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Joint Association of Birth Weight and Physical Activity/Sedentary Behavior with Obesity in Children Ages 9-11 Years from 12 Countries

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Objective: To examine the joint association of birth weight and physical activity/sedentary time with childhood obesity in 12 countries.

Methods: A cross-sectional study of 5,088 children aged 9 to 11 years was conducted. Birth weight was recalled by parents or guardians. Moderate-to-vigorous physical activity (MVPA) and sedentary behavior were objectively measured using accelerometry.

Results: The association of birth weight with the odds of obesity, central obesity, and high body fat was significant among children with either low MVPA or high sedentary time but not among children with either high MVPA or low sedentary time. In comparison with children with normal birth weight and high MVPA, children with high birth weight and low MVPA showed 4.48- to 5.18-fold higher odds of obesity, central obesity, and high body fat; children with normal birth weight and low MVPA showed 3.00- to 3.30-fold higher odds of obesity, central obesity, and high body fat, and children with high birth weight and high MVPA showed 1.16- to 1.68-fold higher odds of obesity, central obesity, and high body fat.

Conclusions: High MVPA is more important than high birth weight as a correlate of obesity in children.

Obesity (2017) **25**, 1091-1097. doi:10.1002/oby.21792

Introduction

Obesity is an important lifestyle-related public health problem worldwide (1). The prevalence of childhood obesity has risen dramatically during the past few decades (2). Obesity has negative health impacts in childhood and later in life, as people with obesity experience adverse outcomes including hypertension, early markers of cardiovascular disease, insulin resistance, and adverse psychological effects (3).

Childhood obesity is potentially affected by many lifestyle factors, including moderate-to-vigorous physical activity (MVPA) and

sedentary behaviors (4). It has been shown that engaging in regular physical activity can reduce the risks of coronary heart disease, stroke, diabetes, and several types of cancer (5). Additionally, physical activity is a key determinant of daily energy expenditure and thus is fundamental to energy balance and weight control (5). The available evidence from prospective studies suggests that increased physical activity, MVPA, and decreased sedentary behavior are protective against relative gains in adiposity during childhood and adolescence (6).

Birth weight reflects the product of the growth trajectory during fetal life. Several studies have shown that high birth weight is

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See Commentary, pg. 985.

Funding agencies: The International Study of Childhood Obesity, Lifestyle, and the Environment (ISCOLE) was funded by The Coca-Cola Company. GH was supported by a grant from the National Institute of Diabetes and Digestive and Kidney Diseases of the National Institutes of Health under Award Number R01DK100790. 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.

Disclosure: The authors declared no conflict of interest.

Received: 26 July 2016; **Accepted:** 17 January 2017; **Published online** 25 May 2017. doi:10.1002/oby.21792

associated with higher levels of body weight or obesity in childhood (7-10). However, few studies have assessed the modifying effects of children's physical activity on the association between birth weight and subsequent obesity in childhood (11-13) or adulthood (14-16). The aim of the present study was to examine the cross-sectional joint association of birth weight and objectively determined physical activity/sedentary behavior with the odds of obesity in 9- to 11-year-old children from 12 countries.

Methods

Study design

The International Study of Childhood Obesity, Lifestyle, and the Environment (ISCOLE) is a multinational, cross-sectional study conducted at urban and suburban sites in 12 countries (Australia, Brazil, Canada, China, Colombia, Finland, India, Kenya, Portugal, South Africa, United Kingdom, and the United States) (17). More details on the study design and methods can be found elsewhere (17). 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.

Participants

A total of 7,372 children aged 9 to 11 years participated in ISCOLE, of whom 5,088 remained in the present study after excluding those who did not have valid accelerometer ($n = 1,214$), birth weight ($n = 698$), BMI ($n = 5$), waist circumference ($n = 3$), percentage of body fat ($n = 55$), gestational age ($n = 118$), or other information/data ($n = 191$). Children who were excluded from the present analysis did not differ in age or BMI z scores, but there were a higher proportion of boys excluded than included in the analysis (32.1% versus 30.0%). Data were collected from September 2011 through December 2013.

Measurements

Demographics and family health history. A demographic and family health history questionnaire was completed by parents or guardians. The questionnaire collected information on child age, sex, birth weight, infant feeding mode, gestational age, maternal history of gestational diabetes, and parent education. High birth weight was defined as birth weight $\geq 4,000$ g. Maternal history of gestational diabetes was recalled by parents or guardians. The highest parental education completed by the child's mother was asked, as was the highest level of education completed by the father. These responses were collapsed into three categories: did not complete high school, completed high school or some college, and completed bachelor or postgraduate degree. A derived variable was then created that represented the highest education level obtained by either parent, and if one of the parents' responses to this question was missing, the highest level obtained would be that of the parent who did provide data. The child's parents were asked whether the child was fed breast milk or not, age when they completely stopped being fed breast milk, age when first fed formula, and age when completely stopped drinking formula. These responses were classified into four categories: exclusive breast feeding, mixed feeding, weaned from breast feeding, and exclusive formula feeding.

Dietary intake. A food frequency questionnaire that was adapted from the Health Behavior in School-aged Children Survey (18) was administered to all ISCOLE participants. The food frequency questionnaire asked the participants about their "usual" consumption of 23 food categories, with response categories *never*, *less than once per week*, *once per week*, *2 to 4 days per week*, *5 to 6 days per week*, *once a day every day*, and *more than once a day*. Two diet scores that represent an "unhealthy diet pattern" (with positive loadings for fast food, hamburgers, soft drinks, sweets, fried food, etc.) and a "healthy diet pattern" (with positive loadings for vegetables, fruit, whole grains, low-fat milk, etc.) were obtained using principal components analyses (19,20).

Accelerometry. An ActiGraph GT3X+ accelerometer (ActiGraph, LLC, Pensacola, Florida) was used to objectively measure MVPA, sedentary behavior, and nocturnal sleeping time. The accelerometer was worn at the waist on an elasticized belt on the right midaxillary line. Participants were encouraged to wear the accelerometer 24 hours per day (removing only for water-related activities) for at least 7 days (plus an initial familiarization day and the morning of the final day), including two weekend days. The minimal amount of accelerometer data that was considered acceptable was 4 days with at least 10 hours of waking wear time per day, including at least one weekend day (17). Several studies have indicated that 4 to 7 days of accelerometry data provide reliable estimates of usual physical activity (21,22). Nocturnal sleep duration was estimated from the accelerometer data using a fully automated algorithm for 24-hour waist-worn accelerometers that was recently validated for ISCOLE (23). This new algorithm produces more precise estimates of sleep duration than previous algorithms and captures total sleep time from sleep onset to the end of sleep, including all epochs and wakefulness after onset (23). The weekly total sleep time averages were calculated using only days when valid sleep was accumulated (total sleep period time ≥ 160 min) and only for participants with at least three nights of valid sleep, including one weekend day (24). After exclusion of total sleep time and awake nonwear time (any sequence of ≥ 20 consecutive minutes of zero activity counts), MVPA was defined as all activity ≥ 574 counts per 15 seconds and total sedentary activity as all movement ≤ 25 counts per 15 seconds, which was consistent with the widely used cutoffs from Evenson et al (25). High (versus low) MVPA was defined as accumulating an average of at least 60 minutes of daily MVPA, similar to the WHO global recommendations on physical activity for health (5); sedentary behavior was defined as accumulating an average of at least 482 minutes of sedentary time daily, based on a cutoff developed previously in ISCOLE (4).

Anthropometric measurements. A battery of anthropometric measurements was taken according to standardized procedures across all study sites. Height was measured without shoes using a Seca 213 portable stadiometer (Seca, Hamburg, Germany), with the participant's head in the Frankfurt plane. Waist circumference was measured with a nonelastic tape held midway between the lower rib margin and the iliac crest at the end of a gentle expiration (26). Waist circumference was measured on the bare skin in all countries except in Australia, where it was measured over light clothing. The regression equation ($y = 0.994 \times -0.42$) developed by McCarthy et al. was applied to the Australian data to correct for the over-the-clothes measurement (27). Each measurement was repeated, and the average was used for analyses (a third measurement was obtained if

TABLE 1 Characteristics of study participants

Characteristic	Overall (N = 5,088)	Normal birth weight (n = 4,607)	High birth weight (n = 481)	P value
Age, mean (SD), y	10.4 (0.6)	10.4 (0.6)	10.4 (0.5)	0.12
Male, %	45.7	44.3	58.4	<0.001
Body weight, mean (SD), kg	37.5 (9.4)	37.1 (9.3)	40.6 (9.9)	<0.001
Body height, mean (SD), cm	142 (7.5)	142 (7.5)	145 (7.5)	<0.001
BMI, mean (SD), kg/m ²	18.4 (3.4)	18.3 (3.4)	19.1 (3.7)	<0.001
Waist circumference, mean (SD), cm	64.2 (8.9)	64.1 (8.8)	66.1 (9.1)	<0.001
Body fat, mean (SD), %	20.8 (7.6)	20.8 (7.6)	21.2 (8.1)	0.31
Birth weight, mean (SD), g	3277 (581)	3171 (495)	4294 (295)	<0.001
Moderate-to-vigorous physical activity, mean (SD), min/d	60.0 (24.8)	59.4 (24.7)	65.0 (25.2)	<0.001
Sedentary, mean (SD), min/d	517 (68.2)	517 (68.5)	513 (65.6)	0.23
Obesity, % ^a	12.3	11.8	16.8	0.001
Central obesity, % ^b	9.9	9.5	13.3	0.008
High body fat, % ^c	8.3	8.0	11.0	0.02
Parental education, %				0.84
Did not complete high school	17.7	17.8	16.8	
Completed high school/some college	42.7	42.7	42.6	
Bachelor's degree or postgraduate degree	39.6	39.5	40.5	
Maternal history of gestational diabetes, %	4.3	4.1	6.9	0.004
Pregnancy term, mean (SD), wk	38.6 (2.2)	38.5 (2.2)	39.6 (1.6)	<0.001
Infant breast feeding, %				0.22
Exclusive breast feeding	37.4	37.0	41.4	
Mixed feeding	47.0	47.2	44.5	
Weaned from breast feeding	1.1	1.2	0.6	
Exclusive formula feeding	14.4	14.5	13.5	
Unhealthy diet pattern score, mean (SD),	-0.11 (0.89)	-0.11 (0.89)	0.02 (0.97)	0.061
Healthy diet pattern score, mean (SD),	-0.00 (0.99)	-0.01 (0.99)	0.02 (0.97)	0.56
Duration of night sleep, mean (SD), min	528 (53.0)	528 (52.9)	529 (54.4)	0.62

^aObesity was defined as BMI z score >+2 SD for age- and gender-specific distribution using World Health Organization growth reference.

^bCentral obesity was defined as waist circumference ≥ 90th percentile for age- and gender-specific distribution using NHANES III reference.

^cHigh body fat was defined as body fat ≥ 90th percentile for age- and gender-specific distribution using NHANES IV reference.

the first two measurements were greater than 0.5 cm apart, and the average of the two closest measurements was used in analyses).

The participants' weight and body fat were measured using a portable Tanita SC-240 Total Body Composition Analyzer (Tanita Corporation of America, Arlington Heights, Illinois) after all outer clothing, heavy pocket items, and shoes and socks were removed. Two measurements were obtained, and the average was used in analyses (a third measurement was obtained if the first two measurements were more than 0.5 kg or 2.0% apart, for weight and percentage body fat, respectively, and the closest two were averaged for analyses). The Tanita SC-240 showed acceptable accuracy for estimating percent body fat when compared with dual-energy x-ray absorptiometry, supporting its use in field studies (28). BMI was calculated by dividing weight in kilograms by the square of height in meters. BMI z scores were computed using age- and sex-specific reference data from the World Health Organization (29). General obesity was defined as BMI z scores > +2 standard deviations (SD). Central obesity was defined as waist circumference ≥ 90th percentile of the

National Health and Nutrition Examination Survey (NHANES) III (30,31). High body fat was defined as body fat ≥ 90th percentile of the NHANES IV (32).

Statistical analyses. Variables were compared using *t* test for means and χ^2 test for proportions between children classified as having normal birth weight and high birth weight. The joint associations of birth weight, time spent in MVPA, and sedentary behavior with the risks of obesity, central obesity, and high body fat were evaluated using a multilevel (three-level) logistic regression model (SAS[®] version 9.4, PROC GLMMIX) by individual (level 1), nested in school (level 2) and study site (level 3). Two categories each of birth weight (normal and high), MVPA (low and high), and sedentary time (low and high) were used in the analyses. Study sites (level 3) and schools (level 2) nested within study sites were viewed as having random effects. The analyses were adjusted for highest parental education, infant feeding mode, gestational age, child age, sex, unhealthy diet pattern scores, healthy diet pattern scores, and

TABLE 2 Odds ratios (OR) for obesity, central obesity, and high body fat by different effects of birth weight, moderate-to-vigorous physical activity (MVPA), and sedentary behavior

	Birth weight	Obesity		Central obesity		High body fat	
		No.	OR (95%CI) ^a	No.	OR (95%CI) ^a	No.	OR (95%CI) ^a
MVPA							
Low	Normal	411	1.00	340	1.00	306	1.00
Low	High	53	1.50 (1.03-2.06)	49	1.76 (1.23-2.51)	41	1.43 (1.02-2.01)
High	Normal	132	1.00	98	1.00	64	1.00
High	High	28	1.55 (0.97-2.48)	15	1.08 (0.59-1.96)	12	1.60 (0.99-2.60)
Sedentary time							
High	Normal	431	1.00	344	1.00	293	1.00
High	High	66	1.53 (1.12-2.09)	54	1.65 (1.18-2.31)	42	1.43 (1.04-1.96)
Low	Normal	112	1.00	94	1.00	77	1.00
Low	High	15	1.14 (0.63-2.07)	10	0.92 (0.46-1.87)	11	1.36 (0.77-2.41)

High birth weight was defined as birth weight $\geq 4,000$ g; high MVPA was defined as accumulating at least 60 min of MVPA daily; high sedentary time was defined as accumulating at least 482 min of sedentary time daily.

^aAdjusted for highest parental education, maternal history of gestational diabetes, infant feeding mode, gestational age, and child age, sex, unhealthy diet pattern scores, healthy diet pattern scores, and sleeping times.

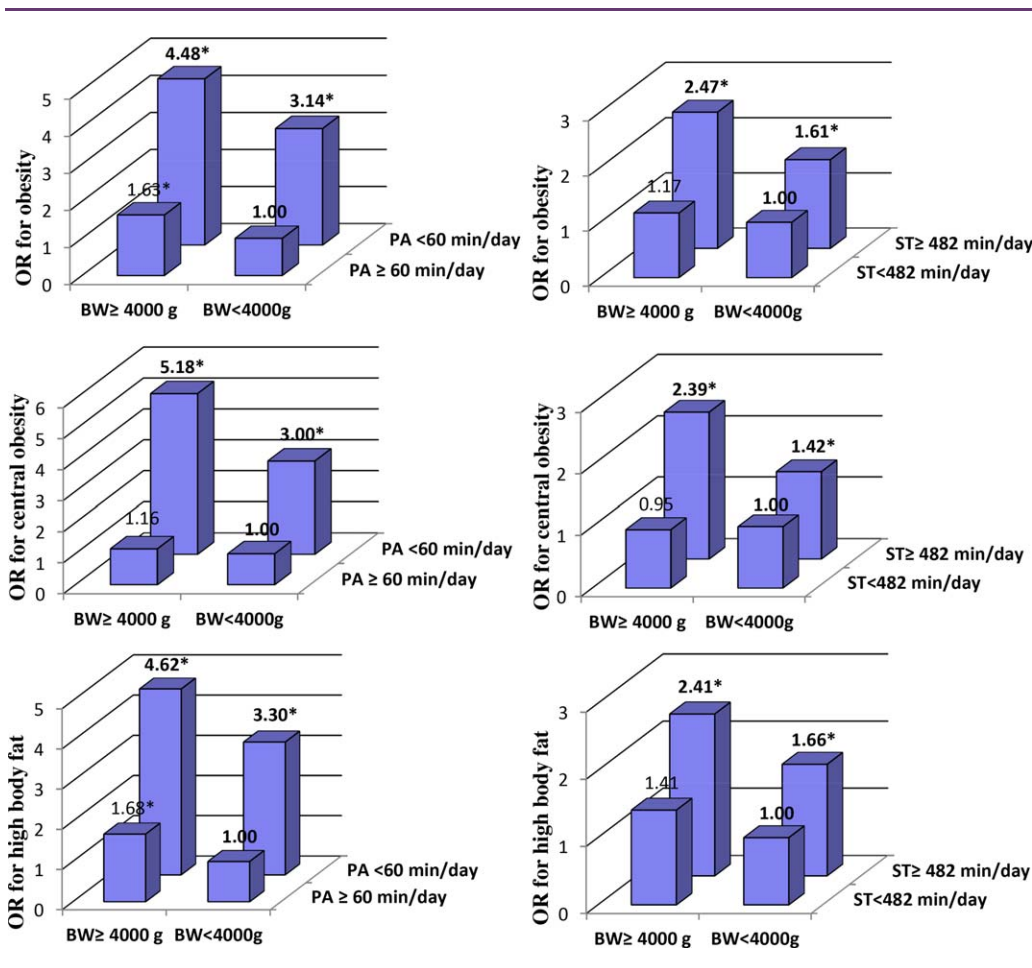


Figure 1 Odds ratio (OR) for obesity, central obesity, and high body fat among children by joint associations of birth weight, moderate-to-vigorous physical activity, and sedentary behavior. Adjusted for highest parental education, maternal history of gestational diabetes, and child age, sex, infant feeding mode, gestational age, unhealthy diet pattern scores, healthy diet pattern scores, and sleeping times. * $P < 0.05$. [Color figure can be viewed at wileyonlinelibrary.com]

TABLE 3 Odds ratios (OR) for obesity, central obesity, and high body fat among children with normal birth weight and low MVPA/high sedentary time in comparison with those with high birth weight and high MVPA/low sedentary time

Category	No. of participants	Obesity		Central obesity		High body fat	
		No.	OR (95%CI) ^a	No.	OR (95%CI) ^a	No.	OR (95%CI) ^a
Birth weight & MVPA							
Normal BW & low MVPA	2620	411	1.00	340	1.00	306	1.00
High BW & high MVPA	245	28	0.54 (0.34-0.84)	15	0.39 (0.22-0.69)	12	0.55 (0.40-0.75)
Birth weight & sedentary time							
Normal BW & high sedentary time	3190	431	1.00	344	1.00	293	1.00
High BW & low sedentary time	158	15	0.70 (0.40-1.25)	10	0.63 (0.32-1.24)	11	0.81 (0.47-1.39)

High birth weight was defined as birth weight $\geq 4,000$ g; high MVPA was defined as accumulating at least 60 min of MVPA daily; high sedentary time was defined as accumulating an average of at least 482 min of sedentary time daily.

^aAdjusted for highest parental education, maternal history of gestational diabetes, and child age, sex, infant feeding mode, gestational age, unhealthy diet pattern scores, healthy diet pattern scores, and sleeping times.

BW, birth weight; MVPA, moderate-to-vigorous physical activity.

sleeping time. Likelihood ratio test was used to examine the interactions between birth weight and MVPA or sedentary behavior with the odds of obesity, central obesity, and high body fat. The criterion for statistical significance was $P < 0.05$. All statistical analyses were performed using SPSS Statistics® for Windows, version 21.0 (IBM Corp., Armonk, New York) or SAS® for Windows, version 9.4 (SAS Institute, Cary, North Carolina).

Results

A total of 5,088 children (2,324 boys and 2,764 girls) were included in the present study. The overall prevalence of obesity, central obesity, and high body fat was 12.3%, 9.9%, and 8.3%, respectively. The overall mean birth weight was 3,277 g. The mean time spent in MVPA and sedentary behavior was 60.0 and 517 min/d, respectively. General characteristics of the study population are presented in Table 1.

Among children with low MVPA at 9 to 11 years old, those born with high birth weight had higher odds for obesity (OR 1.50; 95% CI: 1.03-2.06), central obesity (OR 1.76; 95% CI: 1.23-2.51), and high body fat (OR 1.43; 95% CI: 1.02-2.01) than those born with normal birth weight (Table 2). However, the associations of birth weight with the odds of obesity, central obesity, and high body fat were not significant among children with high MVPA at 9 to 11 years of age. The associations of high birth weight with high odds of obesity, central obesity, and high body fat were significant among children with high time spent in sedentary behavior at 9 to 11 years old but not among those with low sedentary time.

The joint association of birth weight and time spent in MVPA/sedentary behavior with the odds of obesity, central obesity, and high body fat in children with normal birth weight and high MVPA/low sedentary time as the reference group is shown in Figure 1. In comparison with children with normal birth weight and high MVPA, children with high birth weight and low MVPA showed 4.48- to 5.18-fold higher odds of obesity, central obesity, and high body fat; children with normal birth weight and low MVPA showed 3.00- to 3.30-fold higher odds of obesity, central obesity, and high body fat; and children with high birth

weight and high MVPA showed 1.16- to 1.68-fold higher odds of obesity, central obesity, and high body fat, respectively. Similarly, children with high birth weight and high time spent in sedentary behavior showed the highest odds of obesity, central obesity, and high body fat, while children with normal birth weight and high sedentary time had higher odds of obesity, central obesity, and high body fat compared with children with normal birth weight and low time spent in sedentary activity. There were no significant interactions between birth weight and MVPA or sedentary behavior with the odds of obesity, central obesity, and high body fat (all $P > 0.10$).

Table 3 presents results for children with normal birth weight and low MVPA/high sedentary time compared against those with high birth weight and high MVPA/low sedentary time for the odds of obesity, central obesity, and high body fat. Children with high birth weight and high MVPA had significantly lower odds of obesity (OR 0.54; 95% CI: 0.34-0.84), central obesity (OR 0.39, 95% CI: 0.22-0.69), and high body fat (OR 0.55, 95% CI: 0.40-0.75) at 9 to 11 years old than those with normal birth weight and low MVPA. The odds of general obesity, central obesity, and high body fat were nonsignificantly lower among children with high birth weight and high sedentary behavior than among those with normal birth weight and a sedentary lifestyle at 9 to 11 years old.

Discussion

In this multinational, cross-sectional study, we found that high MVPA is more important than high birth weight in determining obesity in 9- to 11-year-old children. These findings suggest that physical activity is a stronger predictor than birth weight for childhood obesity.

Several studies have indicated that high birth weight is associated with subsequently higher levels of body weight or obesity in childhood (7-10). Physical inactivity and sedentary behavior are important risk factors for incident type 2 diabetes, coronary heart disease, several types of cancer, and death (5). However, few epidemiological studies have assessed the joint associations of birth weight and physical activity/sedentary behavior with different health outcomes in children (11-13). A recent study found that among girls with self-reported low MVPA, those born with high birth weight had greater

BMI at 12 to 15 years of age than those born with normal birth weight, and this difference diminished among girls with greater MVPA (13). Among boys, MVPA did not modify the associations between high birth weight and greater BMI (13). The present study indicates that the association of high birth weight with childhood obesity was significant among children with either low MVPA or high sedentary time but was not significant among children with either high MVPA or low sedentary time. However, the present study did not find any sex differences in the joint association of birth weight, MVPA, and sedentary behaviors with the risk of childhood obesity. Moreover, we found that children with high birth weight and low MVPA showed the highest (4.48-5.18-fold) odds of obesity, and children with normal birth weight and low MVPA and children with high birth weight and high MVPA showed high (3.00-3.30-fold and 1.16-1.68-fold) odds of obesity compared with children with normal birth weight and high MVPA.

In the current study, we first showed that the odds of childhood obesity were lower among children born with high birth weight who had high objectively monitored MVPA at 9 to 11 years compared to those with normal birth weight and low MVPA at 9 to 11 years. This finding has important public health implications because people who have high birth weight might have higher obesity risk later in life, but this risk could potentially be reduced if they engage in regular MVPA. These cross-sectional findings are consistent with the hypothesis that MVPA is a crucial component of a healthy lifestyle in prevention of chronic diseases such as obesity.

There are several strengths in our study, including the recruitment of a large multinational sample of children from low- to high-income countries across several regions of the world, the highly standardized measurement protocol, the use of direct measurements whenever possible, and the rigorous quality control program. In addition, MVPA and sedentary time were objectively measured using a 24-hour waist-worn accelerometer protocol. However, there are several limitations in the present study. First, the cross-sectional study precludes us from making cause-and-effect inferences. Second, birth weight records may have been recalled incorrectly by the parent or guardian. Third, because information on maternal prepregnancy BMI is not available in the present study, we were not able to fully control for the association of this variable on the association of birth weight and childhood physical activity with the risk of childhood obesity. Fourth, we did not collect information on the pubertal development of the participants in our study, which may influence growth and body composition. The degree to which these factors may have biased the results is unknown.

Conclusion

In conclusion, high birth weight was significantly associated with increased odds of childhood obesity, but the higher odds were not found at higher levels of MVPA and lower levels of sedentary behavior. High MVPA is more important than high birth weight as a correlate of obesity in 9- to 11-year-old year old children. **O**

Acknowledgments

We wish to thank the ISCOLE External Advisory Board and the ISCOLE participants and their families who made this study

possible. The ISCOLE Research Group includes: **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 D. Denstel, 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 Physio (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, 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 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, MD, Jian Ma, MD, Yijuan Qiao, MD, 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 Matilda, 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, PhD, 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.

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