Distribution Agreement

Signature:

______________________________ ______________

Paul N. Elish Date

Longitudinal weight status, cardiorespiratory fitness, and academic achievement
in elementary schoolchildren

By

Paul Elish
Master of Public Health

Global Epidemiology

____

Julie Gazmararian, PhD, MPH
Committee Chair

Longitudinal weight status, cardiorespiratory fitness, and academic achievement in elementary schoolchildren

By

Paul Elish

BA
Yale University
2015

Thesis Committee Chair: Julie Gazmararian, PhD, MPH

An abstract of
a thesis submitted to the Faculty of the
Rollins School of Public Health of Emory University
in partial fulfillment of the requirements for the degree of
Master of Public Health in Global Epidemiology
2021

Abstract

Longitudinal weight status, cardiorespiratory fitness, and academic achievement in elementary schoolchildren
By Paul Elish

Introduction

Childhood overweight and obesity have a well-established negative impact on children's health. Overweight and obesity might also negatively impact children's academic performance, but existing literature on this association is inconclusive. This study uses a longitudinal design in a large, diverse elementary school sample to rigorously test the association between longitudinal weight status and academic achievement. Analyses also investigate moderation by sex, race/ethnicity, and cardiorespiratory fitness (CRF), as well as mediation by CRF, school-day moderate-to-vigorous physical activity (MVPA), school-day sedentary time, and attendance.

Methods

In a large suburban school district, 4,936 Grade 4 students were recruited. Demographic, course grade, and standardized test data were collected from school records for Grades 3 to 5, and body mass index (BMI) and CRF were assessed each year. Students wore accelerometers during the school day for up to 15 days across three semesters (Grade 4 Fall and Spring, Grade 5 Fall) to objectively measure physical activity. Multiple imputation addressed missing data and multilevel analyses controlled for student demographics.

Results

Unadjusted multilevel models found small negative associations for persistent overweight/obesity with course grades and standardized test scores, but these associations largely disappeared when controlling for demographic characteristics. Residual associations for math and writing course grades were attenuated when controlling for CRF, though some marginal negative associations for math and writing remained for students who became overweight/obese during follow up. There was no evidence of moderation by sex or race/ethnicity. For students who were persistently overweight/obese, mediation analyses found a small significant positive indirect effect through lower school-day MVPA (e.g., 0.110, 95% CI: 0.046, 0.184 for math course grades) and a larger negative indirect effect through lower CRF (e.g., -0.643, 95% CI: -0.871, -0.416 for math course grades). Persistently obese students also had a small negative indirect effect through lower attendance. There was no significant indirect effect through school-day sedentary time.

Conclusion

Analyses suggest that there were very small associations between overweight/obesity and academic achievement that were largely explained by CRF. The findings align with growing evidence that increasing CRF is more important than losing weight for boosting children's cognition and academic achievement.

Longitudinal weight status, cardiorespiratory fitness, and academic achievement in elementary schoolchildren

By

Paul Elish

BA
Yale University
2015

Thesis Committee Chair: Julie Gazmararian, PhD, MPH

A thesis submitted to the Faculty of the
Rollins School of Public Health of Emory University
in partial fulfillment of the requirements for the degree of
Master of Public Health in Global Epidemiology
2021

Acknowledgements

I would like to thank my exceptional advisor, Dr. Julie Gazmararian, for all her mentorship and support throughout my time at Rollins. Very sincere appreciation also goes to Dr. Peter Boedeker for his analytic mentorship throughout the thesis process. I would also like to extend my gratitude to Christi Kay, Adria Meyer, and Chuck Truett at HealthMPowers, without whom this study would not have been possible. And as always, special thanks to my parents and sister for supporting me throughout my educational journey.

Table of Contents

I. Background

Childhood obesity has reached epidemic proportions in the United States. From 1978 to 2016, the prevalence of obesity among youth aged 2 to 19 years in the U.S. soared from 5% to 18.5% (Anderson et al., 2019). Children living with obesity have a higher risk of health problems such as high blood pressure, type 2 diabetes, asthma, and sleep apnea (Africa et al., 2016; Bacha & Gidding, 2016; Cote et al., 2013; Lloyd et al., 2012; Mohanan et al., 2014; Narang & Mathew, 2012; Pollock, 2015). Childhood obesity is also associated with psychosocial issues including anxiety and depression (Beck, 2016; Halfon et al., 2013; Morrison et al., 2015). Individuals who are obese as children also have a higher risk of obesity as adults (Gordon-Larsen et al., 2010; Whitaker et al., 1997), and by extension, a higher risk of mortality and diseases including coronary heart disease, stroke, and various forms of cancer (Bhaskaran et al., 2014; Kasen et al., 2008; Luppino et al., 2010; National Institutes of Health, 1998, 2013). All of these phenomena highlight the importance of preventing and treating obesity in childhood.

In addition to childhood obesity's negative health consequences, researchers suggest it might be associated with poorer academic performance. In turn, this poorer academic performance negatively impacts children's professional and economic prospects. Research suggests that childhood obesity's long-term impacts include a decreased likelihood of obtaining a bachelor's degree (Ryabov, 2018) and poorer cognition in midlife (Cohen-Manheim et al., 2017). If the negative relationship between childhood obesity and academic performance indeed exists, it further strengthens the critical need to address obesity early in life.

Various mechanisms have been hypothesized for a negative relationship between childhood obesity and academic performance. Obesity may hinder academic performance by affecting brain development and cognition (Liang et al., 2014; Smith et al., 2011). There may also be an indirect relationship between obesity and academic performance through increased school absenteeism due to poorer physical and mental health (An et al., 2017), social isolation and bullying (Gunnarsdottir et al., 2012; Krukowski et al., 2009), weight-based stigmatization by teachers (MacCann & Roberts, 2013; Moon, 2020; Shackleton & Campbell, 2014), and poorer sleep due to obesity-related breathing problems (Galland et al., 2015; Tan et al., 2014). Obesity's association with lower levels of physical activity (PA) and cardiorespiratory fitness (CRF) (McManus & Mellecker, 2012; Tsiros et al., 2020) may also indirectly impact academic achievement (Bustamante et al., 2016; Martin et al., 2018).

Literature on the association between obesity and academic achievement is not conclusive. A 2017 systematic review synthesized 31 studies from 17 observational prospective cohort studies enrolling participants aged 3 to 18 and meeting a quality score threshold of 70% or higher. The studies' cohorts ranged from 405 to 21,260 students (median study population size was 3,362 students) and followed students for between 1 and 9 years (median follow up was 3 years). Many of the U.S.-based studies included in this review analyzed data from the Early Childhood Longitudinal Study Kindergarten Class of 1998-99 (ECLS-K) cohort, a nationally-representative sample of public and private school students followed from kindergarten in 1998-1999 to Grade 8 spring in 2007. Four ECLS-K studies found some negative associations between overweight/obesity and academic achievement (Gable et al., 2012; Kranjac, 2015; Murasko, 2015; Wendt, 2009), while three found no associations (Datar et al., 2004; Kenney et al., 2015; Zavodny, 2013). ECLS-K studies that found a significant negative association primarily observed it for math performance and among girls (Gable et al., 2012; Kranjac, 2015; Murasko, 2015; Wendt, 2009); some also noted negative associations for children who became obese (Gable et al., 2012; Wendt, 2009). ECLS-K studies that found no significant association generally noted that associations disappeared when controlling for sociodemographic variables (Datar et al., 2004; Zavodny, 2013). Beyond ECLS-K, a study of 915 U.S. students followed from ages 9 to 15 found a significant negative association between BMI and reading and math achievement that disappeared when controlling for executive function and concentration (Manes, 2014). Another U.S. study of 2,820 students followed from 8 to 14 years found no significant association between overweight and obesity and reading performance (Palermo & Dowd, 2012). Overall, this systematic review did not find consistent evidence of a relationship between obesity and academic performance, except for a negative relationship for adolescent girls' math achievement. The authors postulated that this relationship for adolescent girls was mediated by weight-related bullying and executive function (Martin et al., 2017).

Another 2017 systematic review examining 23 cross-sectional and 11 longitudinal studies published from 1990 to 2016 concluded that the relationship between obesity and academic performance was uncertain in most studies after controlling for covariates including socioeconomic status (SES) and PA (Santana, Hill, et al., 2017). Among the four longitudinal studies determined to have low risk of bias, two identified a significant negative association between obesity and academic performance, including one ECLS-K cohort study from kindergarten to Grade 5 (Gable et al 2012), and a study in the United Kingdom that followed 5,966 participants from ages 11 to 16 (Booth et al., 2014). Just two of the seven longitudinal studies with medium risk of bias found a negative association between overweight and academic performance, one following ECLS-K students from kindergarten to Grade 3 (Datar & Sturm, 2006) and the other following 8,061 Finnish students for 7 years (Kantomaa et al., 2013). North American studies with non-significant findings included two ECLS-K cohort studies from kindergarten to Grade 8 (Zavodny, 2013) and from kindergarten to Grade 1 (Datar et al., 2004), a study of 4,647 Canadian students from ages 2-5 to ages 8-11 (Carter et al., 2010), and a 2009 longitudinal study of 2,500 U.S. students from a cohort recruited through the National Longitudinal Survey of Youth (Kaestner & Grossman, 2009).

A 2019 metanalysis of the relationship between body mass index (BMI) and academic achievement found a weak negative correlation when accounting for data from 60 studies (41 conducted in North America) enrolling 164,049 participants (He et al., 2019). The analyzed studies were published from 1999 to 2017 and included participants ranging in age from 4 to 34 years old. The correlation between BMI and academic achievement among children and adolescents ranged from -0.560 to 0.280. After adjusting for publication bias, the authors arrived at a pooled effect size of $r = -0.165$ (95% CI: -0.221 to -0.105; $P < 0.01$). The pooled effect size had higher magnitude in Europe ($r = -0.204$; 95% CI: -0.290 to -0.114; $P < 0.01$) and North America ($r = -0.106$; 95% CI: -0.164 to -0.047) than in Asia ($r = -0.066$; 95% CI: -0.111 to -0.020; $P < 0.01$). The authors suggested that the stronger relationship between BMI and academic achievement in Europe and North America could be due to unique cultural phenomena (He et al., 2019), but the meta-analysis was weakened by the lack of control for SES or CRF.

It is often difficult to compare study results due to the use of different academic achievement measures. Many studies use standardized tests to measure academic performance, while others rely on unstandardized outcomes such as teacher- or self-reported grades or grade point average (GPA) (He et al., 2019; Martin et al., 2017). Studies also measure academic achievement across different course subjects, although reading / language arts and math are most commonly examined. Additionally, although many studies use objectively-measured weight and height, some rely on self-reported weight and height. Other studies use different approaches for measuring weight status, such as waist circumference, dual-energy X-ray absorptiometry, skinfold thickness, and bioelectrical impedance (Martin et al., 2017; Santana, Hill, et al., 2017).

Findings also differ by demographic characteristics such as age and sex. For example, one systematic review found that there was less evidence of an association between obesity and academic achievement among younger children and pre-adolescents than among adolescents (Martin et al., 2017). Similarly, a metanalysis found that elementary school students had the smallest pooled effect size for BMI on academic achievement ($r = -0.075$) compared to middle school ($r=-0.128$) and high school students ($r=-0.184$) (He et al., 2019). Many studies also find differences between girls and boys. One systematic review only found evidence of a significant negative association for adolescent girls (Martin et al., 2017). A metanalysis similarly found a larger pooled effect size among females than males ($r=-0.152$ versus $r=-0.085$), though the difference was not statistically significant (He et al., 2019). These findings could reflect the unique stigma of overweight and obesity for girls (Branigan, 2017; Livermore et al., 2020; Martin et al., 2017).

Studies in the United States place more emphasis on race/ethnicity as a moderator given the country's diversity and ongoing history of racial discrimination. Some studies have only found significant associations among certain racial and ethnic groups, such as among White girls (Branigan, 2017) or among Latino and White students (Clark et al., 2009). Other studies have found race to be more important than BMI for predicting academic performance (Baxter et al., 2013) or have found characteristics like "grit" to be more important than BMI for academic performance among minority students (Cosgrove et al., 2018). There is an ongoing need for U.S. studies that account for unique patterns across racial and ethnic groups through diverse study populations.

Across studies, SES is identified as an important confounder of the relationship between obesity and academic achievement (He et al., 2019; Martin et al., 2017). In the U.S., childhood obesity declines as SES rises (18.9% of youth aged 2-19 years old are obese in the lowest income group compared to 10.9% in the highest income group) and higher SES is associated with higher academic achievement (American Psychological Association, 2017; Centers for Disease Control and Prevention, 2019). A systematic review concluded that the relationship between obesity and academic achievement was uncertain after controlling for covariates including socioeconomic status (Santana, Hill, et al., 2017). Some common measures of SES include parent level of education, parent income, and parent occupation or employment status. In studies of U.S. schoolchildren, participation in the free / reduced-price lunch (FRL) program is also used as a proxy for SES (Dickinson & Adelson, 2014; Food and Nutrition Service, 2019).

Various mediators have also been examined in the association between obesity and academic achievement. One systematic review accounted for cognitive abilities, age of menarche, physical health, internalizing behavior, self-efficacy, and psychosocial factors such as exposure to bullying as mediators, but did not find compelling evidence for any of these mediators’ roles (Martin et al., 2017). PA is another potential mediator, and CRF is especially likely to mediate the association. Childhood obesity is associated with reduced PA (McManus & Mellecker, 2012) and CRF (Tsiros et al., 2020), and while there is inconclusive evidence for PA’s effect on academic achievement (Barbosa et al., 2020; Donnelly et al., 2016; Li et al., 2017; Marques et al., 2018; Wassenaar et al., 2020), there is strong evidence for CRF as a positive predictor of academic achievement (Álvarez-Bueno et al., 2020; Marques et al., 2018; Santana, Azevedo, et al., 2017). Like CRF, attendance is another particularly compelling mediator since overweight and obese children generally have lower attendance (An et al., 2017), which disrupts academic progress.

CRF's role as a mediator relates to the "fat but fit paradox," or the phenomenon where physical fitness attenuates obesity's negative health consequences. Literature suggests that all-cause and cardiovascular disease mortality risk among obese people who have a high CRF level is about the same as among fit, normal-weight people. Some studies even indicate that normal-weight but unfit people are at higher risk of adverse health outcomes than obese but fit people (Ortega et al., 2018). Among children, obesity is associated with detectable changes in the brains, including reduced gray matter volumes (Maayan et al., 2011; Ou et al., 2015), but there is evidence that CRF can counteract the negative effects of obesity on brain development (Esteban-Cornejo et al., 2017). These findings suggest that any negative association between obesity and academic achievement could be attenuated by high CRF (Ortega et al., 2018).

In summary, research on the relationship between weight status and academic achievement remains inconclusive. If there is indeed an association, studies suggest it is stronger among girls and older students, and it may be moderated by CRF, PA, and attendance. Significant gaps in the literature remain. Multiple systematic reviews have called for studies that better account for CRF and PA levels (Martin et al., 2017; Santana, Hill, et al., 2017). There are also calls for better control of confounding factors such as SES and for additional longitudinal studies (Santana, Hill, et al., 2017). Longitudinal studies that account for change in obesity status over time are especially lacking (Martin et al., 2017). In the U.S., studies that account for race/ethnicity and SES are particularly important given the country's history of systemic racism and income inequality.

The present study addresses existing research gaps and limitations by examining longitudinal data from a large, diverse sample of elementary school age children, by adequately controlling for confounders, and by investigating whether CRF, accelerometer-measured PA, and attendance mediate the relationship between obesity and academic performance. Specifically, this study seeks to answer the following questions:

1. Is longitudinal overweight/obesity associated with academic performance among children when controlling for SES and other covariates?
2. Does the relationship between overweight/obesity and academic performance differ across genders and race/ethnicity when controlling for SES and other covariates?
3. Is the relationship between overweight/obesity and academic performance moderated or mediated by CRF?
4. Is the relationship between overweight/obesity and academic performance mediated by objectively-measured school-day moderate-to-vigorous PA (MVPA), objectively-measured school-day sedentary time, or school attendance?

II. Methods

A. Study Design

A cluster-randomized control trial was conducted in a large suburban school district in Georgia, USA following students from 4th grade fall to 5th grade fall over a three-semester intervention period (original plans for a four-semester study period were disrupted by the COVID-19 pandemic). School selection and randomization is described in a previous manuscript (Boedeker et al., 2021).

Intervention

The intervention employed components from the evidence-based *Health Empowers You!* program. This program was designed using the Comprehensive School PA Program approach promoted by the Centers for Disease Control and Prevention (CDC) and had already been implemented in more than 67 schools since 2013 (HealthMPowers, 2021). It is a multi-level intervention that aims to shift school PA practices and culture and allow students to engage in at least 45 minutes of PA during the school day. Prior evaluations of *Health Empowers You!* document improvements in average daily steps, moderate-to-vigorous PA (MVPA) levels in physical education (PE) classes, and student fitness and BMI (Burke et al., 2014; Hyde et al., 2020).

Trained PA Specialists (PASs) provided training and technical assistance to teachers to implement *Health Empowers You!* throughout the school year. Before the start of the 2018-2019 school year, PASs and research team members engaged administrators to obtain top-down buy-in and conducted baseline assessments on schools' current PA practices. PASs then led customized in-person trainings teaching school teams how to increase PA before and during the school day. Training sessions highlighted the main intervention categories: Schoolwide Activities, Recess Strategies, Brain Boosters (PA breaks), and Academic Accelerators (PA breaks combined with academic content). During the trainings, school teams created a weekly calendar of activities to increase PA time to a minimum of 45 minutes per day based on the school environment, resources provided, and *Health Empowers You!* evidence-based strategies. Teachers were also trained on the use of accelerometers that would track student PA during two reporting weeks of the school year. Teacher accountability was secured by a participation agreement outlining all responsibilities that were expected of teachers in order to receive their stipend at the end of each year. After training, teachers were provided with resources and teaching aids to facilitate the integration of PA into the school day. Resources included classroom exercise DVDs and integration strategies, PA game ideas and lesson plans, activity trackers, and exercise equipment. Short (10-minute) interactive videos refreshed teachers on previous content and provided more detailed implementation support every month. PASs also provided classroom teachers with ongoing in-person and virtual technical assistance. Additionally, PE teachers received professional development to learn and develop strategies to increase physically-active time during PE, and environmental cues were posted throughout the school to promote PA engagement.

PASs trained 132 fourth grade teachers from the 20 intervention schools on integrating PA in their classrooms at the beginning of the 2018-2019 school year. All students in the 4th grade participated in the PA intervention. Prior to training, consent/assent forms were distributed through district and school protocol along with a brief informational video in order to obtain guardian consent and student assent to measure PA via accelerometry, and authorization for the school district to share and link de-identified archival records of standardized test scores, grades, attendance, and tardiness as part of the analytic dataset provided to the research team each year. At the beginning of the 2019-2020 school year, 132 fifth grade teachers from the 20 intervention schools received the PAS training on integrating PA in their classrooms.

The intent in implementing the intervention was not to evaluate its effectiveness, but rather, to increase variability in MVPA to enable better assessment of the MVPA-achievement association. Intervention/control status was not included in this analysis because differences in MVPA between intervention and control students were small; intervention students had approximately 3 more daily minutes of MVPA in Grade 4 Fall, 4.5 minutes more in Grade 4 Spring, and 5 minutes more in Grade 5 Fall.

Study Population

The participating elementary schools included diverse student race/ethnicity and a mix of higher- and lower socioeconomic status (SES) based on FRL rates. The school selection procedure ensured the schools were representative of the school district (Boedeker et al., 2021). Of 6,525 fourth graders in the 40 study schools, 4,966 (76%) returned consents. For analysis, students who spent the entirety of the day with a special education teacher who did not implement the intervention were removed from the analytic sample (n=30), leaving 4,936 students eligible for analysis.

B. Data Sources

Data for this analysis are provided from two sources: (1) school district routinely-collected data; and (2) accelerometer data. Each of these data sources are described in more detail below.

School District Data

Demographic data included student gender, race/ethnicity, students with disabilities (SWD), English language learners (ELL), and participation in free/reduced-price lunch (FRL) during the 2018-2019 (Grade 4) school year.

Attendance data included the number of days that students were absent or tardy during the 2018-2019 school year, as well as the number of days they were enrolled.

FitnessGram data included data on students' performance on the FitnessGram assessment, an assessment developed by The Cooper Institute and implemented in school district physical education classes (Meredith, 2008). Physical education teachers were trained in the FitnessGram protocol to ensure consistent implementation across schools. The assessment includes physical fitness tests assessing CRF, muscle strength, muscle endurance, flexibility, and body composition. Students complete the FitnessGram assessment on a semesterly basis in September/October for the fall semester and in May/June in the spring semester. Physical education instructors measured student height and weight to calculate student BMI. Results from the FitnessGram PACER test were used to estimate CRF. In the PACER test, students run back and forth between two points that are 20 meters apart. Students must run from one point to the other before a recorded beep sounds. The time between beeps is progressively shortened. The test ends when students either stop running or can no longer complete the distance in the time between beeps. Full FitnessGram data was collected in Grade 4 Fall and Spring and Grade 5 Fall. FitnessGram data was not collected in Grade 5 Spring due to COVID-related disruptions. The PACER test was also not completed in Grade 3 because it has not been validated among third grade students, but BMI data was collected in the Grade 3 Fall FitnessGram (Fall 2017).

Semesterly course grades data for mathematics, reading, spelling, and writing from Grade 3 Fall and Spring, Grade 4 Fall and Spring and Grade 5 Fall. Grade 5 Spring course grades were not recorded due to the COVID pandemic.

Georgia Milestones Test data included student scores for Grade 3 Spring and Grade 4 Spring Georgia Milestones standardized tests for English language arts (ELA), mathematics, and lexile (measuring literacy). The Georgia Milestones standardized tests were not administered in Spring 2020 due to the COVID pandemic.

Accelerometer Data

Accelerometer data during school hours for the full study population was collected in the three study semesters (Grade 4 Spring and Fall, Grade 5 Fall). During one week in each semester, consented students wore ActiGraph wGT3X-BT accelerometers to objectively track PA during the school day. Accelerometers were attached to an elastic belt which students wore on the waist, with the accelerometer positioned over the hip. Teachers were trained on proper accelerometer wear and were provided with instructional videos for putting them on, removing them, and storing them. Students were assigned an accelerometer with a specific number on the belt. When students entered class each day, they selected their assigned belt and attached it around their waist. Students wore the accelerometer belt for the entire school day before removing them upon leaving school.

C. Study Measures

Exposures

The exposure for this analysis is longitudinal weight status based on BMI measured in the Grade 3, Grade 4, and Grade 5 FitnessGram tests. Age and sex-specific growth charts from the CDC (Centers for Disease Control and Prevention, 2001) were used to categorize participants as obese, overweight, healthy weight, and underweight. Ages at time of height and weight measurement were calculated using dates of birth and assuming the FitnessGram was performed on May 15 and September 15 each year since the exact dates of FitnessGram test administration were not consistently recorded. In accordance with CDC definitions, those children with a BMI at or above the 95th percentile for their age and sex were categorized as obese, those from the 85th

to the 95th percentile were categorized as overweight, those from the 5th to the 85th percentile were classified as healthy weight, and those with a BMI less than the 5th percentile were classified as underweight (Centers for Disease Control and Prevention, 2018).

Two different types of exposure were used. The first was based on overweight/obesity status at two time points and coded into four categories. Students who were overweight or obese at baseline and at follow-up were assigned “persistently overweight/obese,” those who were not overweight or obese at baseline but were at follow-up were assigned “became overweight/obese,” those who were overweight or obese at baseline but not at follow-up were assigned “formerly overweight/obese,” and those who were not overweight or obese at both time points were considered “persistently non-overweight/obese.” For analyses examining Grade 4 standardized test scores as outcomes, baseline BMI was Grade 3 Fall and follow-up was Grade 4 Spring. For analyses examining Grade 5 fall course grades as outcomes, baseline BMI was Grade 3 Fall and follow-up was Grade 5 Fall. Outlier heights and weights were set to missing before calculation of BMI.

The second exposure used the same process for exposure categorization, but it focused specifically on obesity status. The following four categories were used: “persistently obese,” “became obese,” “formerly obese,” and “persistently non-obese.”

Outcomes

Two different types of academic achievement measures were assessed as outcomes. The first was standardized test results from the ELA, math, and lexile Georgia Milestones standardized tests collected for Spring 2019. Georgia Milestones is a statewide Georgia assessment system, and end-of-grade ELA, math, and lexile assessments are conducted every year for Georgia students in grades 3 to 8. On the ELA and math Georgia Milestones tests, a score at or higher than 525 indicated proficiency (Forsyth County Schools, 2019). Grade 4 Milestones scores were used because the Grade 5 Milestones test was canceled due to the COVID pandemic. Analyses were conducted using the Milestones scores as continuous variables.

The second type of academic achievement measure was course grades as assigned by classroom teachers for reading, writing, spelling, and math. Course grades for Grade 3 Fall to Grade 5 Fall were collected and ranged from 0 to 100, with 100 indicating highest achievement. Analyses were conducted with course grades as continuous variables, and considering each subject's course grade separately.

Moderators

Students were categorized according to sex (male or female) and race/ethnicity (Asian, Black, Latino, White, or Other). Student CRF was measured through the FitnessGram's PACER test. PACER laps were converted to an estimated CRF using the standard formula from the Cooper Institute. The median CRF across Grade 4 Fall, Grade 4 Spring, and Grade 5 Fall was assigned to each student. The resulting CRF scores were then categorized as "Healthy Fitness Zone," "Needs Improvement," or "Needs Improvement – Health Risk" in accordance with Cooper Institute guidelines. Students categorized as "Healthy Fitness Zone" for CRF are considered to have sufficient CRF for good health (The Cooper Institute, 2020). The healthy fitness zone cutoff for CRF in this age group is 40.2 (California Department of Education, 2019). A dichotomous cardiorespiratory fitness variable was created based on the Healthy Fitness Zone cutoff and categorized students as "fit" or "unfit." Moderation analyses were conducted for sex, race/ethnicity, and CRF given literature suggesting their moderation of the association between weight status and academic achievement.

Mediators

The median CRF score described above in the “Moderators” section was also assessed as a mediator to investigate its role in the pathway from weight status to academic achievement.

Analyses also explored percent Grade 4 attendance, MVPA during school hours, and sedentary time during school hours as mediators. Percent Grade 4 attendance was calculated by dividing the number of days attended by the number of days enrolled in the school district in Grade 4.

Accelerometer data was aggregated over 15-second epochs to capture the sporadic nature of children’s activity and to mirror the collection intervals from which the Freedson cut points were developed (Freedson et al., 1998). Accelerometer data were used to objectively measure metabolic equivalents (METs), which are categorized as: time spent in sedentary behavior (<1.5 METs), light PA (1.5–3.99 METs); moderate PA (4–5.99 METs), vigorous PA (≥6 METs), and moderate and vigorous PA (>4 METs). In addition, PA intensity was measured using mean activity counts per minute divided by each of the three axes, as well as sum of counts, average counts, and maximum counts. Greater counts per minute indicated a higher intensity.

A day’s accelerometer data was set to missing if it did not meet criteria for a valid day of measurement. Criteria for a valid day required students to have worn the accelerometer for at least 80% of the school day. To meet criteria for inclusion in the analyses, students had to accrue at least 3 valid days of wear during the 5-day measurement period in a given semester. Though at least four days of wear time is typically recommended for reliable PA estimates in children (Barreira et al., 2015; Trost et al., 2005)**,** school day PA is less variable than full-day data (Fairclough et al., 2007)**.** Measures of mean MVPA minutes and mean sedentary minutes were calculated at each time point (i.e., each semester) for which students had at least 3 days of valid accelerometer data.

Confounders

Analyses controlled for SWD, current ELL, and free/reduced-price lunch (FRL) participation. SWD included those with physical or learning disabilities and was dichotomized as "yes" or "no." Current ELL was also dichotomized as "yes" or "no." FRL status was dichotomized as "receiving" or "not receiving" and was used as a proxy for poverty status since the lowest-income students (specifically, those whose families earn less than 185% of the federal poverty level (FPL)) are eligible for FRL.

D. Analysis

Data was compiled and cleaned in preparation for analysis. Variables were missing data either because the students were not enrolled in the participating schools for the entirety of the study or because their observation did not meet criteria for inclusion (e.g., for accelerometer data). Just 0 to 0.1% of students were missing demographic information about race/ethnicity, FRL status, ELL, and SWD. For BMI, 10.8% were missing data in Grade 3 Fall, 6.6% in Grade 4 Fall, 12.5% in Grade 4 Spring, and 20.5% in Grade 5 Fall. CRF data was missing for 7.5% of students in Grade 4 Fall, 14.9% in Grade 4 Spring, and 18.4% in Grade 5 Fall. Only 6.0% of students were missing Grade 3 standardized test scores, and just 3.3% were missing Grade 4 standardized test scores. Between 8.4% and 12.2% were missing average Grade 3 course grades across the four subjects investigated (math, reading, spelling, and writing), and between 14.4% and 16.5% were missing course grades across the four subjects in Grade 5 Fall. Accelerometer data for MVPA and sedentary time was missing for 12.5% of students in Grade 4 Fall, 23.0% of students in Grade 4 Spring, and 27.3% of students in Grade 5 Fall.

Multiple imputation was used to account for missing data. Twenty imputed datasets were created using the multilevel multiple imputation program Blimp (Enders et al., 2018). Implausible imputed values (e.g., a course grade higher than 100) were set to the upper or lower bound value for each variable. For variables without a clear cutoff for plausible values, imputed values were bounded by the highest and lowest values in the non-imputed data.

Descriptive statistics were first run on the non-imputed data set for student demographics, weight status, accelerometer-measured PA, CRF, attendance, standardized test scores, and course grades.

Two-level multilevel models were run with students nested within schools and synthesizing data across the 20 imputed sets. The teacher level was not included in multi-level analyses since students with departmentalized teachers did not remain with the same teacher across core subjects.

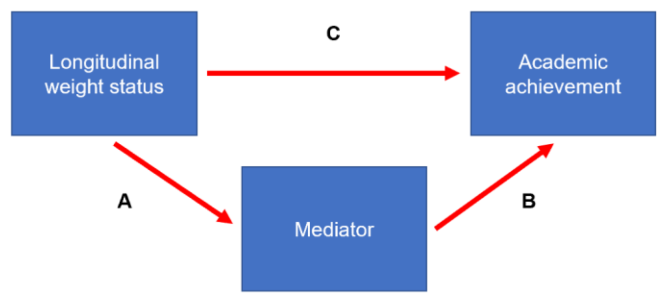
First, models assessed the crude associations between longitudinal weight status and academic outcomes (Model A).

The same associations were then assessed but adjusted for prior achievement, FRL, sex, race/ethnicity, SWD, and ELL (Model B). Adjusting for prior achievement focused analyses on the association of academic achievement with students' weight status specifically during the follow-up period. Prior achievement data was based on Grade 3 academic performance. For analyses with Grade 4 standardized tests as the outcome, Grade 3 standardized test scores were used to measure prior achievement. For analyses with Grade 5 Fall course grades as the outcome, course grades averaged across Grade 3 Fall and Spring were used to measure prior achievement. For example, models with Grade 5 Fall math grade as the outcome adjusted for each student's Grade 3 average math grade.

A third set of models (Model C) adjusted for dichotomized cardiorespiratory fitness in addition to the covariates in Model B. A fourth set of models (Model D) assessed moderation by dichotomized cardiorespiratory fitness while adjusting for the covariates in Model B. A fifth set of models (Model E) assessed moderation by sex while adjusting for the covariates in Model B. A sixth set of models (Model F) assessed moderation by race/ethnicity while adjusting for the covariates in Model B. Final estimates of fixed and random effects were estimated using Rubin's rules (Rubin & Schenker, 1991). Models A through F were first run with longitudinal overweight/obesity status as exposure; then they were run with longitudinal obesity status as exposure.

Mediation analyses were then conducted to measure the indirect effect of weight status on academic achievement through mean school-day MVPA, mean school-day sedentary time, Grade 4 attendance, and median CRF. Pathway A (see Figure 1) was estimated by running a two-level model with longitudinal weight status as the exposure, the mediator of interest as the outcome, and adjusting for all the covariates from Model B except for prior achievement. Pathways B and C (see Figure 1) were estimated by running a two-level model with longitudinal weight status and the mediator of interest as the exposures and adjusting for all the covariates from Model B. Indirect effects were calculated by multiplying pathways A and B (i.e., the product method), and 95% confidence intervals were estimated using Monte Carlo simulation.

Figure 1. Mediation pathways from weight status to academic achievement



III. Results

A. Descriptive statistics

The 4,936-student study population was evenly split between girls (n=2,468, 50%) and boys (n=2,468, 50%) (Table 1). About a third of students were Latino (n=1,640, 33.2%), about a quarter were Black (n=1,243, 25.2%), about a quarter were White (n=1,226, 24.8%), 12.2% were Asian (n=601), and 221 were of other race (4.5%). Slightly more than half received either free (n=2,206, 44%) or reduced-price (n=416, 8.4%) lunch in Grade 4. The median age in Grade 4 Fall was 9 years (interquartile range (IQR) 9-9) and 10 in Grade 4 Spring (IQR 10-10). Almost a quarter of students were current ELL in Grade 4 (n=1,156, 23.4%) and 12.9% had a physical or learning disability (n=637).

Across the four time points where weight status was measured, approximately 25% of students were obese, 18% were overweight, 55% were healthy weight, and 2% were underweight. In both longitudinal follow-up periods (Grade 3 Fall to Grade 4 Spring; Grade 3 Fall to Grade 5 Spring), about 37% of participants were persistently overweight/obese, 51%

persistently non-overweight/obese, 5% became overweight/obese, and 5% became non-overweight/obese. Likewise, longitudinal obesity status was very similar in the two follow-up periods; approximately 21% of participants were persistently obese, 70% were persistently non-obese, 4.5% became obese, and 4.5% became non-obese.

Median CRF was relatively consistent across measurement periods: 40.8 (IQR 39.0-43.9) in Grade 4 Fall, 41.8 (IQR 39.7-45.1) in Grade 4 Spring, and 41.5 (IQR 39.1-45.0) in Grade 5 Fall.

In Grade 3, median standardized ELA score was 527 (IQR 488-566) and median math score was 541 (IQR 506-577). In Grade 4, median ELA score was 535 (IQR 497-574) and median ELA score was 548 (IQR 511-585). Lexile scores rose from a median of 720 (IQR 585-895) in Grade 3 to median 900 (IQR 750-1,055) in Grade 4. When averaging students' two semesters of Grade 3 course grades, median scores for math, reading, and writing were about 85, while median spelling score was 90. The same pattern was observed in Grade 5 Fall course grades.

Average minutes of school-day MVPA declined from Grade 4 to Grade 5. Median average minutes of school-day MVPA was 20.0 (IQR 14.7-26.3) in Grade 4 Fall, 20.0 (IQR 14.6-27.4), in Grade 4 Spring, and 17.5 (IQR 12.6-24.2) in Grade 5 Fall. Conversely, median average minutes of school-day sedentary time rose from Grade 4 to Grade 5. Median average minutes of school-day sedentary time was 244.3 (IQR 221.9-264.5) in Grade 4 Fall, 238.1 (214.7-260.1) in Grade 4 Spring, and 254.6 (233.0-275.8) in Grade 5 Fall. Median percent school days attended in Grade 4 was 97.8 (IQR 95.6-98.9).

B. Multi-level Models – Longitudinal Overweight/Obesity Status

All statistical significance testing is with a Bonferroni corrected p-value of 0.00008 for multiple testing.

In the unadjusted models (Model A), there were small, significant negative associations between persistent overweight/obesity and all academic outcomes (Table 2). Persistently overweight/obese students scored 4.3 points lower on math and ELA standardized tests (p=0.006 to 0.009 respectively), 13.8 points lower on the lexile (p=0.039), and between 1 and 1.5 points lower on Grade 5 Fall course grades (p=0.000). Students who became overweight/obese had significant negative associations of larger magnitude: -7.66 points lower on Grade 4 ELA standardized tests, 33.9 points lower on the lexile, and between -1.5 and 2.4 points lower on Grade 5 Fall course grades. There were no significant associations in Model A for students who became non-overweight/obese.

When adjusting for FRL, race/ethnicity, sex, SWD, ELL, and prior achievement (Model B), all negative associations for standardized test scores became smaller in magnitude (their sign reversed for persistently overweight/obese students) and were no longer statistically significant. There were still small, borderline significant associations for Grade 5 course grades. Persistently overweight/obese students scored 0.63 points lower in math and 0.58 points lower in writing when controlling (p=0.024 and 0.009 respectively). Students who became overweight/obese scored between 0.86 and 1.38 points lower across Grade 5 Fall reading, writing, and math (p=0.035, 0.004, and 0.007 respectively).

When controlling for dichotomized CRF in addition to Model B’s covariates (Model C), all associations became marginal and insignificant for persistently overweight/obese students. There remained some marginally significant associations for students who became overweight/obese for Grade 5 Fall math (β=-1.136, p=0.027) and writing grades (β=-0.952 p=0.018).

When investigating moderation by dichotomized CRF (Model D), interaction coefficients were consistently negative for Grade 4 standardized test scores and generally positive for Grade 5 Fall course grades. No interaction terms were statistically significant.

Models E and F did not indicate moderation by sex or race/ethnicity. This is despite models consistently showing different academic performance patterns across sex and race/ethnicity. Girls consistently performed better in reading, writing, and ELA and worse in math than boys, while White students consistently performed worse than Asian students and better than Black Students.

C. Multi-level Models – Longitudinal Obesity Status

In the unadjusted models (Model A), persistently obese students had consistently lower academic performance across outcomes, including 4.3 points lower on Grade 4 standardized math (p=0.006), 6.9 points lower on standardized ELA (p=0.000), 23.9 points lower on lexile (p=0.002), and between 1.2 and 2.1 points lower on Grade 5 Fall course grades (Table 3). Students who became obese had lower performance of even greater mangitude on standardized test scores, including 16.4 points lower on Grade 4 standardized ELA (p=0.000) and 63.7 points lower on lexile (p=0.000). Course grade associations were more marginal for students who became obese, and the association was only significant for writing (β=-1.605, p=0.004). Associations were very small, generally positive, and statistically non-significant for students who became non-obese during follow up.

When adjusting for FRL, race/ethnicity, sex, SWD, ELL, and prior achievement (Model B), all negative associations between persistent obesity and standardized test scores became smaller in magnitude and were no longer statistically significant. Small negative associations that were borderline significant remained between persistent obesity and Grade 5 Fall math (β=-0.765, p=0.018) and writing grades (β=-0.590, p=0.021). Negative, borderline statistically significant associations remained between students who became obese and standardized ELA (β=-5.986, p=0.025) and lexile (β=-25.308, p=0.032).

When controlling for dichotomized CRF in addition to Model B's covariates (Model C), all associations became marginal and not significant for persistently obese students. Magnitudes of negative associations for students who became obese were larger but not statistically significant. There was one positive, borderline statistically significant positive association between formerly obese students and Grade 4 standardized ELA (β=5.812; p=0.013).

Similar to analyses for longitudinal overweight/obesity status, Models D, E, and F did not indicate moderation by dichotomized CRF, sex, or race/ethnicity.

D. Mediation analyses

Persistent overweight/obesity was significantly negatively associated with school-day MVPA averaged across Grade 4 Fall, Grade 4 Spring, and Grade 5 fall (β=-1.387, p=0.000), and significantly negatively associated with median CRF across Grade 4 Fall, Grade 4 Spring, and Grade 5 Fall (β=-3.230, p=0.000) (Table 4). The association between persistent overweight/obese and average sedentary time across the three accelerometer semesters was marginal and not significant. There was a slight negative association with Grade 4 attendance that was not statistically significant.

Persistent obesity exhibited similar patterns with mediators, but with slightly larger magnitudes. The negative association with mean MVPA was -1.415 (p=0.000) and the negative association with median CRF was -3.537 (p=0.000). Again, the association with mean sedentary time was marginal and not significant. There was also a slight negative, borderline significant association with Grade 4 attendance (β=-0.256, p=0.023).

Mean school-day MVPA was significantly negatively associated with all academic outcomes (Table 5). However, as detailed in a separate manuscript, the magnitudes of these associations are all negligible in practical terms (Elish, 2021).

Mean school-day sedentary time was significantly positively associated with academic achievement. However, as with MVPA, the very small magnitude of these associations makes them negligible in partical terms.

Grade 4 attendance was consistently positively associated with academic performance, though the magnitudes are small. A 1-percent increase in attendance would be expected to increase course grades by between 0.18 and 0.41 points, increase standardized math and ELA scores by about 0.9 points, and lexile by about 3.6 points.

CRF was also consistently positively associated with academic performance, although magnitudes were small. A one-point increase in CRF (which is highly feasible) would be expected to increase course grades by between 0.13 and 0.20 points, increase math and ELA standardized test scores by between 0.25 and 0.59 points, and increase lexile by between 1.8 and 2.1 points.

For persistently overweight/obese students, estimated indirect effects were significant for MVPA and CRF and not significant for sedentary time and attendance (Table 6). Indirect effects from overweight/obesity through MVPA (specifically the lower MVPA associated with overweight/obesity in the sample) were positive, with magnitudes of 0.07 to 0.11 for course grades, of 0.33 to 0.43 for standardized math and ELA respectively, and 1.36 for lexile. The magnitudes of the negative indirect effects through CRF were larger, ranging from -0.43 to –0.64 for course grades, -1.06 and -1.81 for standardized math and ELA respectively, and -6.46 for lexile.

Estimated indirect effects for persistent obesity showed similar patterns, except that negative indirect effects through Grade 4 attendance were also significant. There were small positive indirect effects through MVPA that ranged from 0.07 to 0.11 for Grade 5 Fall course grades, 0.35 and 0.46 for standardized math and ELA respectively, and 1.45 for lexile. Again, these were outweighed by negative indirect effects of larger magnitude through CRF, from -0.46 to -0.67 for course grades, -0.90 and -1.78 for standardized math and ELA respectively, and -6.17 for lexile. Negative indirect effects through Grade 4 attendance were small, ranging from -0.05 (for Grade 5 Fall reading) to -0.927 (for Grade 4 lexile).

IV. Discussion

The present study found only insignificant, marginal negative impacts of persistent overweight/obesity on academic performance after controlling for sociodemographic characteristics. The associations did not differ across sexes or racial/ethnic groups and were primarily seen for teacher-assigned course grades. There were also some indications of negative associations for students who became overweight/obese during follow up. Any negative associations between overweight/obesity and academic achievement appear attributable to obese/overweight students' lower CRF. This indirect effect through CRF outweighed a small positive indirect effect through obese/overweight students' lower school-day MVPA and a small negative indirect effect through obese students' lower attendance. The fact overweight/obesity was significantly associated with school-day MVPA but not school-day sedentary time suggests that PA disparities in school across weight status relate to intensity of PA (i.e., time spent in MVPA as opposed to light PA), rather than amount of PA.

The lack of a strong, consistent negative association between weight status and academic achievement in this study aligns with existing research. A 2019 meta-analysis of 164,049 participants found only a weak negative correlation between BMI and academic achievement, and the meta-analysis did not account for SES or physical fitness (He et al., 2019). A 2017 systematic review of 23 cross-sectional and 11 longitudinal studies found that the association between obesity and academic performance was uncertain after controlling for covariates including socioeconomic status and PA (Santana, Hill, et al., 2017). Among the four longitudinal studies with low risk of bias, only 2 of the 4 identified a negative association, and just 2 of the 7 longitudinal studies with medium risk of bias found a significant negative association (Santana, Hill, et al., 2017).

The lack of moderation by sex is more divergent from previous studies, but may reflect the age of this study's cohort. A 2017 systematic review found evidence of a consistent negative association among girls, but only among adolescents (Martin et al., 2017). More broadly, the lack of significant negative associations in this study aligns with prior research suggesting a weaker association between weight status and academic achievement among pre-adolescent children. A 2019 meta-analysis found the smallest pooled effect size for BMI on academic achievemetn among elementary school students compared to middle school and high school students (He et al., 2019). Two systematic reviews suggest that this could be due to cognitive development processes wherein pubertal prefrontal cortex development is particularly important for the development of executive function (Liang et al., 2014; Martin et al., 2017).

The findings suggesting a slightly more consistent negative association for students who became overweight/obese (as opposed to students who were persistently overweight/obese) aligns with other prior studies. One study from the ECLS-K cohort found that among girls, those that moved from non-overweight to overweight status during kindergarten to third grade experienced a decline in standardized reading and math test scores (Datar & Sturm, 2006). Another ECLS-K study of students from kindergarten to fifth grade found significantly negative math scores in girls who became obese during the study period (Gable et al., 2012). An ECLS-K study of children from kindergarten to third grade found significantly lower math scores in children who became obese (Wendt, 2009).

There is less research on differences in this association across racial and ethnic groups, however, the lack of moderation by race/ethnicity aligns with some prior literature. Studies among racial minorities in the U.S. have generally found other factors beyond weight status to be more important for academic achievement. In one study in Massachusetts, CRF was especially important for Black students; Black students who had high CRF achieved the same performance as Black students of higher socioeconomic status who did not have high CRF (Aske et al., 2018). Another study in a predominantly Latino school system found that grit (a construct representing perseverance) was more important than BMI or physical fitness for predicting Latino students' academic performance in English (Cosgrove et al., 2018).

This study's finding of the importance of CRF for academic achievement aligns with a large body of research. A 2017 systematic review of 45 studies examining the relationship between various physical fitness components and academic achievement found especially strong evidence for a positive relationship between CRF and academic achievement (Santana, Azevedo, et al., 2017). This positive relationship was again identified in a 2018 systematic review of 51 studies (Marques et al., 2018). A 2020 systematic review and meta-analysis also identified a significant positive relationship and noted that the relationship was stronger in boys compared to girls. This meta-analysis also noted a stronger positive relationship between cardiorespiratory fitness and academic achievement among children compared to adolescents (Álvarez-Bueno et al., 2020), which could help explain cardiorespiratory fitness' larger role relative to weight status in this pre-adolescent sample.

This study also contributes support to the "fat but fit paradox" that has been observed in other studies. Several previous U.S. studies similarly suggest that CRF attentuates any negative associations between weight status and academic achievement. A longitudinal study of over 1,200 students in Masschusetts from fifth to eighth grade found that positive associations between healthy weight and standardized test scores in math and ELA became either marginal or entirely disappeared when controlling for sociodemographic characteristics and cardiorespiratory fitness (Aske et al., 2018). Another cross-sectional study of 968 fifth grade students in West Virginia found that there was no association between weight status and standardized test scores for reading and language arts, math, science, and social studies after controlling for cardiovascular risk (blood pressure and presence of diabetes) and an overall fitness score based on the Fitnessgram (Cottrell et al., 2007). A study of 1,989 California students ages 10 to 16 also found that increasing quintiles of BMI scored progressively lower on standardized tests for math and reading, but the association was no longer significant when controlling for fitness level (Roberts et al., 2010).

These “fat but fit paradox” patterns are also evident in research outside the U.S. A study of 36,870 13 and 14-year-olds in Chile found that “high fatness” participants had higher academic achievement if they were fit, and the relationship between fatness variables and academic achievement was partially or fully mediated by physical fitness (García-Hermoso et al., 2017). At least four studies in Spain with samples ranging from 250 to 1,802 also indicate that negative associations between overweight/obesity and academic achievement are reduced or eliminated by high CRF (García-Hermoso et al., 2021; Martinez-Vizcaino et al., 2021; Muntaner-Mas et al., 2018; Torrijos-Niño et al., 2014).

The present study benefits from at least six strengths. First, it has a large sample of nearly 5,000 students across 40 elementary schools. Second, the sample is highly diverse, with the large number of Latino, Black, and Asian participants reflecting diversity across the U.S. nationally. Third, the study is longitudinal and collected student data across two years, allowing greater potential for causal inference. Fourth, the collection of data from a single school district ensured greater consistency in recording data ranging from demographic information to FitnessGram data in physical education classes. Fifth, incorporation of mediation by school-day PA is novel compared to other studies on the association between weight status and academic achievement. Finally, this PA data is also valuable because it objectively measures PA via accelerometers, rather than relying on self reports.

Despite these strengths, this study has at least 4 limitations. First, the 20-meter shuttle run is not a perfect measure of CRF since student performance could be influenced by motivation. Nevertheless, it is a standard measure of CRF in the literature on childhood cardiorespiratory fitness. Second, it is also possible that not all physical education teachers measured height and weight the same way. This inconsistency was reduced by all PE teachers receiving the same training for conducting FitnessGram tests. Third, analyzing Grade 5 spring standardized test scores and course grades would have given the study a longer follow-up time, but this became impossible due to the COVID pandemic. Finally, most variables had some missing data, but this was addressed through multiple imputation and analysis across 20 imputed data sets.

Future research should prioritize longitudinal design to understand how long-term changes in weight status and CRF interact to affect academic achievement across age groups. Longitudinal studies should also investigate how school-day PA contributes to CRF and academic achievement in the long term. There is also a continued need for neuroscience investigations that explore the neuro-cognitive mechanisms underlying the “fat but fit” paradox. Future studies should also compare findings acrosss different measures of academic performance, including standardized tests and teacher-assigned course grades.

This study has important implications for education policy. While overweight and obesity have a multitude of negative impacts on child health and can negatively impact pediatric cognition (Esteban-Cornejo et al., 2019; Maayan et al., 2011; Ou et al., 2015), these impacts are less important than CRF when determining academic performance. Policies that promote CRF among children could help elevate academic performance, especially among overweight/obese students who generally have lower CRF. Some of the existing CRF disparity based on weight status could be attributable to lower levels of MVPA among overweight and obese studenes in the school setting. This could be addressed by designing active breaks, recess activities, and other initiatives during the school-day that focus on higher-intensity PA.

References

Africa, J. A., Newton, K. P., & Schwimmer, J. B. (2016). Lifestyle interventions including nutrition, exercise, and supplements for nonalcoholic fatty liver disease in children. *Dig Dis Sci*, *61*(5), 1375-1386. https://doi.org/10.1007/s10620-016-4126-1

Álvarez-Bueno, C., Hillman, C. H., Cavero-Redondo, I., Sánchez-López, M., Pozuelo-Carrascosa, D. P., & Martínez-Vizcaíno, V. (2020). Aerobic fitness and academic achievement: A systematic review and meta-analysis. *J Sports Sci, 38*(5), 582-589. https://doi.org/10.1080/02640414.2020.1720496

American Psychological Association. (2017). *Education and Socioeconomic Status*. https://www.apa.org/pi/ses/resources/publications/education

An, R., Yan, H., Shi, X., & Yang, Y. (2017). Childhood obesity and school absenteeism: a systematic review and meta-analysis. *Obes Rev, 18*(12), 1412-1424. https://doi.org/10.1111/obr.12599

Anderson, P. M., Butcher, K. F., & Schanzenbach, D. W. (2019). Understanding recent trends in childhood obesity in the United States. *Economics & Human Biology, 34*, 16-25. https://doi.org/https://doi.org/10.1016/j.ehb.2019.02.002

Aske, D. B., Chomitz, V. R., Liu, X., Arsenault, L., Bhalotra, S., & Acevedo-Garcia, D. (2018). Relationship between cardiorespiratory fitness, weight status, and academic performance: longitudinal evidence from 1 school district. *J Sch Health, 88*(8), 560-568. https://doi.org/10.1111/josh.12643

Bacha, F., & Gidding, S. S. (2016). Cardiac abnormalities in youth with obesity and type 2 diabetes. *Curr Diab Rep, 16*(7), 62. https://doi.org/10.1007/s11892-016-0750-6

Barbosa, A., Whiting, S., Simmonds, P., Scotini Moreno, R., Mendes, R., & Breda, J. (2020). Physical activity and academic achievement: an umbrella review. *Int J Environ Res Public Health, 17*(16). https://doi.org/10.3390/ijerph17165972

Barreira, T. V., Schuna, J. M., Tudor-Locke, C., Chaput, J. P., Church, T. S., Fogelholm, M., Hu, G., Kuriyan, R., Kurpad, A., Lambert, E. V., Maher, C., Maia, J., Matsudo, V., Olds, T., Onywera, V., Sarmiento, O. L., Standage, M., Tremblay, M. S., Zhao, P., & Katzmarzyk, P. T. (2015). Reliability of accelerometer-determined physical activity and sedentary behavior in school-aged children: a 12-country study. *Int J Obes Suppl, 5*(Suppl 2), S29-35. https://doi.org/10.1038/ijosup.2015.16

Baxter, S. D., Guinn, C. H., Tebbs, J. M., & Royer, J. A. (2013). There is no relationship between academic achievement and body mass index among fourth-grade, predominantly African-American children. *J Acad Nutr Diet*, *113*(4), 551-557. https://doi.org/10.1016/j.jand.2013.01.004

Beck, A. R. (2016). Psychosocial aspects of obesity. *NASN School Nurse*, *31*(1), 23-27. https://doi.org/10.1177/1942602X15619756

Bhaskaran, K., Douglas, I., Forbes, H., dos-Santos-Silva, I., Leon, D. A., & Smeeth, L. (2014). Body-mass index and risk of 22 specific cancers: a population-based cohort study of 5.24 million UK adults. *Lancet*, *384*(9945), 755-765. https://doi.org/10.1016/s0140-6736(14)60892-8

Boedeker, P., Turner, L., Calvert, H., Kay, C., Meyer, A., Truett, C., & Gazmararian, J. (2021). Study protocol for testing the association between physical activity and academic outcomes utilizing a cluster-randomized trial. *Contemporary Clinical Trials Communications*, *21*, 100747. https://doi.org/https://doi.org/10.1016/j.conctc.2021.100747

Booth, J. N., Tomporowski, P. D., Boyle, J. M., Ness, A. R., Joinson, C., Leary, S. D., & Reilly, J. J. (2014). Obesity impairs academic attainment in adolescence: findings from ALSPAC, a UK cohort. *Int J Obes (Lond)*, *38*(10), 1335-1342. https://doi.org/10.1038/ijo.2014.40

Branigan, A. R. (2017). (How) does obesity harm academic performance? Stratification at the intersection of race, sex, and body size in elementary and high school. *Sociol Educ*, *90*(1), 25-46. https://doi.org/10.1177/0038040716680271

Burke, R. M., Meyer, A., Kay, C., Allensworth, D., & Gazmararian, J. A. (2014). A holistic school-based intervention for improving health-related knowledge, body composition, and fitness in elementary school students: an evaluation of the HealthMPowers program. *Int J Behav Nutr Phys Act*, *11*, 78. https://doi.org/10.1186/1479-5868-11-78

Bustamante, E. E., Williams, C. F., & Davis, C. L. (2016). Physical activity interventions for neurocognitive and academic performance in overweight and obese youth: a systematic review. *Pediatr Clin North Am*, *63*(3), 459-480. https://doi.org/10.1016/j.pcl.2016.02.004

California Department of Education. (2019). *FitnessGram Healthy Fitness Zone Performance Standards*. https://pftdata.org/files/hfz-standards.pdf

Carter, M. A., Dubois, L., & Ramsay, T. (2010). Examining the relationship between obesity and math performance among Canadian school children: a prospective analysis. *Int J Pediatr Obes*, *5*(5), 412-419. https://doi.org/10.3109/17477160903496995

Centers for Disease Control and Prevention. (2001). Data Table of BMI-for-age Charts. https://www.cdc.gov/growthcharts/html_charts/bmiagerev.htm

Centers for Disease Control and Prevention. (2018). *Defining Childhood Obesity*. https://www.cdc.gov/obesity/childhood/defining.html

Centers for Disease Control and Prevention. (2019). *Childhood Obesity Facts*. Centers for Disease Control and Prevention. https://www.cdc.gov/obesity/data/childhood.html#:~:text=Prevalence%20of%20Childhood%20Obesity%20in%20the%20United%20States&text=For%20children%20and%20adolescents%20aged,to%2019%2Dyear%2Dolds.

Clark, D., Slate, J. R., & Viglietti, G. C. (2009). Children's weight and academic performance in elementary school: cause for concern? *Analyses of Social Issues and Public Policy, 9*(1), 185-204. https://doi.org/https://doi.org/10.1111/j.1530-2415.2009.01186.x

Cohen-Manheim, I., Doniger, G. M., Sinnreich, R., Simon, E. S., Murad, H., Pinchas-Mizrachi, R., & Kark, J. D. (2017). Body mass index, height and socioeconomic position in adolescence, their trajectories into adulthood, and cognitive function in midlife. *J Alzheimers Dis, 55*(3), 1207-1221. https://doi.org/10.3233/jad-160843

Cosgrove, J. M., Chen, Y. T., & Castelli, D. M. (2018). Physical Fitness, Grit, School Attendance, and Academic Performance among Adolescents. *Biomed Res Int, 2018,* 9801258. https://doi.org/10.1155/2018/9801258

Cote, A. T., Harris, K. C., Panagiotopoulos, C., Sandor, G. G., & Devlin, A. M. (2013). Childhood obesity and cardiovascular dysfunction. *J Am Coll Cardiol, 62*(15), 1309-1319. https://doi.org/10.1016/j.jacc.2013.07.042

Cottrell, L. A., Northrup, K., & Wittberg, R. (2007). The extended relationship between child cardiovascular risks and academic performance measures. *Obesity (Silver Spring), 15*(12), 3170-3177. https://doi.org/10.1038/oby.2007.377

Datar, A., & Sturm, R. (2006). Childhood overweight and elementary school outcomes. *Int J Obes (Lond), 30*(9), 1449-1460. https://doi.org/10.1038/sj.ijo.0803311

Datar, A., Sturm, R., & Magnabosco, J. L. (2004). Childhood overweight and academic performance: national study of kindergartners and first-graders. *Obes Res, 12*(1), 58-68. https://doi.org/10.1038/oby.2004.9

Dickinson, E. R., & Adelson, J. L. (2014). Exploring the limitations of measures of students' socioeconomic status (SES). *Practical Assessment, Research, and Evaluation, 19*(1), 1.

Donnelly, J. E., Hillman, C. H., Castelli, D., Etnier, J. L., Lee, S., Tomporowski, P., Lambourne, K., & Szabo-Reed, A. N. (2016). Physical activity, fitness, cognitive function, and academic achievement in children: a systematic review. *Med Sci Sports Exerc, 48*(6), 1223-1224. https://doi.org/10.1249/mss.0000000000000966

Elish, P. N., Cassandra S. Bryan, Peter Boedeker, Lindsey Turner, Hannah G. Calvert, Christi M. Kay, Adria Meyer, Chuck Truett, Julie A. Gazmararian. (2021). The Longitudinal Association Between Objectively-Measured Physical Activity and Academic Achievement in US Elementary School Students.

Enders, C. K., Keller, B. T., & Levy, R. (2018). A fully conditional specification approach to multilevel imputation of categorical and continuous variables. *Psychological methods, 23*(2), 298.

Esteban-Cornejo, I., Cadenas-Sanchez, C., Contreras-Rodriguez, O., Verdejo-Roman, J., Mora-Gonzalez, J., Migueles, J. H., Henriksson, P., Davis, C. L., Verdejo-Garcia, A., Catena, A., & Ortega, F. B. (2017). A whole brain volumetric approach in overweight/obese children: Examining the association with different physical fitness components and academic performance. The ActiveBrains project. *Neuroimage, 159*, 346-354. https://doi.org/10.1016/j.neuroimage.2017.08.011

Esteban-Cornejo, I., Rodriguez-Ayllon, M., Verdejo-Roman, J., Cadenas-Sanchez, C., Mora-Gonzalez, J., Chaddock-Heyman, L., Raine, L. B., Stillman, C. M., Kramer, A. F., Erickson, K. I., Catena, A., Ortega, F. B., & Hillman, C. H. (2019). Physical Fitness, White Matter Volume and Academic Performance in Children: Findings From the ActiveBrains and FITKids2 Projects. *Front Psychol, 10*, 208. https://doi.org/10.3389/fpsyg.2019.00208

Fairclough, S. J., Butcher, Z. H., & Stratton, G. (2007, May). Whole-day and segmented-day physical activity variability of northwest England school children. *Prev Med, 44*(5), 421-425. https://doi.org/10.1016/j.ypmed.2007.01.002

Food and Nutrition Service. (2019). *Child Nutrition Programs: Income Eligibility Guidelines (July 1, 2019 - June 30, 2020)*. https://www.fns.usda.gov/cnp/fr-032019

Forsyth County Schools. (2019). *Easy Access to Milestones Scores*. https://www.forsyth.k12.ga.us/cms/lib/GA01000373/Centricity/Domain/1/GA%20Milestones%20Parent%20Information%20Nights_AprilMay%202019_FINAL2.pdf

Freedson, P. S., Melanson, E., & Sirard, J. (1998, May). Calibration of the Computer Science and Applications, Inc. accelerometer. *Med Sci Sports Exerc, 30*(5), 777-781. https://doi.org/10.1097/00005768-199805000-00021

Gable, S., Krull, J. L., & Chang, Y. (2012). Boys' and girls' weight status and math performance from kindergarten entry through fifth grade: a mediated analysis. *Child Dev, 83*(5), 1822-1839. https://doi.org/10.1111/j.1467-8624.2012.01803.x

Galland, B., Spruyt, K., Dawes, P., McDowall, P. S., Elder, D., & Schaughency, E. (2015). Sleep disordered breathing and academic performance: a meta-analysis. *Pediatrics, 136*(4), e934-946. https://doi.org/10.1542/peds.2015-1677

García-Hermoso, A., Esteban-Cornejo, I., Olloquequi, J., & Ramírez-Vélez, R. (2017). Cardiorespiratory fitness and muscular strength as mediators of the influence of fatness on academic achievement. *J Pediatr, 187*, 127-133.e123. https://doi.org/10.1016/j.jpeds.2017.04.037

García-Hermoso, A., Martinez-Gomez, D., Del Rosario Fernández-Santos, J., Ortega, F. B., Castro-Piñero, J., Hillman, C. H., Veiga, O. L., & Esteban-Cornejo, I. (2021). Longitudinal associations of physical fitness and body mass index with academic performance. *Scand J Med Sci Sports, 31*(1), 184-192. https://doi.org/10.1111/sms.13817

Gordon-Larsen, P., The, N. S., & Adair, L. S. (2010). Longitudinal trends in obesity in the United States from adolescence to the third decade of life. *Obesity (Silver Spring), 18*(9), 1801-1804. https://doi.org/10.1038/oby.2009.451

Gunnarsdottir, T., Njardvik, U., Olafsdottir, A. S., Craighead, L. W., & Bjarnason, R. (2012). Teasing and social rejection among obese children enrolling in family-based behavioural treatment: effects on psychological adjustment and academic competencies. *Int J Obes (Lond), 36*(1), 35-44. https://doi.org/10.1038/ijo.2011.181

Halfon, N., Larson, K., & Slusser, W. (2013). Associations between obesity and comorbid mental health, developmental, and physical health conditions in a nationally representative sample of US children aged 10 to 17. *Acad Pediatr, 13*(1), 6-13. https://doi.org/10.1016/j.acap.2012.10.007

He, J., Chen, X., Fan, X., Cai, Z., & Huang, F. (2019). Is there a relationship between body mass index and academic achievement? A meta-analysis. *Public Health, 167*, 111-124. https://doi.org/10.1016/j.puhe.2018.11.002

HealthMPowers. (2021). *Program*. https://healthempowersyou.org/about/

Hyde, E. T., Gazmararian, J. A., Barrett-Williams, S. L., & Kay, C. M. (2020). Health Empowers You: Impact of a school-based physical activity program in elementary school students, Georgia, 2015-2016. *J Sch Health, 90*(1), 32-38. https://doi.org/10.1111/josh.12847

Kaestner, R., & Grossman, M. (2009). Effects of weight on children's educational achievement. *Economics of Education Review, 28*(6), 651-661.

Kantomaa, M. T., Stamatakis, E., Kankaanpää, A., Kaakinen, M., Rodriguez, A., Taanila, A., Ahonen, T., Järvelin, M. R., & Tammelin, T. (2013). Physical activity and obesity mediate the association between childhood motor function and adolescents' academic achievement. *Proc Natl Acad Sci U S A, 110*(5), 1917-1922. https://doi.org/10.1073/pnas.1214574110

Kasen, S., Cohen, P., Chen, H., & Must, A. (2008). Obesity and psychopathology in women: a three decade prospective study. *Int J Obes (Lond), 32*(3), 558-566. https://doi.org/10.1038/sj.ijo.0803736

Kenney, E. L., Gortmaker, S. L., Davison, K. K., & Bryn Austin, S. (2015). The academic penalty for gaining weight: a longitudinal, change-in-change analysis of BMI and perceived academic ability in middle school students. *Int J Obes (Lond), 39*(9), 1408-1413. https://doi.org/10.1038/ijo.2015.88

Kranjac, A. W. (2015). The moderating effect of self-efficacy on normal-weight, overweight, and obese children's math achievement: a longitudinal analysis. *Soc Sci Med, 128*, 168-177. https://doi.org/10.1016/j.socscimed.2015.01.007

Krukowski, R. A., West, D. S., Philyaw Perez, A., Bursac, Z., Phillips, M. M., & Raczynski, J. M. (2009). Overweight children, weight-based teasing and academic performance. *Int J Pediatr Obes, 4*(4), 274-280. https://doi.org/10.3109/17477160902846203

Li, J. W., O'Connor, H., O'Dwyer, N., & Orr, R. (2017). The effect of acute and chronic exercise on cognitive function and academic performance in adolescents: A systematic review. *J Sci Med Sport, 20*(9), 841-848. https://doi.org/10.1016/j.jsams.2016.11.025

Liang, J., Matheson, B. E., Kaye, W. H., & Boutelle, K. N. (2014). Neurocognitive correlates of obesity and obesity-related behaviors in children and adolescents. *Int J Obes (Lond), 38*(4), 494-506. https://doi.org/10.1038/ijo.2013.142

Livermore, M., Duncan, M. J., Leatherdale, S. T., & Patte, K. A. (2020). Are weight status and weight perception associated with academic performance among youth? *J Eat Disord, 8*, 52. https://doi.org/10.1186/s40337-020-00329-w

Lloyd, L. J., Langley-Evans, S. C., & McMullen, S. (2012). Childhood obesity and risk of the adult metabolic syndrome: a systematic review. *Int J Obes (Lond), 36*(1), 1-11. https://doi.org/10.1038/ijo.2011.186

Luppino, F. S., de Wit, L. M., Bouvy, P. F., Stijnen, T., Cuijpers, P., Penninx, B. W., & Zitman, F. G. (2010). Overweight, obesity, and depression: a systematic review and meta-analysis of longitudinal studies. *Arch Gen Psychiatry, 67*(3), 220-229. https://doi.org/10.1001/archgenpsychiatry.2010.2

Maayan, L., Hoogendoorn, C., Sweat, V., & Convit, A. (2011). Disinhibited eating in obese adolescents is associated with orbitofrontal volume reductions and executive dysfunction. *Obesity (Silver Spring), 19*(7), 1382-1387. https://doi.org/10.1038/oby.2011.15

MacCann, C., & Roberts, R. D. (2013). Just as smart but not as successful: obese students obtain lower school grades but equivalent test scores to nonobese students. *Int J Obes (Lond), 37*(1), 40-46. https://doi.org/10.1038/ijo.2012.47

Manes, R. (2014). How childhood obesity predicts academic achievement: a longitudinal study. *CUNY Academic Works*. https://academicworks.cuny.edu/gc_etds/254

Marques, A., Santos, D. A., Hillman, C. H., & Sardinha, L. B. (2018). How does academic achievement relate to cardiorespiratory fitness, self-reported physical activity and objectively reported physical activity: a systematic review in children and adolescents aged 6-18 years. *Br J Sports Med*, *52*(16), 1039. https://doi.org/10.1136/bjsports-2016-097361

Martin, A., Booth, J. N., Laird, Y., Sproule, J., Reilly, J. J., & Saunders, D. H. (2018). Physical activity, diet and other behavioural interventions for improving cognition and school achievement in children and adolescents with obesity or overweight. *Cochrane Database Syst Rev, 1*(1), Cd009728. https://doi.org/10.1002/14651858.CD009728.pub3

Martin, A., Booth, J. N., McGeown, S., Niven, A., Sproule, J., Saunders, D. H., & Reilly, J. J. (2017). Longitudinal associations between childhood obesity and academic achievement:

systematic review with focus group data. *Curr Obes Rep, 6*(3), 297-313. https://doi.org/10.1007/s13679-017-0272-9

Martinez-Vizcaino, V., Álvarez-Bueno, C., Sanchez-Lopez, M., Jimenez-Lopez, E., Soriano-Cano, A., Ortega, F. B., Cavero-Redondo, I., & Garrido-Miguel, M. (2021). A cluster mediation analysis confirms the validity of the "fat but fit" paradigm in children's cognitive function and academic achievement. *J Pediatr, 231,* 231-238.e231. https://doi.org/10.1016/j.jpeds.2020.12.062

McManus, A. M., & Mellecker, R. R. (2012). Physical activity and obese children. *Journal of Sport and Health Science, 1*(3), 141-148. https://doi.org/https://doi.org/10.1016/j.jshs.2012.09.004

Meredith, M. (2008). *Parental Overview of FitnessGram Assessment*. https://www.pcsb.org/cms/lib/FL01903687/centricity/domain/180/Parent_Overview_of_FitnessGram.pdf

Mohanan, S., Tapp, H., McWilliams, A., & Dulin, M. (2014). Obesity and asthma: pathophysiology and implications for diagnosis and management in primary care. *Exp Biol Med (Maywood), 239*(11), 1531-1540. https://doi.org/10.1177/1535370214525302

Moon, R. C. (2020). The associations between childhood obesity, academic performance, and perception of teachers: from kindergarten to fifth grade. *Child Obes, 16*(6), 403-411. https://doi.org/10.1089/chi.2019.0330

Morrison, K. M., Shin, S., Tarnopolsky, M., & Taylor, V. H. (2015). Association of depression & health related quality of life with body composition in children and youth with obesity. *J Affect Disord, 172,* 18-23. https://doi.org/10.1016/j.jad.2014.09.014

Muntaner-Mas, A., Palou, P., Vidal-Conti, J., & Esteban-Cornejo, I. (2018). A mediation analysis on the relationship of physical fitness components, obesity, and academic performance in children. *J Pediatr, 198,* 90-97.e94. https://doi.org/10.1016/j.jpeds.2018.02.068

Murasko, J. E. (2015). Overweight/obesity and human capital formation from infancy to adolescence: evidence from two large US cohorts. *J Biosoc Sci, 47*(2), 220-237. https://doi.org/10.1017/s0021932014000236

Narang, I., & Mathew, J. L. (2012). Childhood obesity and obstructive sleep apnea. *J Nutr Metab, 2012*, 134202. https://doi.org/10.1155/2012/134202

National Institutes of Health. (1998). *Clinical Guidelines on the Identification, Evaluation, and Treatment of Overweight and Obesity in Adults*. https://www.nhlbi.nih.gov/files/docs/guidelines/ob_gdlns.pdf

National Institutes of Health. (2013). *Managing Overweight and Obesity in Adults, Systematic Evidence Review from the Obesity Expert Panel, 2013*. https://www.nhlbi.nih.gov/sites/default/files/media/docs/obesity-evidence-review.pdf

Ortega, F. B., Ruiz, J. R., Labayen, I., Lavie, C. J., & Blair, S. N. (2018). The Fat but Fit paradox: what we know and don't know about it. *Br J Sports Med, 52*(3), 151-153. https://doi.org/10.1136/bjsports-2016-097400

Ou, X., Andres, A., Pivik, R. T., Cleves, M. A., & Badger, T. M. (2015). Brain gray and white matter differences in healthy normal weight and obese children. *J Magn Reson Imaging, 42*(5), 1205-1213. https://doi.org/10.1002/jmri.24912

Palermo, T. M., & Dowd, J. B. (2012). Childhood obesity and human capital accumulation. *Soc Sci Med, 75*(11), 1989-1998. https://doi.org/10.1016/j.socscimed.2012.08.004

Pollock, N. K. (2015). Childhood obesity, bone development, and cardiometabolic risk factors. *Mol Cell Endocrinol*, *410*, 52-63. https://doi.org/10.1016/j.mce.2015.03.016

Roberts, C. K., Freed, B., & McCarthy, W. J. (2010). Low aerobic fitness and obesity are associated with lower standardized test scores in children. *J Pediatr, 156*(5), 711-718, 718.e711. https://doi.org/10.1016/j.jpeds.2009.11.039

Rubin, D. B., & Schenker, N. (1991). Multiple imputation in health-are databases: An overview and some applications. *Statistics in medicine, 10*(4), 585-598.

Ryabov, I. (2018). Childhood obesity and academic outcomes in young adulthood. *Children (Basel), 5*(11). https://doi.org/10.3390/children5110150

Santana, C. C. A., Azevedo, L. B., Cattuzzo, M. T., Hill, J. O., Andrade, L. P., & Prado, W. L. (2017). Physical fitness and academic performance in youth: A systematic review. *Scand J Med Sci Sports, 27*(6), 579-603. https://doi.org/10.1111/sms.12773

Santana, C. C. A., Hill, J. O., Azevedo, L. B., Gunnarsdottir, T., & Prado, W. L. (2017). The association between obesity and academic performance in youth: a systematic review. *Obes Rev, 18*(10), 1191-1199. https://doi.org/10.1111/obr.12582

Shackleton, N. L., & Campbell, T. (2014). Are teachers' judgements of pupils' ability influenced by body shape? *Int J Obes (Lond), 38*(4), 520-524. https://doi.org/10.1038/ijo.2013.210

Smith, E., Hay, P., Campbell, L., & Trollor, J. N. (2011). A review of the association between obesity and cognitive function across the lifespan: implications for novel approaches to prevention and treatment. *Obes Rev, 12*(9), 740-755. https://doi.org/10.1111/j.1467-789X.2011.00920.x

Tan, E., Healey, D., Schaughency, E., Dawes, P., & Galland, B. (2014). Neurobehavioural correlates in older children and adolescents with obesity and obstructive sleep apnoea. *J Paediatr Child Health, 50*(1), 16-23. https://doi.org/10.1111/jpc.12390

The Cooper Institute. (2020). *Healthy Fitness Zone Standards Overview*. https://www.cooperinstitute.org/healthyfitnesszone

Torrijos-Niño, C., Martínez-Vizcaíno, V., Pardo-Guijarro, M. J., García-Prieto, J. C., Arias-Palencia, N. M., & Sánchez-López, M. (2014). Physical fitness, obesity, and academic achievement in schoolchildren. *J Pediatr, 165*(1), 104-109. https://doi.org/10.1016/j.jpeds.2014.02.041

Trost, S. G., McIver, K. L., & Pate, R. R. (2005). Conducting accelerometer-based activity assessments in field-based research. *Med Sci Sports Exerc, 37*(11 Suppl), S531-543. https://doi.org/10.1249/01.mss.0000185657.86065.98

Tsiros, M. D., Tian, E. J., Shultz, S. P., Olds, T., Hills, A. P., Duff, J., & Kumar, S. (2020). Obesity, the new childhood disability? An umbrella review on the association between adiposity and physical function. *Obes Rev, 21*(12), e13121. https://doi.org/10.1111/obr.13121

Wassenaar, T. M., Williamson, W., Johansen-Berg, H., Dawes, H., Roberts, N., Foster, C., & Sexton, C. E. (2020). A critical evaluation of systematic reviews assessing the effect of chronic physical activity on academic achievement, cognition and the brain in children and adolescents: a systematic review. *Int J Behav Nutr Phys Act, 17*(1), 79. https://doi.org/10.1186/s12966-020-00959-y

Wendt, M. (2009). Economic, environmental, and endowment effects on childhood obesity and school performance. *Dissertation Abstracts International Section A: Humanities and Social Sciences, 70(1-A)*(281).

Whitaker, R. C., Wright, J. A., Pepe, M. S., Seidel, K. D., & Dietz, W. H. (1997). Predicting obesity in young adulthood from childhood and parental obesity. *N Engl J Med*, *337*(13), 869-873. https://doi.org/10.1056/nejm199709253371301

Zavodny, M. (2013). Does weight affect children's test scores and teacher assessments differently? *Econ Educ Rev*, *34*, 135-145. https://doi.org/10.1016/j.econedurev.2013.02.003

Table 1. Demographic Characteristics, Physical Fitness Attributes, and Academic Outcomes for Study Participants, Grades 3 to 5 (n=4,936)

Variable	N / median	% / IQR	% Missing
Sex			
Female	2,468	50.0	0
Male	2,468	50.0	
Race / Ethnicity			
Asian	601	12.2	
Black	1,243	25.2	
Latino	1,640	33.2	0.1
White	1,226	24.8	
Other	221	4.5	
Grade 4 Free / Reduced-Price Lunch Status			
Free	2,206	44.7	
Reduced price	416	8.4	0.1
Not receiving free / reduce-price lunch	2,309	46.8	
Age (years)			
Grade 4 Fall	9	9-9	0
Grade 4 Spring	10	9-10	0
Current English Language Learner			
Yes	1,156	23.4	0.1
No	3,775	76.5	
Student with Disabilities			
Yes	637	12.9	0.1
No	4,294	87.0	
Weight status, Grade 3 Fall			
Obese	1,106	25.1	
Overweight	762	17.3	10.8
Healthy weight	2,384	54.1	
Underweight	152	3.5	
Weight status, Grade 4 Fall			
Obese	1,180	25.6	
Overweight	814	17.7	6.6
Healthy weight	2,532	54.9	
Underweight	82	1.8	
Weight status, Grade 4 Spring			
Obese	1,031	23.9	12.5
Overweight	772	17.9	

Healthy weight	2,428	56.2	
Underweight	87	2.0	
Weight status, Grade 5 Fall			
Obese	1,024	26.1	
Overweight	732	18.6	20.5
Healthy weight	2,090	53.2	
Underweight	80	2.0	
Longitudinal obesity status, Grade 3 Fall to Grade 4 Spring			
Persistently Obese	789	20.2	
Became Obese	150	3.8	
Formerly Obese	195	5.0	21.0
Persistently Non-Obese	2,767	70.9	
Longitudinal obesity status, Grade 3 Fall to Grade 5 Fall			
Persistently Obese	756	21.3	
Became Obese	187	5.3	28.0
Formerly Obese	126	3.5	
Persistently Non-Obese	2,486	69.9	
Longitudinal overweight/obesity status, Grade 3 Fall to Grade 4 Spring			
Persistently Overweight/Obese	1,427	36.6	
Became Overweight/Obese	215	5.5	21.0
Formerly Overweight/Obese	235	6.0	
Persistently Non-Overweight/Obese	2,024	51.9	
Longitudinal overweight/obesity status, Grade 3 Fall to Grade 5 Fall			
Persistently Overweight/Obese	1,328	37.4	
Became Overweight/Obese	277	7.8	28.0
Formerly Overweight/Obese	165	4.6	
Persistently Non-Overweight/Obese	1,785	50.2	
Average minutes of school-day MVPA			
Grade 4 Fall	20.0	14.7-26.3	12.5
Grade 4 Spring	20.0	14.6-27.4	23.0
Grade 5 Fall	17.5	12.6-24.2	23.0
Average minutes of school-day sedentary time			
Grade 4 Fall	244.3	221.9-264.5	12.5
Grade 4 Spring	238.1	214.7-260.1	23.0
Grade 5 Fall	254.6	233.0-275.8	27.3
Cardiorespiratory fitness (CRF, VO_2Max)			
Grade 4 Fall	40.8	39.0-43.9	7.5
Grade 4 Spring	41.8	39.7-45.1	14.9
Grade 5 Fall	41.5	39.1-45.0	18.4
Number of days enrolled, Grade 4	180	180-180	0.01

% days attended, Grade 4	97.8	95.6-98.9	0.01
Grade 3 Georgia Milestones Tests			
English Language Arts Scale Score	527.0	488.0-566.0	6.0
Math Scale Score	541.0	506.0-577.0	6.0
Lexile	720.0	585.0-895.0	6.0
Grade 4 Georgia Milestones Tests			
English Language Arts Scale Score	535.0	497.0-574.0	3.3
Math Scale Score	548.0	511.0-585.0	3.3
Lexile	900.0	750.0-1055.0	3.3
Grade 3 Average Course Grades			
Math	85.0	78.5-90.5	8.4
Reading	84.0	77.5-90.0	8.4
Spelling	90.0	83.5-94.5	12.2
Writing	85.5	79.5-90.5	9.1
Grade 5 Fall Course Grades			
Math	84.0	75.0-91.0	15.1
Reading	84.0	77.0-90.0	14.4
Spelling	90.0	82.0-95.0	16.5
Writing	86.0	80.0-91.0	15.0

Table 2. Associations between longitudinal overweight/obesity status from Grades 3 to 4/5 and academic performance measured by Grade 4 standardized test scores and Grade 5 Fall course marks

	Georgia Milestones Grade 4 Standardized Tests						Grade 5 Fall Course Grades							
	Math Score		ELA Score		Lexile		Math		Reading		Spelling		Writing	
Weight Category	Beta (SE)	p	Beta (SE)	p	Beta (SE)	p	Beta (SE)	p	Beta (SE)	p	Beta (SE)	p	Beta (SE)	p
Model A: Unadjusted Model														
Persistently overweight / obese[a]	-4.381 (1.604)	**0.006**	-4.332 (1.651)	**0.009**	-13.843 (6.703)	**0.039**	-1.530 (0.362)	**0.000**	-1.013 (0.283)	**0.000**	-1.036 (0.293)	**0.000**	-1.422 (0.259)	**0.000**
Became overweight / obese[a]	-6.259 (3.394)	0.066	-7.656 (3.405)	**0.025**	-33.946 (13.804)	**0.014**	-2.406 (0.650)	**0.000**	-1.932 (0.517)	**0.000**	-1.639 (0.541)	**0.003**	-1.983 (0.484)	**0.000**
Formerly overweight / obese[a]	0.175 (3.264)	0.957	-0.592 (3.450)	0.864	-1.610 (0.907)	0.907	0.776 (0.822)	0.346	0.586 (0.666)	0.380	0.321 (0.650)	0.622	0.416 (0.588)	0.479
Model B: Adjusted Model 1[a]														
Persistently overweight / obese[a]	0.336 (0.957)	0.725	0.330 (1.052)	0.754	2.679 (4.866)	0.582	-0.630 (0.279)	**0.024**	-0.116 (0.224)	0.605	-0.200 (0.261)	0.443	-0.575 (0.221)	**0.009**
Became overweight / obese[a]	-3.298 (1.878)	0.079	-0.761 (2.104)	0.718	-10.427 (9.460)	0.271	-1.378 (0.507)	**0.007**	-0.861 (0.035)	**0.035**	-0.864 (0.480)	0.073	-1.143 (0.396)	**0.004**
Formerly overweight / obese[a]	1.931 (0.335)	0.335	1.387 (0.508)	0.508	8.195 (9.296)	0.378	0.552 (0.660)	0.403	0.826 (0.107)	0.107	0.491 (0.591)	0.407	0.472 (0.480)	0.326
Model C: Adjusted Model 2[a,b]														
Persistently overweight / obese[a]	1.460 (1.033)	0.158	1.850 (1.130)	0.102	7.015 (5.261)	0.183	-0.161 (0.302)	0.596	0.152 (0.243)	0.531	0.124 (0.280)	0.659	-0.208 (0.239)	0.386

Became overweight / obese[a]	-2.791 (1.889)	0.140	-0.085 (2.109)	0.968	-8.469 (9.464)	0.371	-1.136 (0.513)	**0.027**	-0.722 (0.411)	0.080	-0.695 (0.483)	0.152	-0.952 (0.399)	**0.018**
Formerly overweight / obese[a]	2.083 (0.299)	0.299	1.597 (0.446)	0.446	8.780 (9.298)	0.345	0.612 (0.661)	0.356	0.857 (0.513)	0.096	0.528 (0.590)	0.371	0.516 (0.481)	0.284
Model D: Adjusted, and Moderation by Cardiorespiratory Fitness [a]														
Persistently overweight / obese[a]	3.211 (1.739)	0.065	4.034 (1.920)	**0.036**	15.980 (9.059)	0.078	-0.473 (0.502)	0.347	0.069 (0.403)	0.863	0.088 (0.474)	0.852	-0.306 (0.389)	0.431
Became overweight / obese[a]	-1.915 (3.314)	0.564	1.375 (3.727)	0.712	-6.499 (16.864)	0.700	-1.721 (0.864)	**0.047**	-0.999 (0.643)	0.121	-1.103 (0.796)	0.167	-0.793 (0.608)	0.193
Formerly overweight / obese[a]	2.998 (3.835)	0.435	2.931 (4.319)	0.498	18.341 (19.896)	0.357	0.502 (1.316)	0.703	0.765 (1.039)	0.462	1.168 (1.171)	0.319	0.465 (0.981)	0.636
Persistently overweight / obese[a] * Fit	-2.807 (2.181)	0.199	-3.468 (2.396)	0.148	-14.308 (11.137)	0.199	0.469 (0.652)	0.473	0.109 (0.520)	0.834	0.041 (0.591)	0.944	0.182 (0.489)	0.711
Became overweight / obese[a] * Fit	-1.007 (4.094)	0.806	-1.822 (4.869)	0.709	-1.237 (21.010)	0.953	0.879 (1.119)	0.433	0.429 (0.808)	0.595	0.666 (1.012)	0.511	-0.286 (0.764)	0.708
Formerly overweight / obese[a] * Fit	-1.125 (4.301)	0.794	-1.654 (4.821)	0.732	-12.207 (22.592)	0.589	0.127 (1.463)	0.931	0.116 (1.187)	0.922	-0.848 (1.321)	0.521	0.063 (1.122)	0.955
Model E: Adjusted, and Moderation by Sex [a]														
Persistently overweight / obese[a]	0.202 (1.333)	0.879	0.307 (1.440)	0.831	2.919 (6.630)	0.660	-0.609 (0.383)	0.112	-0.054 (0.319)	0.867	-0.066 (0.358)	0.853	-0.487 (0.308)	0.114

Became overweight / obese[a]	-0.876 (2.516)	0.728	0.126 (2.872)	0.965	-2.407 (13.279)	0.856	-1.541 (0.698)	**0.028**	-0.774 (0.528)	0.143	-1.132 (0.648)	0.081	-0.939 (0.549)	0.088
Formerly overweight / obese[a]	-0.177 (2.800)	0.950	-2.040 (3.002)	0.497	-5.879 (13.634)	0.666	-0.019 (0.950)	0.984	0.218 (0.749)	0.771	0.672 (0.860)	0.435	0.195 (0.683)	0.776
Sex	-7.646 (1.168)	**0.000**	4.026 (1.299)	**0.002**	11.361 (5.937)	0.056	-0.073 (0.366)	0.842	1.465 (0.288)	**0.000**	1.488 (0.337)	**0.000**	1.985 (0.283)	**0.000**
Persistently overweight / obese[a] * Sex	0.276 (1.828)	0.880	0.009 (2.011)	0.997	-0.593 (9.173)	0.948	-0.050 (0.536)	0.925	-0.130 (0.436)	0.765	-0.276 (0.500)	0.581	-0.177 (0.417)	0.671
Became overweight / obese[a] * Sex	-5.297 (3.753)	0.158	-1.997 (4.233)	0.637	-17.615 (19.468)	0.366	0.336 (1.006)	0.738	-0.188 (0.779)	0.810	0.578 (0.903)	0.523	-0.428 (0.746)	0.566
Formerly overweight / obese[a] * Sex	3.889 (3.702)	0.294	6.328 (4.095)	0.123	25.912 (19.320)	0.180	1.109 (1.221)	0.364	1.185 (0.985)	0.229	-0.345 (1.121)	0.758	0.543 (0.897)	0.545
Model F: Adjusted, and Moderation by Race/Ethnicity [a]														
Persistently overweight / obese[a]	-0.414 (2.020)	0.838	-1.874 (2.220)	0.399	-8.665 (10.129)	0.392	-1.038 (0.585)	0.076	-0.634 (0.479)	0.186	-0.378 (0.563)	0.503	-0.787 (0.475)	0.098
Became overweight / obese[a]	-7.100 (3.722)	0.057	1.165 (4.137)	0.778	3.433 (19.386)	0.860	-1.853 (0.958)	0.054	-0.949 (0.778)	0.223	-0.975 (1.000)	0.331	-1.437 (0.810)	0.078
Formerly overweight / obese[a]	3.242 (3.831	0.398	1.999 (4.254)	0.639	14.557 (19.228)	0.449	2.011 (1.197)	0.093	0.021 (0.945)	0.983	-0.044 (1.112)	0.969	0.606 (0.934)	0.517
Asian	6.241 (1.951)	**0.001**	9.342 (2.135)	**0.000**	39.071 (9.667)	**0.000**	2.674 (0.587)	**0.000**	1.054 (0.455)	**0.021**	1.964 (0.564)	**0.001**	2.181 (0.460)	**0.000**

Black	-7.705 (1.715)	**0.000**	-2.442 (1.913)	0.202	-19.178 (8.652)	**0.027**	-2.655 (0.520)	**0.000**	-1.776 (0.416)	**0.000**	-1.087 (0.495)	**0.028**	-1.374 (0.409)	**0.001**
Latino	-2.709 (1.803)	0.133	0.811 (2.030)	0.690	3.497 (9.194)	0.704	-0.828 (0.558)	0.138	-1.028 (0.458)	0.025	-0.770 (0.513)	0.134	-0.244 (0.429)	0.570
Other	-2.968 (2.832)	0.295	1.979 (3.143)	0.529	-0.406 (14.072)	0.977	-0.914 (0.866)	0.291	-0.508 (0.710)	0.475	0.296 (0.836)	0.723	-0.286 (0.689)	0.678
Persistently overweight / obese[a] * Asian	3.414 (3.357)	0.309	3.891 (3.732)	0.297	6.447 (16.873)	0.702	0.739 (0.975)	0.449	1.125 (0.788)	0.154	0.165 (0.921)	0.858	-0.328 (0.775)	0.672
Became overweight / obese[a] * Asian	3.644 (6.389)	0.569	8.150 (6.984)	0.243	21.417 (32.353)	0.508	0.382 (1.784)	0.831	-0.375 (1.345)	0.780	0.349 (1.755)	0.843	0.409 (1.337)	0.760
Formerly overweight / obese[a] * Asian	2.857 (6.262)	0.648	-1.766 (7.041)	0.802	-19.129 (31.884)	0.549	-0.995 (1.999)	0.619	1.861 (1.523)	0.222	-0.137 (1.848)	0.941	-0.256 (1.534)	0.867
Persistently overweight / obese[a] * Black	1.309 (2.674)	0.625	4.075 (2.994)	0.174	31.352 (13.591)	0.021	0.791 (0.782)	0.312	0.829 (0.638)	0.194	0.309 (0.757)	0.683	0.667 (0.619)	0.281
Became overweight / obese[a] * Black	4.328 (5.189)	0.404	-6.639 (5.941)	0.264	-29.510 (27.558)	0.285	0.058 (1.358)	0.966	-0.391 (1.118)	0.727	-0.556 (1.399)	0.691	-0.158 (1.130)	0.889
Formerly overweight / obese[a] * Black	-5.394 (5.191)	0.299	-0.836 (6.047)	0.890	-22.207 (27.406)	0.418	-2.721 (1.816)	0.135	-0.000 (1.363)	1.000	1.403 (1.642)	0.393	-0.243 (1.346)	0.857

Persistently overweight / obese[a] * Latino	0.251 (2.507)	0.920	1.936 (2.827)	0.493	8.197 (12.761)	0.521	0.231 (0.748)	0.757	0.529 (0.611)	0.387	0.302 (0.726)	0.677	0.170 (0.588)	0.772
Became overweight / obese[a] * Latino	5.110 (4.989)	0.306	-4.532 (5.890)	0.442	-25.843 (26.569)	0.331	0.794 (1.314)	0.546	0.574 (1.048)	0.584	0.182 (1.297)	0.888	0.790 (1.030)	0.443
Formerly overweight / obese[a] * Latino	0.255 (5.024)	0.959	0.676 (5.695)	0.906	11.597 (25.734)	0.652	-1.627 (1.716)	0.344	1.692 (1.333)	0.205	0.504 (1.536)	0.743	0.003 (1.262)	0.998
Persistently overweight / obese[a] * Other	-0.631 (4.828)	0.896	-1.883 (5.433)	0.729	-20.147 (24.451)	0.410	0.687 (1.484)	0.643	-0.057 (1.163)	0.961	-0.757 (1.374)	0.581	0.429 (1.132)	0.705
Became overweight / obese[a] * Other	12.862 (8.989)	0.153	0.245 (11.033)	0.982	-27.682 (46.210)	0.549	2.646 (2.137)	0.216	0.804 (1.690)	0.634	2.403 (1.970)	0.223	0.614 (1.672)	0.713
Formerly overweight / obese[a] * Other	-9.039 (11.160)	0.419	-11.507 (11.617)	0.322	-67.422 (52.188)	0.197	-2.031 (3.118)	0.515	0.837 (2.341)	0.721	0.942 (2.705)	0.728	-0.637 (2.284)	0.780

[a]Baseline weight status is from Grade 3 Fall. Follow-up weight status is from Grade 4 Spring for standardized test outcomes and from Grade 5 Fall for course grade outcomes. “Persistently overweight/obese” indicates student was overweight/obese at baseline and follow-up. “Became overweight/obese” indicates student was overweight/obese at follow-up but not baseline. “Formerly overweight/obese” indicates student was overweight/obese at baseline but not follow-up.

[b]Models B through F adjusted for FRL, sex, race/ethnicity, current English language learners, and students with disabilities.

[c]Model C also adjusts for dichotomized cardiorespiratory fitness (fit or unfit).

Table 3. Associations between longitudinal obesity status from Grades 3 to 4/5 and academic performance measured by Grade 4 standardized test scores and Grade 5 Fall course marks

	Georgia Milestones Grade 4 Standardized Tests						**Grade 5 Fall Course Grades**							
	Math Score		**ELA Score**		**Lexile**		**Math**		**Reading**		**Spelling**		**Writing**	
Weight Category	Beta (SE)	p	Beta (SE)	p	Beta (SE)	p	Beta (SE)	p	Beta (SE)	p	Beta (SE)	p	Beta (SE)	p
Model A: Unadjusted Model														
Persistently obese[a]	-4.381 (1.604)	**0.006**	-6.881 (1.894)	**0.000**	-23.870 (7.665)	**0.002**	-2.137 (0.402)	**0.000**	-1.219 (0.322)	**0.000**	-1.383 (0.336)	**0.000**	-1.712 (0.299)	**0.000**
Became obese[a]	-6.259 (3.394)	0.066	-16.391 (4.055)	**0.000**	-63.691 (16.309)	**0.000**	-0.995 (0.766)	0.194	-0.751 (0.616)	0.223	-1.075 (0.657)	0.103	-1.605 (0.562)	**0.004**
Formerly obese[a]	0.175 (3.264)	0.957	4.982 (3.581)	0.164	14.302 (14.427)	0.322	0.290 (0.903)	0.748	0.016 (0.703)	0.982	-0.016 (0.716)	0.982	0.347 (0.624)	0.578
Model B: Adjusted Model 1[a]														
Persistently obese[a]	-1.031 (1.102)	0.349	-0.704 (1.218)	0.564	-2.121 (5.530)	0.701	-0.765 (0.322)	**0.018**	-0.037 (0.258)	0.887	-0.287 (0.300)	0.340	-0.590 (0.255)	**0.021**
Became obese[a]	0.603 (2.247)	0.789	-5.986 (2.666)	**0.025**	-25.308 (11.790)	**0.032**	-0.107 (0.611)	0.862	0.562 (0.491)	0.253	-0.211 (0.591)	0.722	-0.569 (0.232)	0.232
Formerly obese[a]	0.194 (2.015)	0.923	5.035 (2.322)	**0.030**	12.001 (10.525)	0.254	0.008 (0.685)	0.990	0.305 (0.554)	0.582	-0.139 (0.643)	0.829	0.095 (0.855)	0.855
Model C: Adjusted Model 2[a,b]														
Persistently obese[a]	0.223 (0.850)	0.850	1.040 (1.315)	0.429	2.458 (6.030)	0.684	-0.173 (0.342)	0.613	0.345 (0.285)	0.226	0.118 (0.326)	0.718	-0.119 (0.281)	0.673
Became obese[a]	1.378 (0.541)	0.541	-4.921 (2.650)	0.064	-22.501 (11.780)	0.056	0.280 (0.620)	0.651	0.808 (0.105)	0.105	0.052 (0.600)	0.931	-0.261 (0.489)	0.593
Formerly obese[a]	0.755 (0.710)	0.710	5.812 (2.327)	**0.013**	14.055 (10.560)	0.184	0.186 (0.685)	0.786	0.415 (0.455)	0.455	-0.020 (0.640)	0.975	0.236 (0.521)	0.651
Model D: Interaction by Cardiorespiratory Fitness [a]														

Persistently obese[a]	1.426 (1.556)	0.360	1.832 (1.821)	0.315	6.646 (8.317)	0.424	-0.408 (0.453)	0.368	0.069 (0.403)	0.863	0.083 (0.425)	0.845	-0.161 (0.367)	0.660
Became obese[a]	2.777 (3.228)	0.390	-3.644 (3.692)	0.324	-19.585 (17.084)	0.252	-0.357 (0.673)	0.673	-0.999 (0.643)	0.121	-0.190 (0.815)	0.816	-0.320 (0.645)	0.620
Formerly obese[a]	4.765 (3.184)	0.135	5.395 (3.708)	0.146	5.925 (16.526)	0.720	0.317 (0.788)	0.788	0.765 (1.039)	0.462	0.284 (1.061)	0.789	-0.126 (0.863)	0.884
Persistently obese[a] * Fit	-2.301 (2.317)	0.321	-1.799 (2.747)	0.513	-10.485 (12.441)	0.400	0.500 (0.471)	0.471	0.109 (0.520)	0.834	0.073 (0.652)	0.911	0.071 (0.567)	0.900
Became obese[a] * Fit	-2.307 (4.796)	0.631	-2.351 (5.304)	0.658	-5.030 (24.826)	0.840	1.255 (0.333)	0.333	0.429 (0.808)	0.595	0.500 (1.140)	0.661	0.097 (1.004)	0.923
Formerly obese[a] * Fit	-6.653 (4.166)	0.111	0.917 (4.790)	0.848	14.887 (21.657)	0.492	-0.238 (0.872)	0.872	0.116 (1.187)	0.922	-0.488 (1.347)	0.717	0.573 (1.094)	0.600
Model E: Interaction by Sex [a]														
Persistently obese[a]	-1.892 (1.493)	0.205	-0.660 (1.646)	0.688	-0.064 (7.437)	0.993	-0.614 (0.423)	0.146	0.233 (0.354)	0.510	-0.166 (0.418)	0.691	-0.449 (0.351)	0.201
Became obese[a]	-0.134 (2.904)	0.963	-7.339 (3.305)	**0.027**	-27.726 (14.553)	0.057	0.292 (0.796)	0.714	0.784 (0.661)	0.237	-0.242 (0.731)	0.741	-0.494 (0.630)	0.434
Formerly obese[a]	-4.984 (2.950)	0.091	5.816 (3.188)	0.068	10.964 (14.808)	0.459	0.429 (0.982)	0.662	0.256 (0.811)	0.753	-0.025 (0.943)	0.979	-0.010 (0.762)	0.990
Sex	-8.522 (0.981)	**0.000**	4.133 (1.113)	**0.000**	11.733 (0.020)	**0.020**	0.142 (0.313)	0.650	1.627 (0.244)	**0.000**	1.472 (0.291)	**0.000**	1.973 (0.239)	**0.000**
Persistently obese[a] * Sex	1.732 (2.119)	0.414	-0.089 (2.341)	0.970	-4.452 (10.555)	0.673	-0.308 (0.625)	0.622	-0.574 (0.487)	0.239	-0.257 (0.598)	0.667	-0.303 (0.472)	0.522
Became obese[a] * Sex	1.619 (4.638)	0.727	3.564 (5.216)	0.495	6.477 (23.531)	0.783	-1.005 (1.253)	0.423	-0.536 (0.992)	0.589	0.104 (1.122)	0.926	-0.178 (0.949)	0.851

Formerly obese[a] * Sex	10.040 (4.032)	**0.013**	-1.499 (4.421)	0.735	2.015 (20.281)	0.921	-0.784 (1.357)	0.564	0.091 (1.094)	0.933	-0.220 (1.397)	0.875	0.195 (1.056)	0.854
Model F: Interaction by Race/Ethnicity [a]														
Persistently obese[a]	-3.119 (2.658)	0.241	-0.256 (2.980)	0.932	-4.909 (13.495)	0.716	-1.342 (0.749)	0.073	-0.528 (0.614)	0.390	-0.167 (0.730)	0.819	-0.996 (0.593)	0.093
Became obese[a]	2.770 (5.398)	0.608	-8.563 (6.138)	0.164	-53.278 (27.191)	0.051	-0.775 (1.500)	0.606	-0.480 (1.221)	0.695	0.650 (1.406)	0.644	-0.674 (1.180)	0.569
Formerly obese[a]	-2.922 (4.715)	0.536	0.766 (5.138)	0.885	-16.618 (24.048)	0.490	1.260 (1.651)	0.445	1.123 (1.305)	0.390	-0.449 (1.575)	0.776	1.398 (1.278)	0.274
Asian	7.285 (1.706)	**0.000**	10.421 (1.859)	**0.000**	39.615 (8.367)	**0.000**	2.857 (0.509)	**0.000**	1.302 (0.398)	**0.001**	1.996 (0.481)	**0.000**	2.170 (0.394)	**0.000**
Black	-7.974 (1.503)	**0.000**	-2.185 (1.689)	0.196	-19.570 (7.589)	**0.010**	-2.765 (0.448)	**0.000**	-1.755 (0.371)	**0.000**	-0.819 (0.442)	0.065	-1.297 (0.357)	**0.000**
Latino	-2.578 (1.590)	0.105	1.042 (1.761)	0.554	4.381 (8.010)	0.584	-0.862 (0.489)	0.078	-0.812 (0.389)	**0.037**	-0.584 (0.461)	0.206	-0.110 (0.371)	0.766
Other	-2.596 (2.439)	0.287	0.763 (2.739)	0.781	-12.705 (12.310)	0.302	-0.384 (0.754)	0.610	-0.492 (0.597)	0.410	0.637 (0.714)	0.372	-0.197 (0.583)	0.736
Persistently obese[a] * Asian	3.508 (4.354)	0.420	2.060 (4.858)	0.672	9.755 (21.964)	0.657	0.102 (1.265)	0.936	0.560 (1.030)	0.128	0.402 (1.174)	0.732	0.044 (0.972)	0.964
Became obese[a] * Asian	6.052 (10.979)	0.582	12.424 (11.869)	0.296	25.489 (54.724)	0.642	1.831 (2.766)	0.509	2.105 (2.291)	0.443	-0.571 (2.520)	0.821	0.985 (2.175)	0.651
Formerly obese[a] * Asian	-4.633 (8.305)	0.577	-5.967 (8.968)	0.506	-30.369 (39.708)	0.444	-1.692 (2.653)	0.524	0.151 (2.154)	0.248	0.052 (2.378)	0.983	-3.240 (2.025)	0.110
Persistently obese[a] * Black	2.745 (3.411)	0.421	0.554 (3.794)	0.884	21.588 (17.330)	0.213	1.398 (0.998)	0.161	0.971 (0.790)	0.133	-0.520 (0.950)	0.584	0.540 (0.754)	0.473

Became obese[a] * Black	-0.784 (6.764)	0.908	-0.379 (7.531)	0.960	29.741 (33.927)	0.381	0.965 (1.811)	0.595	1.348 (1.492)	0.425	-0.836 (1.703)	0.624	1.244 (1.440)	0.389
Formerly obese[a] * Black	6.941 (6.132)	0.258	10.088 (6.825)	0.140	62.832 (30.113)	0.037	-1.439 (2.159)	0.505	-0.844 (1.744)	0.251	0.418 (1.996)	0.834	-0.625 (1.664)	0.708
Persistently obese[a] * Latino	2.195 (3.054)	0.472	-1.639 (3.457)	0.635	-6.697 (15.767)	0.671	0.482 (0.890)	0.588	0.389 (0.719)	0.122	0.023 (0.853)	0.979	0.479 (0.694)	0.490
Became obese[a] * Latino	-3.697 (6.601)	0.576	4.839 (7.215)	0.503	38.798 (32.274)	0.230	0.784 (1.771)	0.658	1.077 (1.419)	0.377	-1.253 (1.607)	0.436	-0.823 (1.327)	0.535
Formerly obese[a] * Latino	3.696 (5.615)	0.511	5.326 (6.458)	0.410	36.031 (29.106)	0.216	-1.465 (1.963)	0.456	-1.344 (1.501)	0.088	0.479 (1.905)	0.802	-1.725 (1.486)	0.246
Persistently obese[a] * Other	2.132 (5.839)	0.715	0.698 (6.560)	0.915	-4.245 (29.569)	0.886	-0.206 (1.730)	0.905	0.315 (1.353)	0.092	-0.885 (1.598)	0.580	0.797 (1.333)	0.550
Became obese[a] * Other	-18.992 (11.822)	0.108	-0.508 (13.346)	0.970	52.944 (59.667)	0.375	-0.774 (3.080)	0.802	1.514 (2.399)	0.189	-1.803 (2.814)	0.522	-0.541 (2.285)	0.813
Formerly obese[a] * Other	7.025 (12.303)	0.568	-4.250 (14.377)	0.768	-20.714 (63.713)	0.745	-1.459 (5.415)	0.788	-0.844 (4.092)	**0.048**	-0.327 (5.031)	0.948	-0.790 (4.467)	0.860

[a]Baseline weight status is from Grade 3 Fall. Follow-up weight status is from Grade 4 Spring for standardized test outcomes and from Grade 5 Fall for course grade outcomes. “Persistently obese” indicates student was obese at baseline and follow-up. “Became obese” indicates student was obese at follow-up but not baseline. “Formerly obese” indicates student was obese at baseline but not follow-up.

[b]Models B through F adjusted for FRL, sex, race/ethnicity, current English language learners, and students with disabilities.

[c]Model C also adjusts for dichotomized cardiorespiratory fitness (fit or unfit).

Table 4. Associations between longitudinal weight status from Grade 3 to Grades 4/5 and mediators (MVPA, sedentary time, attendance, and CRF)[a]

	Mean MVPA (Grade 4 Fall and Spring)[c]		**Mean MVPA (Grade 4 Fall, Grade 4 Spring, Grade 5 Fall)[c]**		**Mean Sedentary Time (Grade 4 Fall and Spring)[c]**		**Mean Sedentary Time (Grade 4 Fall, Grade 4 Spring, Grade 5 Fall)[c]**		**Grade 4 % Attended**		**Median CRF (Grade 4 Fall and Spring)**		**Median CRF (Grade 4 Fall, Grade 4 Spring, Grade 5 Fall)**	
Weight Status	Beta (SE)	p	Beta (SE)	p	Beta (SE)	p	Beta (SE)	p	Beta (SE)	p	Beta (SE)	p	Beta (SE)	p
Persistently Overweight / Obese[b]	**-1.457 (0.237)**	**0.000**	**-1.387 (0.213)**	**0.000**	0.995 (0.860)	0.247	0.879 (0.772)	0.255	-0.172 (0.094)	0.067	**-3.100 (0.112)**	**0.000**	**-3.230 (0.118)**	**0.000**
Persistently Obese[b]	**-1.525 (0.276)**	**0.000**	**-1.415 (0.248)**	**0.000**	1.211 (1.014)	0.232	1.031 (0.916)	0.261	**-0.256 (0.113)**	**0.023**	**-3.385 (0.135)**	**0.000**	**-3.537 (0.136)**	**0.000**

[a] Controlling for race/ethnicity, sex, free/reduced-price lunch, *current* English language learner, and student with disabilities

[b]Baseline weight status is from Grade 3 Fall. Follow-up weight status is from Grade 4 Spring for standardized test outcomes and from Grade 5 Fall for course grade outcomes. “Persistently overweight/obese” indicates student was overweight/obese at baseline and follow-up. “Became overweight/obese” indicates student was overweight/obese at follow-up but not baseline. “Formerly overweight/obese” indicates student was overweight/obese at baseline but not follow-up. “Persistently obese” indicates student was obese at baseline and follow-up. “Became obese” indicates student was obese at follow-up but not baseline. “Formerly obese” indicates student was obese at baseline but not follow-up.

[c]Models for MVPA and sedentary time also control for whether students were in intervention or control schools.

Table 5. Associations between longitudinal overweight/obesity status, mediators (MVPA, Sedentary Time, Attendance, and CRF), and academic performance measured by Grade 4 standardized test scores and Grade 5 Fall course marks

	Grade 4 Standardized Test Scores						Grade 5 Fall Course Grades							
	Math Scale Score		**ELA Scale Score**		**Lexile**		**Math**		**Reading**		**Spelling**		**Writing**	
Weight Status	Beta (SE)	p	Beta (SE)	p	Beta (SE)	p	Beta (SE)	p	Beta (SE)	p	Beta (SE)	p	Beta (SE)	p
MVPA														
Persistently Overweight / Obese[a]	0.118 (0.902)	0.896	-0.178 (1.004)	0.860	1.459 (4.601)	0.751	-0.603 (0.268)	0.025	-0.179 (0.217)	0.410	-0.195 (0.250)	0.435	-0.554 (0.216)	0.010
Mean MVPA[b]	**-0.225 (0.062)**	**0.000**	**-0.294 (0.071)**	**0.000**	**-0.931 (0.314)**	**0.003**	**-0.079 (0.022)**	**0.000**	**-0.076 (0.016)**	**0.000**	**-0.048 (0.021)**	**0.023**	**-0.065 (0.018)**	**0.000**
Persistently Obese[a]	-1.441 (1.078)	0.181	-1.189 (1.198)	0.321	-2.994 (5.429)	0.581	**-0.873 (0.319)**	**0.006**	-0.205 (0.256)	0.424	-0.334 (0.295)	0.258	**-0.648 (0.253)**	**0.011**
Mean MVPA[b]	**-0.232 (0.062)**	**0.000**	**-0.299 (0.071)**	**0.000**	**-0.953 (0.314)**	**0.003**	**-0.079 (0.021)**	**0.000**	**-0.075 (0.016)**	**0.000**	**-0.049 (0.021)**	**0.021**	**-0.065 (0.018)**	**0.000**
Sedentary Time														
Persistently Overweight / Obese[a]	0.371 (0.900)	0.681	0.167 (1.001)	0.868	2.608 (4.602)	0.571	-0.511 (0.266)	0.055	-0.091 (0.217)	0.674	-0.144 (0.248)	0.562	**-0.480 (0.216)**	**0.027**
Mean Sedentary Time[c]	**0.074 (0.017)**	**0.000**	**0.087 (0.019)**	**0.000**	**0.215 (0.086)**	**0.013**	**0.020 (0.005)**	**0.000**	**0.020 (0.004)**	**0.000**	**0.019 (0.005)**	**0.000**	**0.018 (0.004)**	**0.000**
Persistently Obese[a]	-1.180 (1.072)	0.271	-0.840 (1.191)	0.481	-1.816 (5.420)	0.738	**-0.781 (0.317)**	**0.014**	-0.119 (0.255)	0.642	-0.284 (0.295)	0.336	**-0.576 (0.253)**	**0.023**
Mean Sedentary Time[c]	**0.075 (0.017)**	**0.000**	**0.087 (0.019)**	**0.000**	**0.217 (0.086)**	**0.012**	**0.020 (0.005)**	**0.000**	**0.020 (0.004)**	**0.000**	**0.019 (0.005)**	**0.000**	**0.018 (0.004)**	**0.000**
Grade 4 % Attendance														

Persistently Overweight / Obese[a]	0.563 (0.897)	0.530	0.369 (1.000)	0.712	3.338 (4.597)	0.468	-0.428 (0.263)	0.103	-0.043 (0.216)	0.842	-0.082 (0.247)	0.740	-0.414 (0.214)	0.054
Mean Grade 4 Attendance	**0.942 (0.145)**	**0.000**	**0.829 (0.161)**	**0.000**	**3.634 (0.752)**	**0.000**	**0.410 (0.045)**	**0.000**	**0.184 (0.037)**	**0.000**	**0.289 (0.041)**	**0.000**	**0.306 (0.035)**	**0.000**
Persistently Obese[a]	-0.885 (1.071)	0.409	-0.535 (1.192)	0.653	-0.664 (5.418)	0.902	**-0.671 (0.313)**	**0.032**	-0.054 (0.255)	0.832	-0.200 (0.293)	0.495	-0.486 (0.255)	0.057
Mean Grade 4 Attendance	**0.937 (0.145)**	**0.000**	**0.825 (0.161)**	**0.000**	**3.620 (0.752)**	**0.000**	**0.409 (0.045)**	**0.000**	**0.184 (0.037)**	**0.000**	**0.289 (0.041)**	**0.000**	**0.306 (0.035)**	**0.000**
Cardiorespiratory Fitness														
Persistently Overweight / Obese[a]	1.520 (0.973)	0.118	2.087 (1.077)	0.053	9.408 (4.983)	0.059	0.148 (0.291)	0.610	0.360 (0.234)	0.123	0.368 (0.271)	0.174	0.127 (0.595)	0.595
Median Cardiorespiratory Fitness[d]	**0.343 (0.120)**	**0.004**	**0.585 (0.133)**	**0.000**	**2.085 (0.598)**	**0.001**	**0.199 (0.035)**	**0.000**	**0.134 (0.028)**	**0.000**	**0.154 (0.032)**	**0.000**	**0.183 (0.000)**	**0.000**
Persistently Obese[a]	-0.181 (1.133)	0.873	1.059 (1.271)	0.404	4.692 (5.832)	0.421	-0.098 (0.337)	0.771	0.365 (0.275)	0.185	0.250 (0.426)	0.426	0.078 (0.272)	0.775
Median Cardiorespiratory Fitness[d]	**0.266 (0.117)**	**0.023**	**0.526 (0.132)**	**0.000**	**1.822 (0.594)**	**0.002**	**0.188 (0.034)**	**0.000**	**0.131 (0.027)**	**0.000**	**0.146 (0.032)**	**0.000**	**0.179 (0.027)**	**0.000**

[a]Baseline weight status is from Grade 3 Fall. Follow-up weight status is from Grade 4 Spring for standardized test outcomes and from Grade 5 Fall for course grade outcomes. “Persistently overweight/obese” indicates student was overweight/obese at baseline and follow-up. “Became overweight/obese” indicates student was overweight/obese at follow-up but not baseline. “Formerly overweight/obese” indicates student was overweight/obese at baseline but not follow-up. “Persistently obese” indicates student was obese at baseline and follow-up. “Became obese” indicates student was obese at follow-up but not baseline. “Formerly obese” indicates student was obese at baseline but not follow-up.

[b]For standardized test outcomes, incorporates MVPA from Grade 4 Fall and Spring only. For course grades, incorporates MVPA from Grade 4 Fall, Grade 4 Spring, and Grade 5 Fall.

[c]For standardized test outcomes, incorporates sedentary time from Grade 4 Fall and Spring only. For course grades, incorporates sedentary time from Grade 4 Fall, Grade 4 Spring, and Grade 5 Fall.

[d]For standardized test outcomes, incorporates CRF measures from Grade 4 Fall and Spring only. For course grades, incorporates CRF measures from Grade 4 Fall, Grade 4 Spring, and Grade 5 Fall.

Table 6. Indirect effect from longitudinal overweight/obesity status through mediators (MVPA, Sedentary Time, Attendance, and CRF) to academic performance measured by Grade 4 standardized test scores and Grade 5 Fall course marks

Exposure: Persistently Overweight/Obese[a]								
	MVPA[b]		**Sedentary Time[c]**		**Grade 4 Attendance**		**CRF[d]**	
Academic Outcome	Indirect Effect	95% CI	Indirect Effect	95% CI	Indirect Effect	95% CI	Indirect Effect	95% CI
Standardized Math	**0.328**	**(0.138, 0.551)**	0.074	(-0.050, 0.217)	-0.162	(-0.355, 0.012)	**-1.063**	**(-1.798, -0.333)**
Standardized ELA	**0.428**	**(0.203, 0.693)**	0.087	(-0.060, 0.253)	-0.143	(-0.320, 0.009)	**-1.814**	**(-2.653, -1.002)**
Lexile	**1.359**	**(0.431, 2.444)**	0.214	(-0.147, 0.713)	-0.625	(-1.417, 0.039)	**-6.464**	**(-10.161, -2.826)**
Math	**0.110**	**(0.046, 0.184)**	0.018	(-0.012, 0.053)	-0.071	(-0.151, 0.005)	**-0.643**	**(-0.871, -0.416)**
Reading	**0.105**	**(0.056, 0.164)**	0.018	(-0.013, 0.051)	-0.032	(-0.172, 0.184)	**-0.433**	**(-0.614, -0.255)**
Spelling	**0.067**	**(0.009, 0.132)**	0.017	(-0.012, 0.051)	-0.050	(-0.108, 0.003)	**-0.497**	**(-0.705, -0.293)**
Writing	**0.090**	**(0.038, 0.151)**	0.016	(-0.011, 0.047)	-0.053	(-0.112, 0.004)	**-0.578**	**(-0.757, -0.405)**

Exposure: Persistently Obese[a]								
	MVPA[b]		**Sedentary Time[c]**		**Grade 4 Attendance**		**CRF[d]**	
Academic Outcome	Indirect Effect	95% CI	Indirect Effect	95% CI	Indirect Effect	95% CI	Indirect Effect	95% CI
Standardized Math	**0.354**	**(0.152, 0.601)**	0.016	(-0.139, 0.174)	**-0.240**	**(-0.476, -0.029)**	**-0.900**	**(-1.688, -0.124)**
Standardized ELA	**0.456**	**(0.214, 0.750)**	0.105	(-0.067, 0.303)	**-0.211**	**(-0.432, -0.026)**	**-1.781**	**(-2.674, -0.906)**
Lexile	**1.453**	**(0.473, 2.634)**	0.263	(-0.165, 0.857)	**-0.927**	**(-1.918, -0.119)**	**-6.167**	**(-10.142, -2.200)**
Math	**0.112**	**(0.048, 0.189)**	0.021	(-0.015, 0.063)	**-0.105**	**(-0.203, -0.013)**	**-0.665**	**(-0.908, -0.426)**
Reading	**0.106**	**(0.053, 0.169)**	0.021	(-0.015, 0.061)	**-0.047**	**(-0.097, -0.006)**	**-0.463**	**(-0.656, -0.275)**
Spelling	**0.069**	**(0.011, 0.139)**	0.020	(-0.015, 0.060)	**-0.074**	**(-0.146, -0.009)**	**-0.516**	**(-0.743, -0.292)**
Writing	**0.092**	**(0.038, 0.157)**	0.019	(-0.014, 0.056)	**-0.078**	**(-0.152, -0.010)**	**-0.633**	**(-0.829, -0.442)**

[a]Baseline weight status is from Grade 3 Fall. Follow-up weight status is from Grade 4 Spring for standardized test outcomes and from Grade 5 Fall for course grade outcomes. "Persistently overweight/obese" indicates student was overweight/obese at baseline and follow-up. "Became overweight/obese" indicates student was overweight/obese at follow-up but not baseline. "Formerly overweight/obese" indicates student was overweight/obese at baseline but not follow-up.

"Persistently obese" indicates student was obese at baseline and follow-up. "Became obese" indicates student was obese at follow-up but not baseline. "Formerly obese" indicates student was obese at baseline but not follow-up.

[b]For standardized test outcomes, incorporates MVPA from Grade 4 Fall and Spring only. For course grades, incorporates MVPA from Grade 4 Fall, Grade 4 Spring, and Grade 5 Fall.

[c]For standardized test outcomes, incorporates sedentary time from Grade 4 Fall and Spring only. For course grades, incorporates sedentary time from Grade 4 Fall, Grade 4 Spring, and Grade 5 Fall.

[d]For standardized test outcomes, incorporates CRF measures from Grade 4 Fall and Spring only. For course grades, incorporates CRF measures from Grade 4 Fall, Grade 4 Spring, and Grade 5 Fall.