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Overcoming birth weight: can physical activity mitigate birth weight related differences in adiposity?

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Abstract

Background—Individuals born at low or high birth weight (BW) have elevated adiposity. The extent to which physical activity can mitigate this risk is unknown.

Objectives—To determine if associations between BW and adiposity vary by self-reported MVPA among adolescents.

Methods—We use data on adolescents in the National Health and Nutrition Examination Survey (1999–2006; 12–15 years; n=4,064). Using gender-stratified linear regression, we modeled Body Mass Index (BMI) and waist circumference (WC) z-scores as a function of low, normal, and high BW, MVPA (weekly Metabolic Equivalent Task-hours), and MVPA*BW cross-product terms, adjusting for sociodemographics, diet, and, in WC models, BMI.

Results—Among girls with low MVPA, those born with high BW had greater BMI than normal BW; this difference diminished with greater MVPA [coeff (95% CI): low MVPA: 0.72 (0.29, 1.14); high MVPA: −0.04 (−0.48, 0.39); p for interaction=0.05]. Among boys, MVPA did not modify the associations between BW and BMI. WC was unrelated to BW, regardless of MVPA.

Conclusions—Findings suggest that effects of high BW in total adiposity can be more easily modified with MVPA in adolescent girls than in boys.

Keywords

birth weight; physical activity; adolescents; Body Mass Index; Waist Circumference

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CONFLICTS OF INTEREST

The authors have no conflicts of interest to disclose.

AUTHOR CONTRIBUTIONS

JBH conceived of the research question, designed the statistical analysis plan, and drafted the manuscript. SM conducted the statistical analysis. SPF and KLT critically reviewed the manuscript. All authors were involved in writing the paper and had final approval of the submitted and published versions.

INTRODUCTION

Early life development is a critical determinant of obesity susceptibility. Low and high birth weight (BW) is consistently associated with elevated risk of obesity-related disease.^{1,2} Strategies to mitigate the deleterious effects of adverse fetal development on obesity later in life are not well understood.

Moderate to vigorous physical activity (MVPA) increases energy expenditure and improves energy regulation.³ These benefits can potentially normalize characteristics of low and high BW individuals that place them at high risk of obesity and cardiometabolic disease. Low and high BW are indicators of intrauterine growth restriction and fetal over-nutrition, respectively; these adverse perinatal environments increase cardiometabolic risk through distinct mechanisms.⁴ In particular, intrauterine growth restriction can result in low skeletal muscle volume and function,⁵ while fetal over-nutrition involves elevated fat deposition and metabolic dysregulation. Adolescence is a critical window for obesity prevention because it precedes substantial weight gain that occurs in the transition to adulthood.⁶

In animal studies, post-weaning exercise attenuated the effects of maternal high fat diet^{7,8} or intrauterine growth restriction⁹ on increased adiposity in the offspring. A handful of human studies suggest that physical activity can attenuate developmental programming effects on glucose tolerance.^{10,11} Analogous studies examining estimated effects on adiposity or interactions between physical activity and fetal overgrowth are scant.¹²

In this study, we tested the hypothesis that elevated total and central adiposity that are associated with low and high BW would be ameliorated by MVPA in a nationally representative sample of U.S. adolescents.

METHODS

Study population

We used data from four 2-year cycles of the continuous National Health and Nutrition Examination Survey (NHANES; 1999–2006).¹³ NHANES is conducted by the Centers for Disease Control and Prevention's (CDC) National Center for Health Statistics (NCHS). In each 2-year cycle, NHANES participants are derived from a stratified random sample of the U.S. population of all ages including oversampling of persons 60 and older, African Americans, and Hispanics. Approximately 5,000 adults and children participate in NHANES annually (n=41,474 in 1999–2006). NHANES methodologies include an extensive interview, physical examination, and biological specimen collection and analysis.

We examined children and adolescents 12 to 15 years of age in NHANES 1999–2006 (n=4,774), which provided BW (collected for participants $\geq$ 15 years of age) and consistent physical activity measures ($\geq$ 12 years).

Study measures

Outcomes—Trained health technicians collected height, weight, and waist circumference (WC; measured just above the right iliac crest at the mid-axillary line) according to standard

protocol.¹³ Body Mass Index (BMI; kg/m²) was calculated from height and weight. To normalize anthropometry measures to age- and sex-specific norms for growth, we converted BMI and WC to z-scores using 2000 CDC growth charts and growth curve parameters developed from three historical U.S. study populations,¹⁴ respectively.

Exposure—BW was reported by the adult proxy respondent in pounds and ounces; if exact BW was unknown or refused, the respondent indicated if BW was more or less than 5.5 pounds, and more or less than 9.0 pounds. Parent-reported BW is accurate (e.g., mean difference from registered BW of 25 grams¹⁵). We classified BW as low (<5.5 pounds), normal, or high (>9.0 pounds) according to the reported pounds and ounces or, if missing, the corresponding indicators (<5.5 lb [n=35]; >5.5 and <9 lb [n=206]; >9 lb [n=15]). Gestational age at birth was not collected.

Effect modifier of interest—The NHANES Physical Activity Questionnaire (PAQ) collected type, frequency, and duration of moderate- and vigorous-intensity activities performed in the past 30 days for participants 12 years and older. The PAQ has been validated in adults, with moderate agreement with a reference standard.¹⁶ We omitted moderate (n=36) or vigorous (n=75) physical activity values indicating >840 weekly minutes (>2 hours per day). We calculated leisure-time MVPA Metabolic Equivalent Task [MET]-hours per week using MET values recommended by NHANES.

Control variables—Control variables included child's sex, age (at interview), race/ethnicity (non-Hispanic White, non-Hispanic Black, Mexican American, other), and smoking status (current, not current); family income as a percent of Federal Poverty Level; and primary respondent education (<high school, high school diploma or GED, college or more). Total calories, percent calories from fat, and percent calories from protein were collected from a single 24-hour dietary recall; implausible energy intake (<500 or >5000 kilocalories) was coded to missing (n=97).

Statistical analysis

Analyses were conducted using Stata version 12.1 and corrected for complex survey sampling using Stata's "svy" functions unless otherwise indicated. Analyses were gender-stratified because of gender differences in how physical activity is associated with obesity-related outcomes, and how fetal development effects obesity-related health.¹⁷

Analytic study population and multiple imputation—Of 4,774 NHANES 1999–2006 participants who met age criteria (12–15 years), 324 did not perform 24-hour dietary recalls; multi-cycle sampling weights¹⁸ corresponding to participants in the 1-day dietary sample accounted for dietary recall non-participation. 4,202 participants met inclusion criteria (11 and 237 excluded due to pregnancy and physical activity limitations, respectively). Of these, 3,353 adolescents had complete data; 843 (20.0%) had missing or implausible data, largely comprised of missing MVPA (7.0%) and household income (6.3%). Among those meeting inclusion criteria, adolescents with missing or implausible data (vs. complete data) had higher energy intake and lower income, and were slightly older

and more likely to be normal BW; but were similar with respect to other study variables (Supplemental Materials; Section A, Table S1).

To reduce bias due to missing data, we conducted multiple imputation (Stata mi). Imputation methods and number of observations imputed for each variable are reported in the Supplemental Materials (Section B; Table S2). While included in the imputation model, participants with imputed BW (n=68, 1.6%) or outcomes (n=71, 1.6%) were excluded from regression analysis, resulting in 4,064 adolescents in our primary analysis.

Descriptive analysis (n=3,353 with complete data)—Means and proportions were calculated by gender and BW category, then compared across BW, within gender, using design-based F-tests for categorical variables and adjusted Wald tests for continuous variables.

Multivariable analysis (n=4,064)—We conducted a series of gender-stratified linear regression analyses modeling adiposity measures (BMI z-score, WC z-score) as a function of BW category, MVPA MET-hours, and interactions between MVPA MET-hours and BW category. We used the Stata mim2 function, which allows post-estimation of multiple imputation analysis. Models corrected for survey strata (robust cluster) and weights (pweight); coefficients and standard errors were similar for models run using “svy” functions.

We interpret BMI and WC models to represent total and relative central adiposity, respectively. Our primary WC analysis adjusts for BMI z-score to distinguish central adiposity from total adiposity.¹⁹ In sensitivity analyses, we fit (a) BMI and WC models that did not adjust for diet variables, because MVPA benefits may occur through energy intake regulation, and (b) BMI models in non-smokers, as an alternative to adjusting for smoking, which may confound the association between MVPA and adiposity, but was rare and differential by BW and sex.

MVPA MET-hours was natural-log transformed to account for the shape of the relationships and minimize the influence of large values in the skewed distribution. Based upon graphical display and testing of higher order terms, relationships between other continuous variables and the outcomes were linear. BW-MVPA interaction terms were retained regardless of statistical significance. Statistical significance was assessed at $p < 0.05$ for main effects and $p < 0.10$ for interactions.

To facilitate interpretation, we calculated estimates using the adjusted parameter estimates for BW category, MVPA, and interaction terms. First, we calculated associations between BW category and adiposity measures, given high and low (10th and 90th percentiles) MVPA levels. Second, we calculated associations between MVPA and adiposity, within each BW category. Third, we calculated predicted BMI and WC z-scores specific to BW category and MVPA MET-hours corresponding to values ranging from the 5th to 95th percentiles, given the following profile: white race, HS/GED primary respondent education, and mean values of continuous covariates.

RESULTS

6.3% and 4.5% of girls and boys, respectively, were born low BW; 7.5 and 11.5% of girls and boys were high BW (Table 1). High BW adolescents had higher BMI and WC than normal BW, in which average BMI z-score was elevated (0.61) but within “normal” range (z-score -1.645 to 1.036). Boys born low BW had lower BMI and WC z-scores than boys with normal BW. Race/ethnicity and, in boys, diet, age, and income varied by BW. MVPA and other sociodemographics were similar across BW categories.

Associations between high BW and greater BMI were attenuated by MVPA in girls

Girls born with high BW had greater BMI than normal and low BW girls, but only at low levels of MVPA (Figure 1; Table 2). Specifically, among girls with low (10th percentile) MVPA, high BW was associated with 0.72 greater BMI z-score than normal BW (Table 2). MVPA was more strongly associated with BMI in high BW than normal BW girls (p for interaction=0.05): 2-fold greater MVPA MET-hours was associated with a -0.12 difference in BMI z-score in girls born high BW ($\ln(2)$ *coefficient of -0.17), compared to a 0.03 difference in girls born normal BW. Correspondingly, high BW was not associated with BMI among girls with high MVPA (90th percentile; 59.1 MET-hours). For reference, MVPA recommendations for youth (60 minutes per day) reflect approximately 21 MET-hours (walking, 3 METs) to over 70 MET-hours (running 10 min/mile, 10 METs). In boys, high BW was associated with 0.25 to 0.29 higher BMI z-score, which did not vary by MVPA (Figure 1; Table 2; p for interaction=0.92).

Associations between low BW and BMI did not vary by MVPA in boys or girls

In girls, low (versus normal) BW was unrelated to BMI, regardless of MVPA level (p for interaction=0.52) (Table 2). In boys, low BW was associated with lower BMI, with no modification by MVPA. MVPA was not associated with BMI z-score in low BW boys or girls.

Birth weight and physical activity were not related to relative central adiposity

BW and MVPA were unrelated to WC after controlling for BMI z-score (Table 2).

Sensitivity analysis

Fully adjusted associations were substantively similar to crude or, for WC, BMI-adjusted associations (Tables S3–S4). The strongest attenuation resulted from controlling for sociodemographic characteristics, particularly for associations involving low BW; the largest difference was 0.32 crude versus 0.12 adjusted coefficient for low BW among girls with low MVPA. Removal of diet measures did not change the magnitude or precision of the associations of interest, but we retained them as *a priori* confounders. Likewise, models limited to non-smokers (Tables S3a, S3b) were substantively similar, although associations with low BW were slightly stronger than in the primary analysis (Table 2).

DISCUSSION

In a nationally representative population of adolescents, high BW was generally associated with greater BMI; this association was attenuated in girls with high MVPA. In boys, associations between low BW and lower BMI likely reflect deficient lean body mass,²⁰ and were similar across levels of MVPA. Relative central adiposity was unrelated to BW, regardless of MVPA. These findings suggest that high BW-related elevations in BMI can be reduced by MVPA in girls more easily than in boys.

Few epidemiological studies have assessed the interactive relationship between BW and MVPA in predicting health.^{10,11,21,22} Most previous studies have focused on effects of glucose tolerance, as opposed to adiposity. In a previous study that estimated interactive effects of birth size and physical activity on fat mass and WC, Ridgway and colleagues did not find evidence that physical activity moderated birth size associations with greater adiposity or insulin resistance in European youth.²²

Our findings emphasize important study design considerations. First, sex differences in our study population are consistent with sex differences in developmental programming often observed in animal and human studies.¹⁷ In our study, pooling boys and girls would have masked the observed associations. Second, most prior studies testing BW-physical activity interactions examine BW as a continuous linear variable or as tertiles. By classifying BW into clinically meaningful categories, we accounted for elevated disease risk observed at both BW extremes and may have identified groups of adolescents that were more homogenous with respect to adverse developmental programming risk. Third, heterogeneity of findings across geographic regions^{10,21} or countries may reflect differences in factors such as meal patterning, sleep, or physical activity levels observed across populations.

The inverse associations between low BW and adiposity observed in boys is consistent with lower obesity risk in prior research.¹ Few studies examine sex-specific associations between BW and adiposity,¹ but the gender difference observed in our study may reflect variation in fetal programming by sex.¹⁷ Another consideration is that the age group in our study (12–15 years) may precede substantial weight gain in adolescents, especially in boys.²³ Furthermore, low BW-related central adiposity and cardiovascular and metabolic risk²⁴ may emerge later in life even in the absence of overall obesity. In the Helsinki birth cohort, boys who later acquired cardiovascular disease were not fat compared to their peers.²⁵ In contrast, girls who acquired the disease had increased in BMI centiles as pre-adolescents.

In contrast, high BW has been consistently and strongly associated with obesity and cardiometabolic risk as early as birth, even in the absence of gestational diabetes.²⁶ In addition, maternal obesity is associated with greater risk of both high and low²⁷ BW deliveries; therefore, modification of low and high BW effects is relevant in the context of the obesity epidemic.

Our findings are also consistent with the small body of animal studies showing effects of postnatal exercise following adverse prenatal exposure. With regard to maternal obesity, exercise reduced adiposity and improved metabolic regulation in female offspring of high fat-fed dams.^{7,8} Importantly, these studies suggest benefits of not only sustained exercise

from the weaning period⁸ but also exercise adopted in adulthood.⁷ These benefits were attributed to increased energy expenditure and improved appetite regulation, which is impaired by maternal obesity. In another study, exercise reduced adiposity and improved leptin sensitivity in male offspring of high fat-fed dams, but body weight was not affected.²⁸ With regard to fetal undergrowth, animal studies suggest that exercise can reverse its effects on total and visceral fat and metabolic regulation.⁹

Implications for obesity prevention and research

Our findings suggest that MVPA is important for achieving energy balance among girls born with high BW. They further suggest that girls born with high BW must perform high levels of MVPA to achieve BMI comparable to their normal BW peers. Meeting MVPA recommendations for youth can be achieved with 21 MET-hours per week (60 minutes per day of MPA). In contrast, equivalent predicted BMI z-scores were observed for normal BW versus high BW girls at approximately 40 MET-hours per week. Consistent with many prior studies,²⁹ MVPA was weakly or unrelated to BMI in most strata; our findings suggest that high BW girls represents a subgroup that is particularly sensitive to physical inactivity.

Our findings suggest critical research areas for future longitudinal studies. We examined self-reported MVPA at a single adolescent time point, but investigation of the timing and continuity of high, objectively measured physical activity required to overcome programmed risk is needed. BW is a crude indicator of fetal development and future disease risk. Maternal obesity can induce fetal programming changes via elevated glucose and leptin exposure or inflammatory effect on placental development, which can result in the full spectrum of BW. Studies that account for maternal height, weight, diet, physical activity, and health status are needed to measure developmental programming risk in epidemiological studies. Assessment of MVPA as a modifier of association with more direct measures of body composition and distribution (e.g., Dual-energy X-ray absorptiometry) are needed to further distinguish associations with total versus visceral adiposity¹⁹ and muscularity or bone mineral density. Such studies should be powered to test interactive relationships between physical activity and obesity-related outcomes by sex. Advancement of strategies to mitigate the effects of developmental programming prior to childbearing age is critical for disrupting the intergenerational cycle of obesity.

Strengths and limitations

This study's cross-sectional design limits our ability to draw causal inferences from our findings. Reverse causation (e.g., those with greater BMI become less likely to engage in physical activity) is of particular concern, but is unlikely to be differential according to BW. BW is a gross proxy of fetal programming and was reported by an adult proxy respondent; however, parent-reported BW is strongly correlated with measured BW, with non-systematic error that likely attenuated the observed associations.¹⁵ We also lacked data on gestational age at birth and early life growth and feeding. Gestational age at birth is needed to distinguish preterm birth from fetal growth restriction, which is a stronger indicator of maternal constraint factors that drive fetal programming.

MVPA was self-reported. The NHANES PAQ has not been validated in youth; however, in adults, decomposition of reporting error compared to a doubly-labeled water standard suggested that PAQ-measured MVPA likely yields attenuated associations with health outcomes and thus reduced our statistical power.¹⁶ It is also unlikely that reporting error varies systematically according to BW. Gender differences in MVPA reporting error may have contributed to the observed gender differences. We did not include transportation or occupational physical activity, but leisure-time MVPA is an important component of physical activity in youth. Pubertal stage is an important determinant of BMI and in our target age group (12–15 years), but was not measured and should be addressed in future research. We had inadequate sample size to examine race/ethnic differences in the degree to which MVPA modifies the relationships between birth weight and adiposity.

These limitations are balanced by several strengths. We leveraged the large, diverse, nationally representative population offered by the NHANES. Few other data sources offer information on BW, MVPA, and objectively measured anthropometry for sufficient numbers individuals needed to examine BW- and gender-specific associations between MVPA and adiposity.

Conclusion

In our nationally representative sample of U.S. youth 12–15 years of age, adverse associations between high BW and BMI were attenuated in girls with high physical activity. The observed interactions between BW and MVPA suggest that the efficacy of physical activity in ameliorating accumulation of total body fat varies according to prenatal development.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

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References

1. Schellong K, Schulz S, Harder T, Plagemann A. Birth weight and long-term overweight risk: systematic review and a meta-analysis including 643,902 persons from 66 studies and 26 countries globally. *PLoS One*. 2012; 7(10):e47776. [PubMed: 23082214]
2. Johnsson IW, Haglund B, Ahlsson F, Gustafsson J. A high birth weight is associated with increased risk of type 2 diabetes and obesity. *Pediatr Obes*. Apr; 2015 10(2):77–83. [PubMed: 24916852]
3. Stubbs RJ, Sepp A, Hughes DA, et al. The effect of graded levels of exercise on energy intake and balance in free-living women. *Int J Obes Relat Metab Disord*. Jun; 2002 26(6):866–869. [PubMed: 12037658]
4. Dabelea D, Crume T. Maternal environment and the transgenerational cycle of obesity and diabetes. *Diabetes*. Jul; 2011 60(7):1849–1855. [PubMed: 21709280]

5. Jensen CB, Storgaard H, Madsbad S, Richter EA, Vaag AA. Altered skeletal muscle fiber composition and size precede whole-body insulin resistance in young men with low birth weight. *J Clin Endocrinol Metab.* Apr; 2007 92(4):1530–1534. [PubMed: 17284623]
6. Gordon-Larsen P, The NS, Adair LS. Longitudinal trends in obesity in the United States from adolescence to the third decade of life. *Obesity (Silver Spring).* Sep; 2010 18(9):1801–1804. [PubMed: 20035278]
7. Bahari H, Caruso V, Morris MJ. Late-onset exercise in female rat offspring ameliorates the detrimental metabolic impact of maternal obesity. *Endocrinology.* Oct; 2013 154(10):3610–3621. [PubMed: 23928377]
8. Rajia S, Chen H, Morris MJ. Voluntary post weaning exercise restores metabolic homeostasis in offspring of obese rats. *Nutr Metab Cardiovasc Dis.* Jun; 2013 23(6):574–581. [PubMed: 22305126]
9. Gattford KL, Kaur G, Falcao-Tebas F, et al. Exercise as an intervention to improve metabolic outcomes after intrauterine growth restriction. *Am J Physiol Endocrinol Metab.* May 1; 2014 306(9):E999–1012. [PubMed: 24619880]
10. Ortega FB, Ruiz JR, Hurtig-Wennlof A, et al. Physical activity attenuates the effect of low birth weight on insulin resistance in adolescents: findings from two observational studies. *Diabetes.* Sep; 2011 60(9):2295–2299. [PubMed: 21752955]
11. Eriksson JG, Yliharsila H, Forsen T, Osmond C, Barker DJ. Exercise protects against glucose intolerance in individuals with a small body size at birth. *Prev Med.* Jul; 2004 39(1):164–167. [PubMed: 15207998]
12. Bayol SA, Bruce CR, Wadley GD. Growing healthy muscles to optimise metabolic health into adult life. *J Dev Orig Health Dis.* Oct 9.2014 :1–15.
13. Centers for Disease Control and Prevention. National Health and Nutrition Examination Survey (NHANES). Hyattsville, MD: U.S. Department of Health and Human Services, National Center for Health Statistics; 1999–2006. Available at: http://www.cdc.gov/nchs/nhanes/nhanes_questionnaires.htm
14. Cook S, Auinger P, Huang TT. Growth curves for cardio-metabolic risk factors in children and adolescents. *J Pediatr.* Sep; 2009 155(3):S6.e15–26.
15. Jaspers M, de Meer G, Verhulst FC, Ormel J, Reijneveld SA. Limited validity of parental recall on pregnancy, birth, and early childhood at child age 10 years. *J Clin Epidemiol.* Feb; 2010 63(2):185–191. [PubMed: 19682856]
16. Tooz JA, Troiano RP, Carroll RJ, Moshfegh AJ, Freedman LS. A measurement error model for physical activity level as measured by a questionnaire with application to the 1999–2006 NHANES questionnaire. *Am J Epidemiol.* Jun 1; 2013 177(11):1199–1208. [PubMed: 23595007]
17. Gabory A, Roseboom TJ, Moore T, Moore LG, Junien C. Placental contribution to the origins of sexual dimorphism in health and diseases: sex chromosomes and epigenetics. *Biol Sex Differ.* 2013; 4(1):5. [PubMed: 23514128]
18. Johnson C, Paulose-Ram R, Ogden C. National Health and Nutrition Examination Survey: Analytic Guidelines, 1999–2010. *Vital Health Stat.* 2013; 2(161)
19. Katzmarzyk PT, Bouchard C. Where is the beef? Waist circumference is more highly correlated with BMI and total body fat than with abdominal visceral fat in children. *Int J Obes (Lond).* Jun; 2014 38(6):753–754. [PubMed: 24018751]
20. Ridgway CL, Brage S, Anderssen S, Sardinha LB, Andersen LB, Ekelund U. Fat-free mass mediates the association between birth weight and aerobic fitness in youth. *Int J Pediatr Obes.* Jun; 2011 6(2–2):e590–596. [PubMed: 21050079]
21. Labayen I, Ortega FB, Moreno LA, et al. Physical activity attenuates the negative effect of low birth weight on leptin levels in European adolescents; the HELENA study. *Nutr Metab Cardiovasc Dis.* Apr; 2013 23(4):344–349. [PubMed: 22397877]
22. Ridgway CL, Brage S, Anderssen SA, Sardinha LB, Andersen LB, Ekelund U. Do physical activity and aerobic fitness moderate the association between birth weight and metabolic risk in youth?: the European Youth Heart Study. *Diabetes Care.* Jan; 2011 34(1):187–192. [PubMed: 20921217]
23. Wang Y, Dinse GE, Rogan WJ. Birth weight, early weight gain and pubertal maturation: a longitudinal study. *Pediatr Obes.* Apr; 2012 7(2):101–109. [PubMed: 22434749]

24. Harder T, Rodekamp E, Schellong K, Dudenhausen JW, Plagemann A. Birth weight and subsequent risk of type 2 diabetes: a meta-analysis. *Am J Epidemiol.* Apr 15; 2007 165(8):849–857. [PubMed: 17215379]
25. Barker DJ, Osmond C, Forsen TJ, Kajantie E, Eriksson JG. Trajectories of growth among children who have coronary events as adults. *N Engl J Med.* Oct 27; 2005 353(17):1802–1809. [PubMed: 16251536]
26. Boney CM, Verma A, Tucker R, Vohr BR. Metabolic syndrome in childhood: association with birth weight, maternal obesity, and gestational diabetes mellitus. *Pediatrics.* Mar; 2005 115(3):e290–296. [PubMed: 15741354]
27. McDonald SD, Han Z, Mulla S, Beyene J. Overweight and obesity in mothers and risk of preterm birth and low birth weight infants: systematic review and meta-analyses. *Bmj.* 2010; 341:c3428. [PubMed: 20647282]
28. Sun B, Liang NC, Ewald ER, et al. Early postweaning exercise improves central leptin sensitivity in offspring of rat dams fed high-fat diet during pregnancy and lactation. *Am J Physiol Regul Integr Comp Physiol.* Nov 1; 2013 305(9):R1076–1084. [PubMed: 24026073]
29. Rauner A, Mess F, Woll A. The relationship between physical activity, physical fitness and overweight in adolescents: a systematic review of studies published in or after 2000. *BMC Pediatr.* 2013; 13:19. [PubMed: 23375072]

What is already known about this subject

- Individuals born at low or high birth weight (LBW, HBW) have elevated adiposity.
- Moderate to vigorous physical activity (MVPA) has beneficial effects on energy homeostasis.
- Physical activity attenuates adverse outcomes of maternal obesity and intrauterine growth restriction in animal studies, but evidence in humans is scant.

What this study adds

- In girls, HBW was associated with greater BMI, but only at low levels of MVPA.
- Findings provide evidence that birth weight-related differences in total adiposity can be mitigated by MVPA in girls.

Figure 1.

Predicted BMI z-score across moderate-vigorous physical activity (MVPA) MET-hours per week, by birth weight category: girls (top) and boys (bottom) 12–15 years of age National Health and Nutrition Examination Survey (NHANES; 1999–2006); n=2,059 girls, 2,005 boys. Predicted values calculated from adjusted regression model estimates (Tables 2 and 3) at MET-hours corresponding to 5th, 10th, 25th, 50th, 75th, 90th, and 95th percentile values, given the following profile: non-Hispanic white race; middle primary respondent education category (HS/GED); mean age, income, caloric intake, and percent calories from fat.

Characteristics of adolescents 12–15 years of age in the National Health and Nutrition Examination Survey (NHANES; 1999–2006), by gender and birth weight (BW) category [mean (SE) or percent]^a

	Girls			Boys		
	Low BW	Normal BW	High BW	Low BW	Normal BW	High BW
Count (% within gender)	154 (6.3%)	1482 (89.2%)	107 (4.5%)	121 (7.5%)	1320 (81.0%)	169 (11.5%)
Count [imputed data] (% within gender)	192 (7.1%)	1741 (88.4%)	124 (4.5%)	162 (8.1%)	1628 (80.9%)	215 (11.0%)
BMI (z-score)	0.79 (0.12)	0.61 (0.06)	0.95 (0.12)*	-0.35 (0.29)*	0.61 (0.05)	0.85 (0.08)*
Waist circumference (z-score)	0.29 (0.13)	0.26 (0.06)	0.57 (0.11)	-0.48 (0.22)*	0.34 (0.04)	0.54 (0.07)*
MVPA (MET-hours per week)	21.0 (1.7)	20.7 (1.1)	19.0 (2.8)	29.9 (3.8)	28.0 (1.2)	28.1 (3.1)
Age (years)	13.5 (0.2)	13.5 (0.0)	13.5 (0.2)	13.1 (0.2)*	13.5 (0.0)	13.4 (0.1)
Household income (percent of FPL)	2.3 (0.3)	2.6 (0.1)	2.5 (0.2)	2.6 (0.3)	2.7 (0.1)	3.3 (0.2)*
Total kilocalories	1,845 (88)	1,904 (28)	1,823 (92)	1,981 (118)*	2,360 (45)	2,506 (129)
Proportion calories from fat	0.34 (0.01)	0.33 (0.00)	0.32 (0.02)	0.32 (0.02)	0.32 (0.00)	0.33 (0.01)
Proportion calories from protein	0.30 (0.01)	0.31 (0.01)	0.31 (0.01)	0.29 (0.01)*	0.32 (0.00)	0.32 (0.01)
Race/ethnicity*						
White non-Hispanic	40.8%	65.3%	46.6%	61.1%	62.5%	70.7%
Black non-Hispanics	35.9%	13.3%	17.0%	18.6%	13.8%	8.7%
Mexican American	12.0%	10.9%	19.8%	10.0%	11.9%	12.0%
Other	11.3%	10.5%	16.6%	10.4%	11.8%	8.7%
Primary respondent education						
Some college+	43.3%	53.3%	41.5%	68.1%	51.0%	61.6%
High School graduate/GED	28.2%	26.0%	39.0%	16.0%	27.9%	26.7%
<High school	28.5%	20.8%	19.5%	15.9%	21.1%	11.6%
Smoker (versus non-smoker)	11.5%	8.8%	1.1%	2.9%	4.1%	4.0%

^aLow BW (<5.5 pounds); Normal BW (5.5–9 pounds); High BW (>9 pounds). Analyses corrected for complex survey sampling.

* Significantly different ($p < 0.05$) compared to Normal BW, within gender, according to design-based F-tests for categorical variables and adjusted Wald tests for continuous variables.

BW, birth weight; MET, Metabolic Equivalent Task; MVPA, Moderate to vigorous physical activity

Table 2

Estimated interactive effects of birth weight category and moderate-vigorous physical activity (MVPA) on BMI and waist circumference [coeff (95% CI)]^a

	Low BW	Normal BW	High BW
Girls			
Count	194	1,741	124
BMI z-score			
Estimated effect of BW category			
At low MVPA	0.12 (−0.22, 0.46)	(referent)	0.72 (0.29, 1.14)
At high MVPA	−0.05 (−0.41, 0.30)	(referent)	−0.04 (−0.48, 0.39)
Estimated effect of MVPA within BW category ^b	−0.01 (−0.14, 0.13)	0.04 (−0.03, 0.12)	−0.17 (−0.37, 0.02)
BW*MVPA interaction ^c	0.52	(referent)	0.05
Waist circumference z-score			
Estimated effect of BW category			
At low MVPA	−0.08 (−0.25, 0.08)	(referent)	0.00 (−0.17, 0.17)
At high MVPA	−0.04 (−0.18, 0.10)	(referent)	0.10 (−0.05, 0.26)
Estimated effect of MVPA within BW category ^b	0.00 (−0.06, 0.06)	−0.01 (−0.04, 0.02)	0.02 (−0.05, 0.09)
BW*MVPA interaction ^c	0.72	(referent)	0.45
Boys			
Count	162	1,628	215
BMI z-score			
Estimated effect of BW category			
At low MVPA	−0.95 (−1.87, −0.04)	(referent)	0.25 (−0.27, 0.78)
At high MVPA	−0.70 (−1.12, −0.28)	(referent)	0.29 (0.00, 0.59)
Estimated effect of MVPA within BW category ^b	0.08 (−0.14, 0.30)	0.01 (−0.08, 0.09)	0.02 (−0.17, 0.21)
BW*MVPA interaction ^b	0.51	(referent)	0.92
Waist circumference z-score			
Estimated effect of BW category			
At low MVPA	0.06 (−0.22, 0.34)	(referent)	−0.03 (−0.27, 0.21)
At high MVPA	−0.06 (−0.26, 0.15)	(referent)	−0.01 (−0.10, 0.08)
Estimated effect of MVPA within BW category ^b	−0.04 (−0.14, 0.05)	−0.01 (−0.04, 0.02)	0.00 (−0.07, 0.06)
BW*MVPA interaction ^c	0.52	(referent)	0.86

^aNational Health and Nutrition Examination Survey (NHANES; 1999–2006), 12–15 years of age. Estimated effects calculated from gender-stratified linear regression, modeling BMI or Waist circumference z-score as a function of natural-log transformed MVPA MET-hours per week and interaction between ln(MVPA) and birth weight category, adjusted for age, race/ethnicity, household income as a percent of the federal poverty level, primary respondent education, total calories, and percent calories from fat and protein. Waist circumference model is also adjusted for BMI z-score. Models adjusted for complex survey sampling.

^bMVPA was natural log transformed, so the coefficient is interpreted as the BMI z-score difference associated with an e-fold (2.72-fold) difference in MVPA MET-hours per week.

^cP value for ln(MVPA)*LBW or ln(MVPA)*HBW interaction; NBW is the referent category.