The reciprocal relationship between body mass index categories and physical fitness: a four-year prospective cohort study of 20,000 Chinese children

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Abstract

Introduction: Body mass index (BMI) categories and physical fitness are associated but the reciprocal relationship between BMI categories and physical fitness has not been investigated. This study aims to investigate the longitudinal reciprocal relationship between BMI categories and physical fitness.

Methods: This is a population-based 4-year cohort study in 48 elementary schools. Children aged 6–9 years at recruitment were included. BMI categories and physical fitness including handgrip strength, core muscle endurance, flexibility, and cardiorespiratory fitness were measured using standard equipment and protocol.

Results: Among 26,392 eligible participants, 19,504 (73.9%) were successfully followed for 3 years. Baseline obesity prevalence was 5.9%. After 3 years, those who were unfit at baseline had an increased risk of obesity (risk ratio [RR] 1.41, 95% CI 1.16–1.71, $P<0.001$) and those who were fit at baseline had a decreased risk of obesity (RR 0.69, 95% CI 0.60–0.80, $P<0.001$) compared with moderately fit children. Furthermore, improvement of fitness predicted decreased risk of obesity. Similarly, normal body weight also predicted better physical fitness. The path analysis confirmed a strong reciprocal relationship between physical fitness and obesity.

Conclusions: Better physical fitness was prospectively associated with normal weight, and vice versa. Physically fit children were more likely to maintain a healthy weight and those with a healthy weight were more likely to be physically fit, which is important for healthy development.

Introduction

Body mass index (BMI) categories, an indicator of childhood obesity, is affected by nutrition and physical activity as well as factors in the environment. Urbanization increases the risk of obesogenic environment that may promote obesity.[1] While obesity affects most developed countries, underweight is more prevalent in developing countries.[2] Hong Kong, as one of the most urbanized cities in China, faces a 'dual burden' of underweight and overweight in children and adolescents.[3] Based on recent representative data of over 200,000 school-aged children and adolescents, the prevalence of underweight was 11% and overweight (including obesity) was 21%, indicating only two-thirds of the Hong Kong population have normal body weight.[3]

Underweight and overweight are both known risk factors for poor child health.[4] Being underweight can lead to low muscular strength, late maturation, decreased bone density, and low work productivity in later life.[5] Children with overweight or obesity are at high risk of hypertension, type 2 diabetes mellitus, and mental disorders,[6-9] contributing to approximately 2.3% of global disability-adjusted life years.[10] These adverse consequences can extend into adulthood, increasing the lifetime risk of non-communicable diseases and disability.[6;11;12]

Several studies have demonstrated correlations between physical fitness and BMI categories. Physical fitness is an integrated measure of the body's ability to perform physical activity and has several parameters including cardiorespiratory fitness and muscle strength, all of which are important child health markers.[13] For example, cardiorespiratory fitness has been shown to be significantly associated with a decreased risk of cardiovascular diseases.[13;14] In addition to cardiorespiratory fitness, muscle strength was also found to impact cardiometabolic risk markers including serum triglyceride and cholesterol levels even after adjusting for cardiorespiratory fitness.[15] Clinical evidence also shows that physical fitness is a significant predictor for mortality and morbidity,[13] and the decline of physical fitness in childhood predicts higher risk of obesity and insulin resistance in adulthood.[16] This suggests that physical fitness in childhood could provide useful information for determining subsequent health and development.

There has been limited evidence on the reciprocal relationship between BMI categories and physical fitness.[17-19] Some studies showed a linear relationship of BMI and BMI categories with physical fitness,[11;20-23] whereas other studies reported a non-linear relationship and found underweight, overweight, and obesity as predictors of poor fitness in children.[4;24-26] Because of cross-sectional design, these studies cannot affirm the direction of the observed associations. To derive reliable estimates on how the two variables predict each other, which in turn predict themselves, longitudinal studies with at least three measurement time points are needed. Hence, using data from a population representative sample of Hong Kong elementary school children aged 6 to 9 years, this 4-year longitudinal study tested whether physical fitness and BMI categories had a reciprocal relationship.

Methods

Study design

The School Physical Fitness Award Scheme (SPFAS), launched in 1990, is jointly organized by the Hong Kong Education Bureau, Physical Fitness Association and the

Hong Kong Childhealth Foundation. To promote awareness on health-related fitness and regular exercise habit, students in the SPFAS participating schools are provided with fitness tests and feedback each year upon obtaining consents from the schools and their parents. The SPFAS initiated an electronic platform to record participating students' anthropometric and fitness data from 2013. The present study retrieved and analyzed the SPFAS data on grade 1-3 students' fitness and anthropometric measurements recorded during 2013-2017 under the SPFAS. As of 2019, 49% of all elementary schools in Hong Kong have participated SPFAS. This study was approved by the Institutional Review Board of the University of Hong Kong/Hospital Authority Hong Kong West Cluster and written informed consent was obtained in schools.

Anthropometric measurements

Body height and weight of students in all schools were measured barefoot and in light clothing by trained teachers following a standardized protocol provided by the panel committee. BMI was calculated as the weight in kilograms (kg) divided by the square of height in meters (m^2). Participants were categorized into underweight, normal weight, overweight, and obese groups by their BMI according to the International Obesity Task Force (IOTF) reference.[27] BMI z-scores were also calculated using the IOTF parameters.

Physical fitness tests

Four fitness tests were carried out during physical education lessons in schools: (i) handgrip test, (ii) one-minute sit-up test, (iii) sit-and-reach test, and (iv) endurance run test. Each class has approximately 30 students who completed the test by a group of 4-6 participants at each station at any given time. Although no information on test–retest reliability was collected during this study, these physical fitness tests have demonstrated good concurrent validity in predicting various health outcomes and are regarded as important health markers.[13] The handgrip, sit-and-reach, and one-minute sit-up tests are part of the validated EUROFIT test battery.[28] Endurance run is a local adaptation of the six-minute walk test, which was shown to have good reliability and validity for exercise tolerance and endurance.[29] The change from walk to endurance run aimed to reduce the ceiling effect of the test, i.e. to better differentiate the well-performing students.

Handgrip strength was measured in kilograms using a handgrip dynamometer (TKK 5101 Grip D; Takey, Tokyo, Japan; precision 0.1 kg). Each student squeezed gradually and continuously for at least 2 seconds while standing with arms straight down the side and without the dynamometer touching any part of the body except the hand being measured. The test was performed on each hand twice in random order. The best measurement for each hand was recorded and the sum of the best measurement scores achieved by both hands was used in the analysis.

One-minute sit-up tests were carried out to measure abdominal muscular strength and endurance. The sit-up test was performed with the student's feet placed flat on the floor and knees bent at 90 degrees. The number of completed sit-ups in 1 minute was recorded and used in the analysis.

In the sit-and-reach test, the student sat on the floor with both legs extended out straight and then bent the trunk to reach forward as far as possible. The reach was measured in centimeters using a standardized box with a ruler. Two trials were conducted, and the best measurement was recorded and used in the analysis.

Cardiovascular fitness was assessed by the endurance run test. The endurance run tests were conducted in a 15 m × 25 m basketball court, which lasted for 6 minutes for participants under 9 years of age and for 9 minutes for participants aged 9 years or above. The distance run was done once and recorded in meters.

During the physical education class at one week before the fitness tests, students were briefed with testing procedures and practiced the procedures to enhance task understanding and shorten the completion time. Standard demonstrations and verbal cues were provided to the students to optimize their performance during the actual tests.

Data analysis

The descriptive statistics are presented as frequencies (percentage) for categorical variables and mean (SD) for continuous variables. The z-scores were calculated for each fitness test according to sex and age groups using the lambda-mu-sigma (LMS) method[30] to control for test-specific differences relating to age and sex, which allows for standardized comparisons of physical fitness between children. The overall physical fitness z-score was calculated as the mean of all four fitness test z-scores. Fitness test z-scores, instead of the raw scores, were used, because performance in a fitness test depends on the students' age and sex. To ensure a fair comparison across age, sex, and test, we reported the results in terms of per-SD difference of the fitness tests and BMI. The descriptive statistics of raw fitness test scores can be found in Supplementary Table 1. To study the change in group membership across time, the fitness z-score and BMI z-score changes were trichotomized using tertiles as the association may not be linear. Sensitivity analysis was conducted for other categorizations such as quartiles. The longitudinal relationship between BMI categories and physical fitness were analyzed using a generalized linear mixed model with individual identifiers as random intercepts. A Poisson model with robust standard errors was used with BMI categories as the dependent variable, and baseline fitness z-score and subsequent changes in z-score as the independent variables. Baseline BMI z-scores, age, and sex were controlled as covariates in this model. For predicting physical fitness z-scores, the linear model included baseline BMI categories and z-score changes as the independent variables. Baseline fitness z-score, age, and sex were controlled as covariates in this model. In addition, a cross-lagged path model was used to investigate the reciprocal association between BMI categories and physical fitness. This model included both the autoregressive paths and cross-lagged paths. Models were regarded as poorly fitted if RMSEA ≥ 0.05 or CFI ≥ 0.95.[31] All statistical computations were performed in the statistical software R (R for Windows, version 3.5.1). A 5% level of significance was regarded as statistically significant.

Results

The SPFAS routinely collected 200,000 students' data every year. All students in the SPFAS schools were enrolled into the program unless the parents opted out (<1%). The cohort study extracted 26,392 students' data (grade 1 to 3 from 48 elementary school) which had identifier for longitudinal tracking. A total of 19,504 students (9,935 boys and 9,569 girls; 26.1% dropout) aged 6–9 years (grade 1-3) at baseline were successfully followed for 3 years. The main reason for loss to follow-up was being absent from school on the day of the physical fitness tests. There were no significant differences between the included students and those lost to follow-up in terms of BMI z-score and physical fitness (P = 0.37 for BMI z-score, P = 0.19 for physical fitness z-score).

Changes in BMI categories

BMI categories by year of study according to the IOTF BMI classifications is presented in Table 1. The overall prevalence of obesity was 5.9% (7.3% in boys and 4.4% in girls) at baseline in 2013/14 and was 5.6% (8.3% in boys, 2.8% in girls) after 3 years in 2016/17, even though the prevalence of overweight among girls remained relatively stable. The prevalence of underweight for boys were 3.0% in 2013/14 and 4.0% in 2016/17 and for girls were 3.3% in 2013/14 and 4.5% in 2016/17. The prevalence of obesity and underweight were similar to the previous population study in Hong Kong Children.[3]

Changes in physical fitness

Physical fitness z-scores by year of study are presented in Table 1. Regardless of sex, there was an increase in age- and sex-specific z-scores for all four fitness tests from 2013/14 to 2016/17. Among the boys, z-scores significantly increased by 0.03 in the handgrip strength test, 0.06 in the sit-up test, 0.04 in the sit-and-reach test, and 0.18 in the endurance run test. Among the girls, z-scores significantly increased by 0.05 in the handgrip strength test, 0.02 in the sit-up test, 0.11 in the sit-and-reach test, and 0.05 in the endurance run test.

Predicting physical fitness by baseline BMI categories

Compared with the normal weight group, both underweight and obese groups had significantly lower overall physical fitness z-scores at the follow-up after 3 years, even after adjusting for changes in BMI z-sores (Table 2a). Changes in BMI z-scores in the underweight and normal weight groups were positively associated with overall physical fitness, whereas changes in BMI z-scores in the obese group were negatively associated with overall physical fitness. Similar results were identified using categorized changes in BMI z-scores variables (Figure 1a).

Next, we compared specific fitness test performance by BMI categories. Changes in BMI z-scores were positively associated with handgrip strength. Handgrip strength for the normal weight group was lower than those for the overweight and obese groups but higher than that for the underweight group. The overweight and obese groups had lower z-scores in the sit-up and endurance run tests compared with the normal weight group. The underweight group had lower z-scores in the sit-up and sit-and-reach tasks but not in the endurance test. The sit-and-reach z-scores for the normal group were higher than that for the obese group but lower than that for the overweight group. The relationships between changes in BMI z-scores and performances in the sit-up test, the sit-and-reach test and the endurance test were all non-linear regardless of BMI categories.

Predicting BMI categories by baseline physical fitness status

Compared with the moderate physical fitness group, there was a 41% increase in the risk for obesity in the low physical fitness group and a 31% reduction in the risk for obesity in the high physical fitness group at the follow-up after 3 years, even after adjusting for changes in the physical fitness scores (Table 2b). For students in the moderate or high physical fitness group, changes in physical fitness levels were associated with a significant reduction in the risk for obesity (20% reduction for the moderate physical fitness group and 25% reduction for the high physical fitness group, $P<0.001$) (Figure 1b). Only extreme BMI categories (obesity and underweight) was included in the reciprocal analysis because overweight was not strongly associated with physical fitness. The path analysis results shown in Figure 2 achieved satisfactory fit indices with CFI = 0.958 and RMSEA = 0.046. Obesity and physical fitness had a significant reciprocal relationship. A unit SD increment in physical fitness was associated with 0.84–0.91 odds ratio of obesity, whereas being obese was associated with 0.02–0.67 SD decrement in fitness. The reciprocal relationship between underweight and physical fitness was less strong by comparison.

Discussion

The present study is the largest longitudinal study investigating the reciprocal relationship between BMI categories and physical fitness in a representative sample of Chinese children. One of the unique characteristics of this sample is that underweight and overweight/obesity co-existed in this population. A number of studies have evaluated the associations between BMI categories and physical fitness in children, but the majority of them only focused on the effect of adiposity (overweight/obese) on physical fitness.[21;26;32;33] Rapid urbanization accounts for significant shifts in dietary patterns and for physical activity levels that tend to increase risks for obesity in children.[34] The implications of urbanization on childhood obesity have been widely discussed. Few studies have examined the effects of both underweight and overweight on childhood fitness. Our longitudinal data demonstrated a non-linear relationship between BMI categories and physical fitness in children during the follow-up period. Several studies have reported a similar association in adolescents, but these were cross-sectional studies.[4;11;24;35] The most comparable study was a 2-year follow-up of a small cohort of South African adolescents which found that BMI and percentage body fat were inversely associated with physical fitness.[36]

Our findings demonstrated that being underweight or overweight/obese was prospectively associated with decreased overall physical fitness, which can cause adverse short- and long-term health consequences.[14;37] Intervention studies or programs for children with underweight or obesity should take into account their physical fitness level and include fitness training particularly for those who have poor physical fitness.

Interestingly, we found an interrelationship between changes in physical fitness and changes in BMI categories over 3 years. Children with increased weight had lower physical fitness, whereas those with low physical fitness level at baseline had a higher risk of becoming overweight or obese compared to those who had a high physical fitness at baseline. Furthermore, for children who were obese at baseline but subsequently improved and maintained weight within normal range, these children's fitness levels were also improved. Similar results were also found in those with persistent normal BMI z-scores. Our findings suggest that regardless of the child's fitness level at baseline, normalization of BMI status could occur concurrently with improvement in physical fitness level. Hence, normalizing BMI categories not only reduces the 'dual burden' of underweight and overweight[3] but also increases the 'dual benefits' of normal body weight and improved physical fitness in children and adolescents.[4;11;24;26]

The relationship between BMI categories and physical fitness is varied by the type of test being performed. We found that as BMI increased, children performed more poorly in tests requiring more body movements such as the sit-up and endurance run tests. Specifically, students who were overweight and obese at baseline showed poorer performance in these tests than those with normal weight at baseline similar to previous studies.[4;38] By contrast, the overweight and obese groups performed better in the handgrip strength test than the normal weight group, possibly because they had greater fat-free mass, which is consistent with previous findings.[11;35] Future studies warrant how different types of physical fitness tests may better predicts subsequent health outcomes.

Coincide with the independent regression analysis, we found a reciprocal association between obesity and physical fitness in the cross-lagged path model. This indicates that promoting physical fitness at an early age may start a virtuous cycle: being physically fit promotes healthy weight, which in turn improves fitness thereby forming a positive feedback loop. It should be noted that the weight normalizing association applies to both children with underweight and children with obesity, which are particularly important for regions with dual body weight burden, including Hong Kong, China, and other countries in Asia and Pacific region.

Despite the longitudinal design with large sample size, our studies have several limitations. First, as with other observational studies, associations could be confounded or could be a result of reverse causation, including genetic predisposition. Second, the IOTF criterion was used instead of the local reference in this study which makes comparing prevalence with previous local studies impossible. IOTF criterion is one of the most commonly used in diagnosis of body size among the children and adolescent based on large-scale studies from Brazil, Britain, Hong Kong, the Netherland, Singapore and the USA.[39] The classification of the body size may be affected by several factors such as ethnicity and distribution of overweight and underweight across the study population but international reference is needed for cross-nation comparison. Therefore, even though a marked decrease in the prevalence of obesity have been reported among the Hong Kong children and adolescents,[41] IOTF criteria was used for the classification of the body size. Third, even though the fitness tests are regarded as important health markers and allow for non-invasive assessment of physical health,[13] the results may not truly reflect actual physical functioning but a combination of genetic predisposition and the effect of aerobic training. The endurance test was also not directly validated, even though it was designed based on a common and validated test for exercise tolerance and endurance. It should also be noted there is no well accepted definition for ‘physical unfit’. Future studies may consider biometric measurements. The dietary habits of these participants were not recorded. Those with poor fitness level might also tend to eat unhealthily leading to overweight and obesity. Despite this, physical fitness also serves as an important risk marker for subsequent obesity and underweight. Last but not least, physical activity level, a hypothesized mediator in this study, was not measured due to a lack of reliable tool at this scale.

Conclusion

In conclusion, better fitness was prospectively associated with normal weight, and vice versa. Physically fit children were more likely to maintain a healthy weight and those with a healthy weight were more likely to be physically fit, which is important for healthy development.

(Words: 3032)

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Table 1. Characteristics of the 19,504 elementary students by sex and year of study

	2013/14		2014/15		2015/16		2016/17	
	Boys (N=9935)	Girls (N=9569)	Boys (N=9935)	Girls (N=9569)	Boys (N=9935)	Girls (N=9569)	Boys (N=9935)	Girls (N=9569)
Age, n (%), years								
6	2342 (23.6)	1889 (19.7)	104 (1.0)	11 (0.1)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
7	2547 (25.6)	2393 (25.0)	2320 (23.4)	2047 (21.4)	28 (0.3)	11 (0.1)	0 (0.0)	0 (0.0)
8	3194 (32.1)	4053 (42.4)	2658 (26.8)	2316 (24.2)	2308 (23.2)	1860 (19.4)	34 (0.3)	94 (1.0)
9	1852 (18.6)	1234 (12.9)	3428 (34.5)	4068 (42.5)	2603 (26.2)	2508 (26.2)	2312 (23.3)	1815 (19.0)
10	0 (0.0)	0 (0.0)	1415 (14.2)	1123 (11.7)	3480 (35.0)	4081 (42.6)	2652 (26.7)	2439 (25.5)
11	0 (0.0)	0 (0.0)	10 (0.1)	4 (0.0)	1515 (15.2)	1103 (11.5)	3316 (33.4)	3864 (40.4)
12	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (0.0)	6 (0.1)	1606 (16.2)	1353 (14.1)
13	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	15 (0.2)	4 (0.0)
BMI categories, n (%)								
Underweight	298 (3.0)	316 (3.3)	387 (3.9)	431 (4.5)	447 (4.5)	450 (4.7)	397 (4.0)	431 (4.5)
Normal weight	7402 (74.5)	7435 (77.7)	7074 (71.2)	7416 (77.5)	6607 (66.5)	7483 (78.2)	6656 (67.0)	7454 (77.9)
Overweight	1510 (15.2)	1397 (14.6)	1749 (17.6)	1388 (14.5)	3136 (21.5)	1320 (13.8)	2047 (20.6)	1416 (14.8)
Obese	725 (7.3)	421 (4.4)	725 (7.3)	344 (3.6)	745 (7.5)	306 (3.2)	825 (8.3)	268 (2.8)
Physical fitness tests, mean (SD), z-scores								
Handgrip test	0.24 (1.04)	0.27 (1.09)	0.28 (1.02)	0.31 (1.09)	0.28 (1.03)	0.29 (1.03)	0.27 (1.06)	0.32 (1.05)
One-minute sit-up test	-0.01 (1.13)	0.05 (1.12)	0.06 (1.16)	0.12 (1.05)	0.08 (1.08)	0.11 (1.08)	0.05 (1.09)	0.07 (1.07)
Sit-and-reach test	-0.12 (1.17)	-0.07 (1.14)	-0.02 (1.07)	0.00 (1.05)	-0.11 (1.18)	-0.01 (1.08)	-0.08 (1.09)	0.04 (1.08)
Endurance run test	0.14 (1.03)	0.20 (1.09)	0.30 (1.05)	0.26 (0.98)	0.24 (1.16)	0.25 (1.02)	0.32 (1.15)	0.25 (1.03)

Table 2a. Predicting physical fitness after three years using baseline BMI categories and increment of BMI z-score

	Overall fitness z-score			**Handgrip z-score**			**Sit-up z-score**		
	β (95% CI)	P		β (95% CI)	P		β (95% CI)	P	
Baseline Body Weight									
Obese	-0.18 (-0.21, -0.15)	< 0.001	***	0.35 (0.30, 0.40)	< 0.001	***	-0.28 (-0.33, -0.24)	< 0.001	***
Overweight	0.03 (0.01, 0.05)	0.01	*	0.23 (0.20, 0.26)	< 0.001	***	-0.05 (-0.08, -0.02)	0.002	**
Underweight	-0.06 (-0.11, -0.01)	0.01	*	-0.23 (-0.29, -0.16)	< 0.001	***	-0.15 (-0.22, -0.09)	< 0.001	***
Normal	0 (Reference)	-		0 (Reference)	-		0 (Reference)	-	
Unit increment in BMI z-score									
Among children with underweight at baseline	0.07 (0.05, 0.09)	< 0.001	***	0.08 (0.06, 0.11)	< 0.001	***	0.05 (0.03, 0.08)	< 0.001	***
Among children with normal weight at baseline	0.02 (0.01, 0.02)	< 0.001	***	0.12 (0.11, 0.13)	< 0.001	***	0.02 (0.01, 0.03)	< 0.001	***
Among children with overweight at baseline	0.00 (-0.01, 0.01)	0.62		0.11 (0.10, 0.13)	< 0.001	***	-0.02 (-0.04, -0.01)	0.004	**
Among children with obesity at baseline	-0.06 (-0.08, -0.05)	< 0.001	***	0.10 (0.08, 0.12)	< 0.001	***	-0.10 (-0.12, -0.08)	< 0.001	***

	Sit-and reach z-score			**Endurance run z-score**		
	β (95% CI)	P		β (95% CI)	P	
Baseline Body Weight						
Obese	-0.06 (-0.11, -0.01)	0.01	*	-0.66 (-0.72, -0.59)	< 0.001	***
Overweight	0.05 (0.02, 0.08)	0.003	**	-0.17 (-0.22, -0.13)	< 0.001	***
Underweight	-0.09 (-0.15, -0.02)	0.009	**	0.14 (0.05, 0.23)	0.002	**
Normal	0 (Reference)	-		0 (Reference)	-	
Unit increment in BMI z-score						
Among children with underweight at baseline	0.06 (0.03, 0.08)	< 0.001	***	0.06 (0.02, 0.10)	0.004	**
Among children with normal weight at baseline	0.00 (0.00, 0.01)	0.27		-0.08 (-0.09, -0.06)	< 0.001	***
Among children with overweight at baseline	0.00 (-0.02, 0.02)	0.99		-0.09 (-0.12, -0.07)	< 0.001	***
Among children with obesity at baseline	-0.04 (-0.06, -0.02)	< 0.001	***	-0.21 (-0.24, -0.17)	< 0.001	***

Adjusted for age, sex, length of follow-up, and baseline fitness z-score. This model assumes linear relationship between changes in BMI z-score and physical fitness.

Table 2b. Predicting BMI categories after three years using baseline fitness status and improvement in fitness z-score

	Obese			Overweight			Underweight		
	β (95% CI)	P		β (95% CI)	P		β (95% CI)	P	
Baseline Physical Fitness									
Low	1.41 (1.16, 1.71)	< 0.001	***	1.05 (0.98, 1.13)	0.13		0.97 (0.81, 1.18)	0.79	
Moderate	0 (Reference)	-		0 (Reference)	-		0 (Reference)	-	
High	0.69 (0.60, 0.80)	< 0.001	***	0.92 (0.88, 0.97)	< 0.001	***	0.88 (0.77, 1.01)	0.06	
Unit improvement in fitness z-score									
Among low fitness children at baseline	1.08 (0.95, 1.22)	0.26		0.95 (0.89, 1.02)	0.15		0.63 (0.54, 0.73)	< 0.001	***
Among moderate fitness children at baseline	0.80 (0.74, 0.86)	< 0.001	***	0.99 (0.96, 1.03)	0.66		0.72 (0.66, 0.79)	< 0.001	***
Among high fitness children at baseline	0.75 (0.68, 0.82)	< 0.001	***	0.90 (0.86, 0.93)	< 0.001	***	0.72 (0.66, 0.78)	< 0.001	***

Adjusted for age, sex, length of follow-up, and baseline BMI z-score. This model assumes linear relationship between changes in physical fitness and BMI categories.

Figure 1. Longitudinal associations between physical fitness and BMI categories. Panel A: Physical fitness composite z-scores predicted by categories of baseline BMI categories and changes in BMI categories. Panel B: Risk ratio of obesity predicted by categories of baseline physical fitness and changes in physical fitness.

Adjusted for age, sex, and length of follow-up. Reference group is the stable / baseline normal weight group (A) and stable / baseline moderate physical fitness group (B). BMI categories categories (A) and physical fitness tertiles (B) were classified using tertile cut-off points.

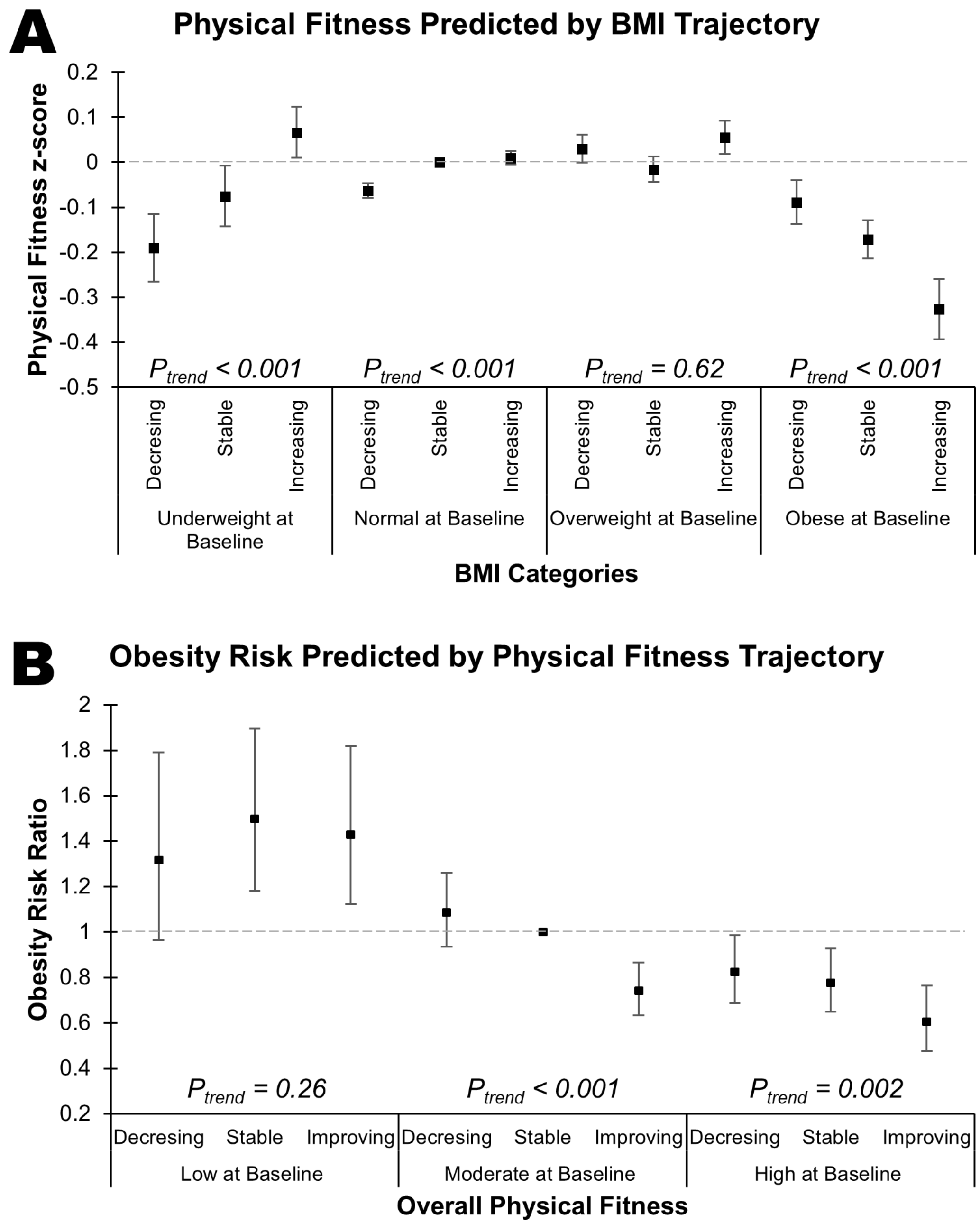
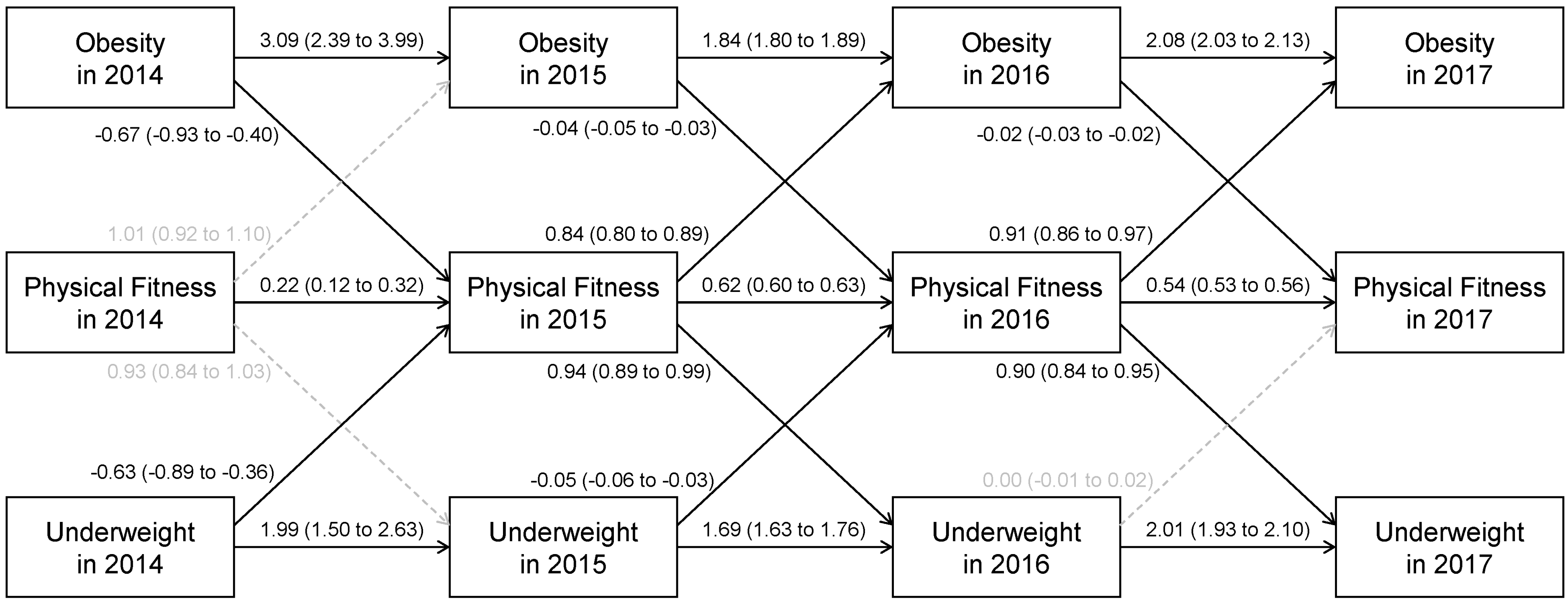

A
Physical Fitness Predicted by BMI Trajectory
Physical Fitness z-score
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
P trend < 0.001
P trend < 0.001
P trend = 0.62
P trend < 0.001
Decresing
Stable
Increasing
Underweight at Baseline
Normal at Baseline
Overweight at Baseline
Obese at Baseline
BMI Categories
B
Obesity Risk Predicted by Physical Fitness Trajectory
Obesity Risk Ratio
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
P trend = 0.26
P trend < 0.001
P trend = 0.002
Decresing
Stable
Improving
Low at Baseline
Moderate at Baseline
High at Baseline
Overall Physical Fitness

Figure 2. Reciprocal relationship of underweight and obesity with physical fitness across baseline and the three annual follow-ups

Cross-sectional paths and cross-lagged paths between obesity and underweight are not shown. Grey dotted lines indicate non-significant paths.


Obesity in 2014
Obesity in 2015
Obesity in 2016
Obesity in 2017
Physical Fitness in 2014
Physical Fitness in 2015
Physical Fitness in 2016
Physical Fitness in 2017
Underweight in 2014
Underweight in 2015
Underweight in 2016
Underweight in 2017
3.09 (2.39 to 3.99)
1.84 (1.80 to 1.89)
2.08 (2.03 to 2.13)
-0.67 (-0.93 to -0.40)
-0.04 (-0.05 to -0.03)
-0.02 (-0.03 to -0.02)
1.01 (0.92 to 1.10)
0.84 (0.80 to 0.89)
0.91 (0.86 to 0.97)
0.22 (0.12 to 0.32)
0.62 (0.60 to 0.63)
0.54 (0.53 to 0.56)
0.93 (0.84 to 1.03)
0.94 (0.89 to 0.99)
0.90 (0.84 to 0.95)
-0.63 (-0.89 to -0.36)
-0.05 (-0.06 to -0.03)
0.00 (-0.01 to 0.02)
1.99 (1.50 to 2.63)
1.69 (1.63 to 1.76)
2.01 (1.93 to 2.10)