by study site.

Country (site)	Participants ( <i>N</i> , % boys)	Age (years)	Obesity <sup>1</sup> (%)	MVPA <sup>2</sup> (min/day)	SED <sup>3</sup> (h/day)	Screen time score (h/day)
Australia (Adelaide)	490 (45.9)	10.8 (0.5)	10.4	64.7 (23.1)	8.0 (1.0)	3.0 (1.6)
Brazil (Sao Paulo)	484 (49.0)	10.5 (0.5)	21.7	59.7 (26.2)	8.3 (1.1)	3.9 (2.2)
Canada (Ottawa)	523 (41.5)	10.5 (0.4)	12.2	58.6 (19.4)	8.5 (1.0)	2.8 (1.8)
China (Tianjin)	499 (51.9)	9.9 (0.5)	24.4	45.2 (15.9)	9.4 (1.1)	2.2 (1.6)
Colombia (Bogotá)	857 (49.2)	10.5 (0.6)	5.7	68.1 (24.8)	8.3 (1.1)	3.0 (1.5)
Finland (Helsinki, Espoo, Vantaa)	504 (46.6)	10.5 (0.4)	5.4	70.7 (26.4)	8.8 (1.1)	3.0 (1.6)
India (Bangalore)	553 (45.9)	10.5 (0.5)	10.9	49.0 (21.3)	8.6 (1.1)	2.0 (1.2)
Kenya (Nairobi)	501 (46.3)	10.3 (0.7)	6.2	71.7 (31.4)	8.2 (1.1)	2.6 (1.7)
Portugal (Porto)	686 (44.5)	10.5 (0.3)	17.1	56.2 (21.5)	9.2 (1.0)	2.5 (1.4)
South Africa (Cape Town)	465 (39.4)	10.3 (0.7)	10.6	64.9 (25.3)	8.1 (1.1)	3.3 (2.0)
UK (Bath & North East Somerset)	478 (44.1)	10.9 (0.5)	9.1	63.4 (22.3)	8.3 (1.0)	3.2 (1.6)
USA (Baton Rouge)	482 (41.4)	10.0 (0.6)	16.8	49.8 (18.9)	8.7 (1.0)	3.4 (2.2)
All sites	6522 (45.7)	10.4 (0.6)	12.2	60.4 (24.8)	8.6 (1.2)	2.9 (1.8)

MVPA, moderate-to-vigorous physical activity; SED, sedentary time.

Data are shown as mean (SD) unless otherwise indicated.

<sup>1</sup>Obesity was defined according to the World Health Organization criteria.<sup>24</sup>

<sup>2</sup>MVPA and SED were measured with accelerometry and were defined as time spent at  $\geq 574$  counts/15 s and  $\leq 25$  counts/15 s, respectively.<sup>19</sup>