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Cardiorespiratory Fitness as a Mediator of the Association between Physical Activity and Overweight and Obesity in Adolescent Girls

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Abstract

Background: Overweight and obesity (OW/OB) continue to be prominent health issues among adolescent girls. However, little is known about the interrelationships between physical activity (PA), cardiorespiratory fitness (CRF), and OW/OB in this population. The objective of this study was to examine whether CRF mediates the relationship between PA and OW/OB in adolescent girls.

Methods: Moderate-to-vigorous PA (MVPA), CRF, BMI, and percentage body fat (% BF) were measured in adolescent girls ($N = 1519$), aged 10–14 years, from 24 urban middle schools located in the Midwestern United States. Structural equation modeling was used to determine whether CRF is a mediator of the association between MVPA and OW/OB (measured as both BMI and % BF). Multigroup analyses were used to determine whether race, puberty, or socioeconomic status moderate the mediation models.

Results: The indirect effect of MVPA through CRF on OW/OB was significant for both BMI ($p < 0.01$) and % BF ($p < 0.01$), indicating that CRF is a complete mediator between MVPA and OW/OB. Both race and puberty significantly ($p < 0.05$) moderated the mediation between MVPA and OW/OB.

Conclusions: This study demonstrates that CRF is improved by increasing MVPA, and the improvement in CRF results in lower BMI and % BF among adolescent girls.

Keywords: body mass index; exercise; girls; mediation; percentage body fat; physical fitness

Introduction

Overweight and obesity (OW/OB) have many adverse health effects during adolescence, including hypertension, metabolic syndrome, and type 2 diabetes, as well as long-term implications for morbidity and premature mortality during adulthood.[1] In 2015–2016, the National Health and Nutrition Examination Survey (NHANES) estimated that the prevalence of obesity among girls, ages 6 to 11 and 12 to 19, in the United States was 16.3% and 20.9%, respectively.[2] Globally, the prevalence of OW/OB among children and adolescents aged 5–19 years has grown from 4% in 1975 to ~18% in 2016, with similar trends seen in boys and girls.[3] Although obesity prevalence in adolescents has stabilized in the United States, prevalence is rising among those of low socioeconomic status (SES) and decreasing in those of higher SES.[4] Two major factors associated with risk of becoming OW/OB are physical activity (PA) and cardiorespiratory fitness (CRF).[5] PA is defined as any body movement produced by muscle action that increases energy expenditure. CRF refers to how efficiently the body takes in and utilizes oxygen and is typically measured as maximal oxygen consumption (aerobic power). Higher CRF leads to the ability to participate in daily activities without fatigue.[6]

Multiple studies have demonstrated that PA and CRF are independently associated with OW/OB,[5,7,8] and that increased PA is associated with improved CRF in adolescents.[9] However, only a few studies have examined the interrelationships among PA, CRF, and OW/OB in adolescents.[5,9–13] Of these studies, none targeted girls or low SES populations. Low SES girls are an important target

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population because adolescent girls have lower PA levels than boys of the same age, and OW/OB prevalence is higher among those of low SES.[4,14] In addition, only one study, conducted by Ortega et al.,[11] was found that measured PA objectively. Other studies, which were conducted by Raistenskis et al.,[5] Jaakkola et al.,[9] Aires et al.,[10] Fogelholm et al.,[12] and Palomäki et al.,[13] included self-reported PA. Self-reported PA is subject to recall and social desirability bias.[15,16] The one study that included an objective measure of PA, conducted by Ortega et al.,[11] was also the only study found that tested sociodemographic factors as moderators. However, Ortega et al.[11] found that age and gender did not significantly moderate the relationships between PA, CRF, and waist circumference.[11] Clear understanding of the interrelationships among these factors in girls living in low SES areas is important for identifying areas to target in interventions.

The potential mediating effect of CRF on the relationship between PA and OW/OB is biologically plausible, as PA is required to maintain CRF.[17] Aires et al.[10] noted that PA influenced CRF, and CRF influenced BMI in adolescents; but, no association occurred between PA and BMI. This finding is indicative of a *mediating* effect of CRF on the association between PA and BMI.[18] CRF has also been identified as a partial *mediator* between PA and metabolic syndrome in adolescents, a condition described as a cluster of risk factors, one of which includes abdominal obesity.[19] In contrast, Ortega et al.[11] found that CRF *modifies* the relationship between PA and OW/OB in adolescents. For those with low CRF, PA was negatively associated with abdominal adiposity (measured as waist circumference); whereas among those with high CRF, PA was positively associated with abdominal adiposity. Ortega et al.[11] hypothesized that this finding may be due to unmeasured confounding variables, such as genetic variation and energy intake.

Only one study examining the interrelationships among PA, CRF, and OW/OB was found that tested sociodemographic factors as moderators. Results indicated that age and gender did not significantly moderate the relationships between PA, CRF, and waist circumference.[11] Biological and sociodemographic factors influence the effect of PA and CRF on OW/OB. For example, compared with white adults, those who are black have higher proportions of type IIa muscle type fibers and higher glycolytic metabolic pathway enzyme activity, which reduce the capacity of the cardiorespiratory system.[20] Pavón et al.[21] showed that SES influenced CRF in adolescents independent of PA and percentage body fat (% BF), with higher SES being associated with greater CRF. Pavón et al.[21] explained that this association could be resulting from unmeasured variables, such as greater access to sports equipment, extracurricular sport sessions, and awareness of the importance of CRF among adolescents of higher SES. During puberty, increases in both insulin resistance and % BF occur and may be responsible for decreases in weight-relative fitness.[22,23] This situation could potentially modify the association of PA with OW/OB by making CRF more difficult to achieve even if physically active.[23]

Therefore, the objective of this study was to examine whether CRF mediates the association of PA and OW/OB in adolescent girls living in low SES areas. Specifically, we aimed to (1) examine the association of moderate-to-vigorous PA (MVPA) with OW/OB and the association of CRF with OW/OB, (2) determine whether CRF is a mediating variable between PA and OW/OB, and (3) determine whether certain demographic variables (race and SES) and pubertal status are moderating variables when mediation by CRF is present.

Methods

Design, Participants, and Setting

This cross-sectional study is a secondary analysis of a group randomized trial that aimed to increase MVPA in adolescent girls (aged 10–14 years), who indicated that they were not attaining at least 60 minutes of MVPA per day, as recommended by the U.S. Department of Health and Human Services.[24] A total of 24 urban middle schools in low-income communities in the Midwestern United States were included. Researchers present at an assembly in each school invited girls to participate and informed them that their school would be randomly assigned to either receive the PA intervention or continue with usual school offerings. Written parental/guardian consent and assent from each girl were obtained before any baseline data collection. Baseline data were collected from September to November in 2012, 2013, and 2014. Detailed information on the inclusion and exclusion criteria, intervention, and study protocol has been previously published.[25] For analysis in this study, only baseline data from the participating girls ($N = 1519$) were included to avoid any potential intervention effect on the variables of interest.

Measures

Demographics. Information on each girl's age, race, and SES was collected through the consent forms completed by parents/guardians. Age was calculated as the difference between the date of baseline data collection and each girl's birth date. For race, parents/guardians selected one or more of the following options: (1) Asian, Native Hawaiian, or Pacific Islander, (2) black or African American, (3) American Indian, Alaskan Native, or Native American, (4) white or Caucasian, and (5) Other. SES was obtained through a single item asking parents/guardians whether their child was enrolled or not in a free or reduced-price lunch program at school. This measure of SES has been shown to be highly correlated with the percentage of families in poverty ($r = 0.67$) and median household income ($r = -0.60$).[26]

Pubertal status. Pubertal development was determined by girl's responses to the Pubertal Development Scale,[27] which has been validated through comparisons with physician assessments[28] and in girls as young as those in 5th grade. Acceptable reliability has been established with Cronbach's alphas ranging from 0.67 to 0.70.[29] In this study, each girl completed the scale behind a privacy screen. Girls reporting menstruation were categorized as being in late puberty and those who had not reported menstruation were categorized as being in early-middle puberty.[29]

Overweight and obesity. BMI z-score and % BF were used as a proxy for OW/OB. Weight, height, and % BF were measured behind a privacy screen. Height was measured without shoes to the nearest 0.1 cm with a Shorr Board (Shorr Productions, Olney, MD). Weight and % BF were measured using a foot-to-foot bioelectric impedance scale (Tanita BC-534 Innerscan Body Composition Monitor; Tanita Corporation, Tokyo, Japan). The reliability (ICC > 0.97) and validity ($r > 0.8$ with skinfolds) of the Tanita bioelectric impedance scale have been previously reported.[30] Weight was measured to the nearest 0.1 kg and body fat was measured to the nearest 0.1%. Two measurements for weight, height, and % BF were collected and averaged. BMI was calculated (weight in kg/height in meters squared), and z-scores were determined using an SAS program for the Centers for Disease Control Growth Charts, which is available online from the National Center for Chronic Disease Prevention and Health Promotion (www.cdc.gov/nccdphp/dnpao/growthcharts/resources/sas.htm).

Moderate-to-vigorous PA. MVPA was assessed through ActiGraph GT3X-plus (www.theActiGraph.com) accelerometers. Each girl wore an accelerometer for 7 days before the intervention. Girls were instructed to wear it attached to a belt on their right hip from the time they awoke to the time they went to bed for 7 consecutive days, but not when bathing or swimming. The monitors were programmed to start data collection at 5:00 am the day after participants received the monitor at school and data were standardized to a 14-hour weekday (1 hour before school, 7 hours during school, and 6 hours after school). The data were collected and stored in the raw format (30 Hz).[31] Additional information on how accelerometer data were handled is published in Robbins et al.[31] For analysis in this study, average minutes of MVPA per hour were determined for each girl (moderate PA: 574–1002 counts/15 seconds; vigorous PA: ≥1003 counts/15 seconds).[32,33]

Cardiorespiratory fitness. The Progressive Aerobic Cardiovascular Endurance Run (PACER), which is a 15- or 20-m shuttle run, was used to assess CRF by estimating aerobic capacity and endurance.[34] The PACER has been shown to be both reliable and valid in adolescents for estimating VO_{2max}.[35,36] The distance of the run is determined by space available and marked by two cones that the girl must continue to run between before an audio cue is heard. As the test progresses, the time between the audio cues decreases. CRF is calculated based on the number of laps each participant completes in the time allotted. The test is finished when participants fail to complete two laps before the audio cue. The number of laps completed is converted to estimate VO_{2max} based on the following equation: $VO_2 = [-8.41 * (\text{mile-equivalent})] + [0.34 * (\text{mile-equivalent} * \text{mile-equivalent})] + [0.21 * (\text{age} * \text{gender})] - (0.84 * \text{BMI}) + 108.94$.[37]

Procedures

Approval for the study was received from the University Biomedical Institutional Review Board, as well as school administrators in their respective districts. Data from the girls were collected by trained data collectors present at the schools, who were blinded to each school's randomization status. Additional procedural details have been previously published.[25]

Statistical Analysis

Data imputation. Missing accelerometer data were addressed using multiple imputation, which is the recommended approach to produce the most unbiased estimates.[38] A total of 1514 of the original 1519 girls had accelerometer data, and among these 1514 girls, the median hours with missing data were 55 of 180 hours total (estimated time awake across the 7 days was 90 hours). Chi-square and t-tests were used to test whether the missingness of one variable was dependent on the missingness of other variables. These tests indicated that the missingness of each variable was independent; therefore, the data were missing at random, so multiple imputation was determined to be a valid approach capable of resulting in unbiased estimates.[39] Twenty multiple imputations were conducted using multivariate imputation by chained equations.[40] Demographic, pubertal status, MVPA, and CRF data were included in the imputation model.

CRF as a mediator between PA and BMI z-score and % BF. Structural equation modeling using Mplus 7.4 was used to assess CRF (estimated VO_{2max}) as a mediating variable between the separate associations of PA (minutes of MVPA/h) with BMI z-score and % BF. The association between the outcome and exposure variables was confirmed using linear regression before consideration of the mediation model.[41] The mi estimate command in Stata 14.2 was used to average results over the 20 multiple imputed data sets. After determining that PA was significantly associated with BMI z-score and % BF, CRF was tested as a mediator between PA and each of the following two variables: BMI z-score and % BF. Standard errors were adjusted to account for the clustering of the data at the school level in the regression as well as the mediation analyses. Indirect, direct, and total effects were calculated to determine whether CRF was a mediator between PA and both BMI z-score and % BF. Significance of a mediating effect was determined using Sobel's test. If significant

Table 1. Baseline Characteristics of the Girls on the Move Study Participants (N = 1519)

	Overall	Non-Hispanic black	White	Early-middle puberty	Late puberty	Receives free/ reduced-price lunch	Does not receive free/reduced-price lunch
	(*N* = 1519)	(*n* = 756)	(*n* = 412)	(*n* = 803)	(*n* = 710)	(*n* = 1182)	(*n* = 234)
	n (%)	*n* (%)	*n* (%)	*n* (%)	*n* (%)	*n* (%)	*n* (%)
Grade							
Fifth	228 (15.0)	80 (10.6)	81 (19.7)	193 (24.0)	33 (4.6)	154 (13.0)	61 (26.1)
Sixth	584 (38.4)	279 (36.9)	181 (43.9)	399 (49.7)	184 (25.9)	441 (37.3)	108 (46.2)
Seventh	573 (37.7)	317 (41.9)	133 (32.3)	198 (24.7)	372 (52.4)	472 (37.9)	56 (23.9)
Eighth	134 (8.8)	80 (10.6)	17 (4.1)	13 (1.6)	121 (17.0)	115 (9.7)	9 (3.9)

	Overall	Non-Hispanic black	White		Early-middle puberty	Late puberty		Receives free/ reduced-price lunch	Does not receive free/reduced-price lunch	
	M (SD)	M (SD)	M (SD)	p^a	M (SD)	M (SD)	p^b	M (SD)	M (SD)	p^c
Age, years	12.05 (1.00)	12.17 (0.97)	11.86 (0.95)	<0.01	11.59 (0.83)	12.57 (0.93)	<0.01	12.12 (1.00)	11.62 (0.90)	<0.01
BMI	23.26 (6.08)	23.96 (6.37)	22.12 (5.37)	<0.01	21.11 (5.13)	24.69 (6.22)	<0.01	23.32 (6.07)	22.62 (5.67)	0.09
BMI z-score	0.97 (1.06)	1.06 (1.07)	0.82 (1.02)	<0.01	0.73 (1.11)	1.25 (0.91)	<0.01	0.98 (1.04)	0.93 (1.09)	0.51
% BF	29.96 (9.71)	31.00 (9.95)	28.17 (9.11)	<0.01	27.41 (9.43)	32.78 (9.24)	<0.01	30.05 (9.62)	29.11 (9.72)	0.20
CRF	37.89 (5.19)	37.32 (5.38)	38.83 (4.64)	<0.01	39.32 (4.61)	36.29 (5.35)	<0.01	37.83 (5.15)	38.47 (4.98)	0.08
MVPA	2.96 (1.32)	3.13 (1.37)	2.73 (1.22)	<0.01	3.16 (1.34)	2.73 (1.26)	<0.01	2.88 (1.23)	2.88 (1.23)	<0.01

Table includes noninputted data. A total of 103 missing lunch data, 0 missing race, 0 missing grade, 0 missing age, 6 missing pubertal stage, 27 missing BMI, 32 missing BMI z-score, 5 missing % BF, 9 missing CRF, 20 missing MVPA.

[a] *p*-value calculated using two-sample *t*-test comparing non-Hispanic black vs. white

[b] *p*-value calculated using two-sample *t*-test comparing early-middle vs. advanced puberty.

[c] *p*-value calculated using two-sample *t*-test adjusting for unequal sample sizes comparing those who received free/reduced-price lunch vs. those who do not.

% BF, percentage body fat; CRF, cardiorespiratory fitness; GOTM, Girls on the Move; M, mean; MVPA, moderate-to-vigorous physical activity; SD, standard deviation.

mediation was present, multigroup analyses were used to examine whether the mediation models were moderated by race (non-Hispanic black vs. white), pubertal status (early-middle vs. late), or SES (enrollment in free or reduced-price lunch program at school or not). To test moderation, the mediation paths among all groups were constrained to be equal, and model fit was compared with the unconstrained model using chi-square difference tests.

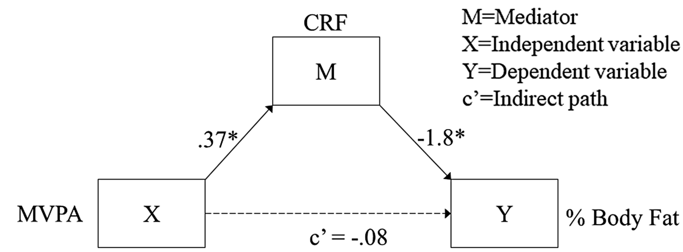

Figure 2. Mediation of MVPA and % BF by CRF. *$p<0.05$. Numbers represent path coefficients. % BF, percentage body fat.

Results

Table 1 describes the baseline demographic characteristics of the sample ($N = 1519$). In the preliminary linear regression analysis, mean minutes of MVPA per hour were significantly and negatively associated with BMI z-score ($\beta = -0.06$, $p < 0.01$) and % BF ($\beta = -0.74$, $p < 0.01$).

Mediation Analysis

Results indicated significant mediation of the relationship between PA and both BMI z-score and % BF by CRF. The indirect effect between PA and BMI z-score through CRF was significant, although the direct effect was no longer significant after inclusion of the mediator (Fig. 1). Similarly, the indirect effect between PA and % BF through CRF was significant, whereas the direct effect was no longer significant with inclusion of CRF (Fig. 2). These findings indicate that CRF is a mediator of the association between PA and both % BF and BMI z-score.[41]

Moderation Analysis

Moderation results are given in Table 2. For both BMI z-score and % BF, chi-square difference tests ($\Delta\chi^2(3, N = 1168) = 11.72$, $p < 0.05$ and $\Delta\chi^2(3, N = 1168) = 13.38$, $p < 0.05$, respectively) indicated that the freely estimated model was a better fit for race. Non-Hispanic blacks had higher PA, but lower CRF than whites. The indirect path from PA to both BMI and % BF through CRF for non-Hispanic blacks was weaker than that for whites. For pubertal status, the freely estimated model had significantly better fit for both BMI and % BF ($\Delta\chi^2(3, N = 1519) = 220.65$, $p < 0.05$ and $\Delta\chi^2(3, N = 1519) = 97.77$, $p < 0.05$, respectively). Those in early-middle puberty had higher PA and CRF than those in late puberty. Indirect paths from PA to both BMI and % BF through CRF were nonsignificant among those in late puberty, whereas indirect paths were significant among those in early-middle puberty. Lastly, the freely estimated model for SES did not provide better fit to the data than the constrained model for both BMI z-score and % BF, which indicated lack of moderation ($\Delta\chi^2(3, N = 1519) = 5.63$, $p > 0.05$ and $\Delta\chi^2(3, N = 1519) = 3.55$, $p > 0.05$, respectively).

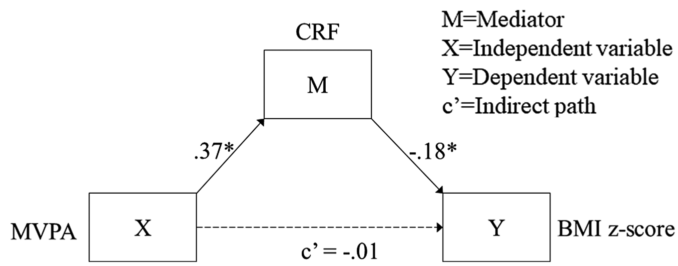

Figure 1. Mediation of MVPA and BMI z-score by CRF. *$p<0.05$. Numbers represent path coefficients. CRF, cardiorespiratory fitness; MVPA, moderate-to-vigorous physical activity.

Discussion

This study examined whether CRF is a mediator of the association between PA and OW/OB in adolescent girls. Similar to results noted by Aires et al.,[10] this study showed that CRF is a complete mediator between PA and OW/OB and, therefore, explains the association between these variables.[12] When CRF is accounted for, the association between PA and both BMI z-score and % BF disappears. This finding indicates that CRF is improved by increasing PA levels, and the improvement in CRF results in lower BMI and % BF. Improved CRF may decrease OW/OB by improving insulin sensitivity and lipid profiles.[42,43] CRF may also be associated with other positive health behaviors that may decrease OW/OB, such as healthy eating behaviors (*i.e.*, eating breakfast and drinking unsweetened beverages).[44,45]

Unlike the findings in Ortega et al.,[11] we found that demographics significantly moderated the mediating effects of CRF on the association between PA and OW/OB. In the multigroup analysis regarding pubertal status, mediation was stronger for those in early-middle puberty (premenses) than late puberty. Weight-relative fitness decreases after puberty in female adolescents, perhaps reducing the beneficial effect of improved CRF.[22,23] In this study, mediation effects were stronger among white girls than among non-Hispanic black girls. The mechanisms for this trend in race may be explained by unmeasured social factors or biological differences. For instance, adolescent girls who are white may have additional advantages such as increased access to healthier foods and social resources.[46] In addition, compared with white girls, black girls have lower Hb concentrations and different muscle fiber type composition that reduce metabolic capacity.[20] Although SES was not a significant moderator, this study makes an important contribution to the literature because, to our knowledge, it is the first to examine SES as a moderator of the interrelationships between PA, CRF, and

Table 2. Moderated Mediation of the Association of Physical Activity and Overweight/Obesity by Race and Pubertal Status

BMI	Path A β (SE)	Path B β (SE)	Path C' β (SE)	Indirect effect
Black girls	**0.41 (0.12)****	**−0.18 (0.01)****	0.02 (0.01)	**−0.07****
White girls	**0.60 (0.17)****	**−0.20 (0.01)****	−0.003 (0.02)	**−0.12****
Early-middle puberty	**0.38 (0.10)****	**−0.22 (0.006)****	**0.03 (0.01)***	**−0.09****
Late puberty	−0.05 (0.10)	**−0.15 (0.005)****	−0.001 (0.01)	0.008
% BF	**Path A β (SE)**	**Path B β (SE)**	**Path C' β (SE)**	**Indirect Effect**
Black girls	**0.41 (0.12)****	**−0.18 (0.04)****	−0.06 (0.06)	**−0.73****
White girls	**0.60 (0.17)****	**−1.90 (0.04)****	−0.07 (0.07)	**−1.14****
Early-middle puberty	**0.38 (0.10)****	**−1.97 (0.03)****	−0.02 (0.06)	**−0.76****
Late puberty	−0.05 (0.10)	**−1.67 (0.04)****	−0.08 (0.08)	0.09

Path A, path from MVPA to CRF; Path B, path from CRF to BMI/% BF; Path C′, path from MVPA to BMI/% BF.

Bold values indicate statistical significance; *$p < 0.05$, **$p < 0.01$.

BMI, body mass index; % BF, percentage body fat; SE, standard error.

OW/OB. However, additional studies are needed to verify this finding.

The results of this study have many practical implications and highlight the importance of considering CRF in designing PA interventions aimed to reduce OW/OB among adolescent girls. Designing PA interventions that optimize both PA and CRF may be necessary, especially in the subgroups that showed weak mediation of CRF in the relationship between PA and OW/OB (*i.e.*, black girls and those in late puberty). For instance, interventions can incorporate high-intensity interval training (HIIT), which is highly effective at improving CRF.[47,48] HIIT involves short repeated sessions of exercise that are close in intensity to VO_{2peak}.[47] Understanding the interrelationships between PA, CRF, and OW/OB in adolescent girls is particularly important because they tend to be less physically active than their male counterparts.[14]

Although this study contributes to understanding some mechanisms underlying OW/OB in adolescent girls, limitations are evident. For instance, the measurement of SES as participation in the free and reduced-price lunch program may not be as accurate as collecting information on other indices of SES, such as family income or wealth.[49] Moreover, geographical areas differ in the availability of these programs, policy implementation varies by area, and program eligibility guidelines are not based on SES alone.[49] Another limitation is the cross-sectional design, which prevents the determination of the temporality of the effect of MVPA and CRF on OW/OB. For example, the possibility exists that OW/OB can negatively affect the ability to perform PA and CRF tests.[12] Future studies are needed to investigate longitudinal mediation analyses. In addition, we did not directly measure VO_{2max}, but estimated CRF through the PACER (shuttle-run). Future studies can confirm the findings with directly measured VO_{2max}. Despite these limitations, this study had many methodological strengths. The inclusion of a large sample of racially diverse girls from 24 different urban schools increases the generalizability of the results. In addition, the study utilized an objective measurement of PA (accelerometers), which is more reliable and accurate than self-report.[15] Furthermore, multiple imputation for missing PA data was used. Multiple imputation results in more precise and less biased estimates, compared with an observed data analysis approach.[39]

In conclusion, the analysis supported our main hypothesis that CRF positively mediates the association between PA and OW/OB in adolescent girls. In addition, race and pubertal status moderated the strength of mediation present. Interventions for reducing OW/OB among adolescent girls should focus on improving both their PA levels and CRF especially for those who are non-Hispanic blacks and in late stages of puberty, where mediation by CRF was weakest. Future studies are needed to confirm these findings in adolescent males and also to investigate whether sedentary behavior affects the relationships among PA, CRF, and OW/OB.

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Author Disclosure Statement

All authors (L.W., D.D.-M., and L.B.R.) declare that no competing financial interests exist.

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