Overweight Is Associated With Decreased Cognitive Functioning Among School-age Children and Adolescents

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Objective: Childhood overweight and obesity have increased substantially in the past two decades, raising concerns about their psychosocial and cognitive consequences. We examined the associations between academic performance (AP), cognitive functioning (CF), and increased BMI in a nationally representative sample of children.
Methods and Procedures: Participants were 2,519 children aged 8–16 years, who completed a brief neuropsychological battery and measures of height and weight as a part of the Third National Health and Nutrition Examination Survey, a cross-sectional survey conducted between 1988 and 1994. *Z*-scores were calculated for each neuropsychological test, and poor performance was defined as *z*-score <2.
Results: The association between BMI and AP was not significant after adjusting for parental/familial characteristics. However, the associations between CF remained significant after adjusting for parental/familial characteristic, sports participation, physical activity, hours spent watching TV, psychosocial development, blood pressure, and serum lipid profile. *Z*-scores on block design (a measure of visuospatial organization and general mental ability) among overweight children and children at risk of overweight were below those of normal-weight children by 0.22 (s.e. = 0.16) and 0.10 (s.e. = 0.10) unit, respectively (*P* for trend <0.05). The odds of poor performance on block design were 1.97 (95% confidence interval: 1.01–3.83) and 2.80 (1.16–6.75), respectively, among children at risk or overweight compared to normal-weight peers.
Discussion: Increased body weight is independently associated with decreased visuospatial organization and general mental ability among children. Future research is needed to determine the nature, persistence, and functional significance of this association.

Obesity (2008) **16,** 1809–1815. doi:10.1038/oby.2008.296

INTRODUCTION

The prevalence and severity of overweight is increasing dramatically in children and adolescents (1). The short- and long-term associations between overweight and a range of adverse health-related outcomes are well established and raise the level of importance for understanding overweight as a major public health concern for children and adolescents. Few studies have been specifically designed and conducted to examine the association between overweight and cognitive functioning (CF), possibly because of the general assumption that overweight or obesity *per se* is not a primary risk factor for poor cognitive performance, but merely predisposes or exacerbates other risk factors for cardiovascular diseases (2). Limited number of studies have provided some evidence that increased body weight status *per se* is associated with lowered CF in men (2,3). It is less clear whether these findings hold true for children because of inconsistent conclusion from previous studies. Li observed that among Chinese elementary school children, severely obese children had significantly lower intelligence quotient than the controls (4). Mo-suwan *et al.* found that an association between overweight status and poor school performance existed among Thai children from grades 7 to 9 but not 3 to 6 (ref. 5). However, Datar *et al.* concluded that among American kindergartners, significant differences in test scores by overweight status were explained by parental education and home environment rather than overweight status *per se* (6). These inconsistent findings may be related to the biosocial complexities of childhood overweight, academic performance (AP), and CF. Parental factors, such as the provision of a stimulating home environment, play critical roles in the development of overweight, less satisfactory

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Received 27 February 2007; accepted 22 September 2007; published online 12 June 2008. doi:10.1038/oby.2008.296

AP, and poor CF as well. Confounding effects may be part of the association observed from some studies, whereas in other studies, over-controlling for some factors, particularly physical activity and television (TV) watching, for which obesity may be as much a cause as a consequence, was also a concern. Given the limitations of previous studies, we undertook a cross-sectional analysis to examine the associations between AP, CF, and increased BMI while focusing on the mediating or confounding effects of socioeconomic characteristics, physical activity, TV viewing, and cardiovascular risk factors among school-aged children enrolled in the Third National Health and Nutrition Examination Survey (NHANES III).

METHODS AND PROCEDURES

Study population

The NHANES III, conducted from 1988 to 1994, is a cross-sectional survey of the US noninstitutionalized civilians living in households. The sampling scheme was a stratified, multistage probability design with oversampling of African Americans and Mexican Americans to allow more precise estimates for these subpopulations. Detailed descriptions of the survey have been published elsewhere (7). NHANES III included medical and cognitive examinations, and interviews conducted with survey children and proxy respondents. A total of 3,903 children aged 8–16 years participated in the AP and CF test with reliable data collected and English as the test language. As the primary goal of this study was to examine abnormally increased body weight, we excluded 163 underweight children (BMI < 5 percentile). Forty-four children who were in the neonatal intensive care unit for >2 weeks and forty-one children in need of special education or suffering from a learning disability or health-related impairment were also excluded. A large number of additional children were excluded because of missing information pertaining to confounder or mediating factors, e.g., iron test, blood lead (n = 300), parental and familial socioeconomic status (SES, n = 264), physical activity and sports participation (n = 129), TV viewing hours (n = 22), traditional cardiovascular disease risks (n = 412), and psychosocial status (n = 9). After exclusions, 2,519 children and adolescents remained for primary analyses.

Measurements and variable definitions

AP/CF. AP/CF was assessed using standardized neuropsychological tests conducted in the mobile examination center. Trained examiners administered tests in a standardized environment using uniform procedures. An automated data-recording system was used to improve adherence to the protocol, help assure accurate timing of the tasks, and streamline data collection. The examination consisted of a series of four tests, including the block-design and digit-span subtests of the Wechsler Intelligence Scale for Children, Revised (WISC-R), and the reading and arithmetic sections of the Wide Range Achievement Test, Revised (WRAT-R).

On the block-design test, the child replicates two-dimensional geometric patterns using a set of three-dimensional cubes; this subtest is a measure of nonverbal reasoning and visuospatial construction. The digit-span test assesses attention and working memory by asking the child to repeat a series of increasingly long number of sequences forward and then backward. The WRAT-R arithmetic test consists of oral and written problems ranging from simple addition to calculus, whereas the reading test assesses letter recognition and word-reading skills. The WISC-R block-design and digit-span tests were age-standardized to a mean of 10 with a s.d. of 3 and WRAT-R arithmetic and reading scores were age-standardized to a mean of 100, with an s.d. of 15 (ref. 7). For this study, a z-score was calculated for each test using the respective standard mean and s.d. Thus, for each individual test, a person scoring at the mean of the sample and another person scoring an s.d. above the mean would have z-scores of 0 and 1, respectively. In addition to the individual test score, a global AP/CF indictor was created by summing the z-scores of the four AP/CF tests and divided by 4.

Overweight and at risk of overweight. Body weight was determined to the nearest 0.05 kg (Toledo 2181 Scale), and height was measured to the nearest 0.1 cm with standardized measuring equipment (Holtain Height Stadiometer). BMI was calculated in kilogram per meter square and then converted to a sex- and age-specific BMI percentile value using a computerized formula derived from the 2000 Centers for Disease Control Growth Charts (8). In accordance with recommendations of the expert panel on childhood obesity (9), we assigned each participant to an overweight BMI stratum (≥95th percentile), an at risk for overweight BMI stratum (85th to 94th percentile), or a normal BMI stratum (<85th percentile).

Potential mediating/confounding factors. The NHANES III did not include measures of parental cognitive ability or the quality of the home environment. Consequently, we relied on ethnicity (non-Hispanic white, non-Hispanic black, and Mexican American and other ethnicities), education (<12 years, high school, college, or higher), marital status of the family head, family income, and dwelling condition as surrogates. The definitions of these indicators can be found in our previous publication (10). There is some evidence that watching TV is associated with a greater likelihood of childhood overweight (11–15). Displacement theory also suggests that as children spend more time watching TV, they spend less time participating in more "valuable" activities, such as reading and doing homework (16), resulting in adverse effects on AP and cognitive development. We therefore included a parent-reported measure of child's TV watching—assessing the total number of hours of TV watched the previous day. The children were also asked "How many times per week do you play or exercise enough to make you sweat or breathe hard?" These activities did not exclude school-related involvements such as physical education. The children were classified as being physically active most days of the week if children reported participating in physical activity at least five times per week as recommended by the Surgeon General's Report on Physical Activity and Health (17). A question was also asked concerning the number of sport teams and exercise programs the children participated in within the past year, not including physical education or gym class. Those who reported playing on one or more sport teams or exercise programs were classified as a participation group, otherwise as nonparticipation one.

Blood pressure (BP) has been demonstrated to be linearly associated with block-design scores and the comobility between high BP and overweight is relatively high among children and adolescents (18,19). During the examination conducted in mobile examination center, the physician took three BP measurements after the child was quiet and undisturbed for at least 5 min. The first and fifth Korotkoff sounds were measured according to the standardized measurement protocols recommended by the American Heart Association. The average of the second and third BP measurements was recorded as the final reading for each subject. Total cholesterol was measured enzymatically and serum triglyceride levels were measured regardless of the examinee's fasting status. Iron deficiency has been well known to be associated with poor CF, and high prevalence of iron deficiency was observed among overweight and obese children and adolescents (20,21). We used the definitions of iron deficiency proposed by Looker *et al.* based on laboratory tests of transferrin saturation, free erythrocyte protoporphytin, and serum ferritin (22). A child was considered iron-deficient if any two of these three values of iron status were abnormal for age and gender. General health status of a child was rated by parent or proxy as excellent, very good, good, fair, or poor. A dichotomous variable was used to compare children in fair or poor health with children having excellent, very good, or good health. Anxiety is known to influence test performance and was measured by heart rate in a previous study (18). During the NHANES, cognitive tests were administered with a focus on decreasing subject anxiety. Nevertheless, it may be that a difference in anxiety level between subjects with various BMI contributed to the difference in test performances; therefore, we included the heart rate as a potential confounder. This study also selected several indicators derived from parents' or proxy's rating to measure children's behaviors and social skills: (i) whether the child had ever seen a mental health professional (psychiatrist, psychologist, or psychoanalyst) about any emotional, mental, or behavioral problems, (ii) whether the child had ever been suspended, excluded, or expelled from school, (iii) whether the child was shy and slow to make new friends, and (iv) whether the child had difficulties getting along with others.

Statistical methods

As recommended by the National Center of Health Statistics, we used the SUDAAN software (SAS-callable version, 8.0.2; Research Triangle Institute, Research Triangle Park, NC) with appropriate weighting and nesting variables to produce accurate national estimates adjusting for the oversampling of specific population groups. We used the linear regression model as primary adjustment tool to estimate the adjusted mean *z*-score on cognitive outcomes for each level of BMI; pairwise comparisons were performed to assess the statistical difference of *z*-score between normal-weight children (referent group) and children at the risk of overweight, and overweight children. A critical two-sided *P* value of 0.05 was used to identify statically significant difference. To assess the mediating/confounding effects from various factors on the association between BMI with AP/CF, we conducted mediation analyses according to the methods discussed by Baron and Kenny (23) and Holmbeck (24). The difference of AP/CF test *z*-score between BMI category is reduced when mediating variable or confounder is included in the model than when not included. As the supplementary analyses, we also repeated all the regressions described above on all subjects (*N* = 3,903) who had valid data of any AP/CF tests to examine potential biases caused by exclusion of a large portion of the subjects due to various reasons. The Bonferroni adjustment was not considered because of the exploratory nature of the study and creation of the indicator for global functioning.

RESULTS

The average age of the weighted population was ~12 years, with subjects divided equally by gender for both included and excluded groups (**Table 1**). The subjects included differed

Table 1 Selected characteristics of 3,903 children aged 8–16 years, United States, NHANES III 1988–1994

	Participants included (N^c = 2,519)		Participants excluded[b] (N^c = 1,384)	
Characteristic[a]	n^c	Mean or % (s.e.m.)	n^c	Mean or % (s.e.m.)
Age (years)	2,519	12.03 (0.08)	1,384	11.69 (0.13)*
Sex, boy, %	2,519	51.98 (2.10)	1,384	49.80 (2.09)
Race, non-Hispanic black, %	2,519	13.90 (1.26)	1,384	20.72 (2.16)**
Education of family head, below high school, %	2,519	9.04 (1.16)	1,361	11.99 (1.40)**
Family income, low[d], %	2,519	27.35 (2.08)	1,099	36.16 (2.48)**
Arithmetic *z*-score	2,502	0.09 (0.04)	1,356	–0.66 (0.06)**
Reading *z*-score	2,430	0.25 (0.04)	1,318	–0.52 (0.06)**
Block-design *z*-score	2,483	0.06 (0.03)	1,379	–0.29 (0.06)**
Digital span *z*-score	2,484	0.04 (0.03)	1,378	–0.54 (0.06)**
Global functioning *z*-score[e]	2,421	0.12 (0.02)	1,309	–0.47 (0.04)**
BMI, at risk of overweight, %	2,519	20.33 (0.19)	1,331	18.31 (0.19)**
Overweight, %	2,519	15.92 (1.36)	1,331	13.87 (1.69)
Physical activity, active[f], %	2,519	59.76 (1.93)	1,195	56.42 (2.92)
TV viewing hours, <2 h, %	2,519	22.07 (1.43)	1,354	19.27 (2.36)
Sports team/program participation, yes, %	2,509	65.40 (1.28)	1,343	55.66 (2.83)**
Systolic blood pressure (mm Hg)	2,519	103.60 (0.39)	1,219	102.45 (0.60)*
Diastolic blood pressure (mm Hg)	2,519	56.65 (0.55)	847	55.92 (0.53)
Ever been suspended from school, yes, %	2,517	11.13 (1.05)	1,383	12.45 (1.30)
Ever see psychological professional, yes, %	2,519	13.93 (1.33)	1,379	14.34 (1.65)
How many good friends, no, %	2,515	1.12 (0.25)	1,377	2.97 (0.77)*
Feel shy when meeting new friends, yes, %	2,519	19.79 (1.18)	1,381	25.28 (2.06)*
Parent-rated general health, poor, %	2,519	3.90 (0.49)	1,384	6.19 (0.84)**
Iron deficiency[g], yes, %	2,519	4.72 (0.84)	1,384	5.03 (0.74)

AP/CF, academic performance and cognitive functioning; NHANES III, the Third National Health and Nutrition Examination Survey.
[a]Presented as mean (s.e.m.) unless otherwise indicated. [b]Children were excluded because of unreliable data, non-English test language, BMI < 5% percentile, a history of 2+ weeks care of neonatal intensive care, learning disability, health impairments or missing data on potential confounder, or mediating factors. [c]Unweighted sample size, *N* = total sample size for the children excluded or included, *n* = total sample size with valid data on the variable for each row. [d]A poverty index ratio was calculated by comparing the midpoint for the family income category and the family size with the federal poverty line. A poverty index ratio <1.30, the federal cut-point for eligibility for the Food Stamp Program, was classified as low. [e]The *z*-score for global AP/CF was created by summing the unweighted *z*-scores of the four individual tests and divided by 4. [f]Children who reported being active most days of the week were defined as children who reported participating in physical activity at least five times per week as recommended by the Surgeon General's Report on Physical Activity and Health (17). [g]Details of the definition of iron deficiency can be found in ref. 22. *P < 0.05, **P < 0.01 (Cochran–Mantel–Haenszel test for categorical variable and *t*-test for continuous variable).

Table 2 Adjusted mean difference (s.e.) of AP/CF test *z*-score from the hierarchy regression models: sample of 2,519 children aged 8–16 years, United States, NHANES III, 1988–1994

Adjusted for	Normal weight (*n* = 1,746)	At the risk of overweight (*n* = 413)	Overweight (*n* = 360)	*P* for trend
Arithmetic test				
Age, gender	0 (ref)	–0.057 (0.113)	–0.365 (0.111)**	0.0019
Age, gender and parental/familial SES		–0.001 (0.105)	–0.190 (0.100)	0.0641
All confounding/mediating variable[a]		0.016 (0.094)	–0.114 (0.112)	0.3137
Reading test				
Age, gender	0 (ref)	–0.097 (0.087)	–0.289 (0.080)**	0.0008
Age, gender and parental/familial SES		–0.072 (0.084)	–0.141 (0.072)	0.0556
All confounding/mediating variable[a]		–0.061 (0.080)	–0.112 (0.071)	0.1230
Block-design test				
Age, gender	0 (ref)	–0.138 (0.097)*	–0.383 (0.117)**	0.0023
Age, gender and parental/familial SES		–0.104 (0.087)	–0.253 (0.115)	0.0324
All confounding/mediating variable[a]		–0.101 (0.103)	–0.220 (0.106)	0.0439
Digit-span test				
Age, gender	0 (ref)	–0.127 (0.099)*	–0.279 (0.052)**	<0.0001
Age, gender and parental/familial SES		–0.109 (0.095)*	–0.209 (0.046)**	<0.0001
All confounding/mediating variable[a]		–0.059 (0.096)	–0.119 (0.058)*	0.0457
Global functioning				
Age, gender	0 (ref)	–0.089 (0.079)	–0.324 (0.063)**	<0.0001
Age, gender and parental/familial SES		–0.054 (0.070)	–0.193 (0.050)**	0.0003
All confounding/mediating variable[a]		–0.029 (0.069)	–0.130 (0.052)*	0.0155

AP/CF, academic performance and cognitive functioning; NHANES III, the Third National Health and Nutrition Examination Survey; ref, reference; SES, socioeconomic status.
[a]Including age, gender, race/ethnicity (non-Hispanic white, non-Hispanic black and Mexican American, and other ethnicities), family income (low, middle, and high) education attainment of family head (<12 years, high school, college, or higher), marital status of the family head (single, not), dwelling condition (≥1 person/room, <1), general health status (good, poor), iron deficiency (yes, no), physical activity level (physically active, and inactive), sports team/program participation (yes, no), systolic and diastolic blood pressure, pulse rate (beats/min), serum total cholesterol and triglyceride, history of school suspension (yes, no), seeking psychological supports (yes, no), number of good friends, whether feel shy when meeting others (yes, no). $^*P < 0.05$, $^{**}P < 0.01$ (for the contrast between normal-weight group and at risk of overweight group, normal-weight group and overweight group).

significantly from those excluded on most of the characteristics selected. Compared with participants included, those excluded were more likely to be non-white and to have a low family SES. Excluded subjects had low *z*-scores on all cognitive tests, high rates of emotional or behavioral problems, and were more likely to be rated by their parents as having poor health. Among children included, 20.33 and 15.92% respectively were identified as overweight or at risk of overweight, significantly higher than the corresponding proportion among the children excluded. Finally, the proportion of children participating on sports teams or programs was also significantly higher among the group of subjects included.

Estimated from linear regressions (**Table 2**), the age–gender-adjusted trends of the association between BMI and all AP/CF test were statistically significant, and *z*-scores of test decreased as the percentile of BMI increased. The trends of the association with AP were quickly diminishing where adjustments were made for parental and familial SES. The trends for block-design, digit-span tests and global functioning remained statistically significant even when the adjustments were further made for all potential confounding/mediating variables. Generally, the effect sizes associated with being overweight or at risk of overweight on the test scores were relatively small. Among all estimates, the maximum effect size was the age–gender-adjusted difference of block-design *z*-scores between normal-weight and overweight children, which was statistically significant but twice the s.e. only. The effect size of overweight on block-design test was only 0.22 (s.e. = 0.11) after adjustment for a comprehensive list of confounding and mediating variables.

When test *z*-scores were dichotomized and performance with score below 2 was defined as "poor," the proportions of poor performers were 5.99, 7.45, 6.84, and 5.16, respectively for arithmetic, reading, block-design, and digit-span test, and 1.67 for global functioning (data not shown) among study population. Because of the reduced statistical power from dichotomizing continuous variables, the logistic regression yielded a different picture to that obtained from linear regressions using continuous *z*-score as the outcome variable. Among all AP/CF measures, only block design demonstrated a strong and significant association with body weight status (**Table 3**). The proportion of poor performers on this task was nearly doubled (odds ratio = 1.97) among children at risk of overweight and tripled (odds ratio = 2.80) among

Table 3 Adjusted OR (95% CI) of poor performance in AP/CF tests: sample of 2,519 children aged 8–16 years, United States, NHANES III, 1988–1994[a]

AP/CF tests	Normal weight (n = 1,746)	At risk of overweight (n = 413)	Overweight (n = 360)	P trend
Arithmetic test				
No. of poor performers	169	32	36	
% (s.e.) of poor performers	5.81 (4.81)	4.92 (2.62)	8.74 (4.18)	0.2313
OR (95% CI) adjusted for age and gender	1	0.84 (0.51, 1.40)	1.57 (0.75, 3.27)	0.2225
Adjusted for age, gender, parental/familial SES	1	0.71 (0.43, 1.18)	1.11 (0.53, 2.29)	0.7843
Adjusted for all confounding/mediating variable[b]	1	0.60 (0.35, 1.04)	0.70 (0.29, 1.68)	0.4216
Reading test				
No. of poor performers	220	52	55	
% (s.e.) of poor performers	7.07 (4.12)	7.57 (3.24)	9.83 (3.35)	0.2464
OR (95% CI) adjusted for age and gender	1	1.08 (0.69, 1.70)	1.42 (0.77, 2.63)	0.2558
Adjusted for age, gender, parental/familial SES	1	1.03 (0.62, 1.70)	1.13 (0.58, 2.19)	0.7123
Adjusted for all confounding/mediating variable[b]	1	0.96 (0.60, 1.54)	0.94 (0.47, 1.90)	0.8578
Block-design test				
No. of poor performers	175	49	53	
% (s.e.) of poor performers	5.04 (5.90)	9.19 (4.60)	12.18 (5.27)	0.0081
OR (95% CI) adjusted for age and gender	1	1.91 (1.07, 3.40)	2.75 (1.33, 5.67)	0.0073
Adjusted for age, gender, parental/familial SES	1	1.85 (1.01, 3.40)	2.42 (1.12, 5.23)	0.0263
Adjusted for all confounding/mediating variable[b]	1	1.97 (1.01, 3.83)	2.80 (1.16, 6.75)	0.0233
Digit span test				
No. of poor performers	164	33	38	
% (s.e.) of poor performers	5.05 (4.18)	5.01 (3.96)	6.09 (3.14)	0.5104
OR (95% CI) adjusted for age and gender	1	1.00 (0.51, 1.96)	1.21 (0.66, 2.24)	0.5288
Adjusted for age, gender, parental/familial SES	1	0.98 (0.48, 1.98)	1.18 (0.63, 2.18)	0.6003
Adjusted for all confounding/mediating variable[b]	1	1.01 (0.46, 2.20)	1.17 (0.51, 2.65)	0.7070
Global functioning				
No. of poor performers	64	15	19	
% (s.e.) of poor performers	1.48 (7.27)	1.96 (6.53)	2.55 (5.76)	0.2162
OR (95% CI) adjusted for age and gender	1	1.34 (0.55, 3.24)	1.81 (0.75, 4.36)	0.1831
Adjusted for age, gender, parental/familial SES	1	1.25 (0.48, 3.29)	1.45 (0.56, 3.74)	0.4335
Adjusted for all confounding/mediating variable[b]	1	1.22 (0.54, 2.74)	1.32 (0.40, 4.40)	0.6464

AP/CF, academic performance and cognitive functioning, CI, confidence interval; OR, odds ratio; NHANES III, the Third National Health and Nutrition Examination Survey; SES, socioeconomic status.
[a]Performance with z-score <2 was defined as "poor." [b]See the footnote of **Table 2** for the list of confounding/mediating variables.

overweight children compared to their normal-weight peers. These estimates were obtained after adjustment for all potential confounding/mediating variables. Supplementary analyses on all subjects (N = 3,903) who had valid data of any AP/CF showed that the estimates remained unchanged and the associations described above was not sensitive to exclusion of a large portion of the subjects due to the reasons previously described.

DISCUSSION

Using a nationally representative sample, we documented an association between BMI percentile category and cognitive impairment in visuospatial organization and general mental ability (as measured via block design) in a large sample of school-age children. This association remained robust even after adjusting for parental and familial SES and other potential confounders such as sports participation, physical activity level, hours of TV watching, psychosocial development, BP, and serum lipid profile. There was a suggestion of a "dose–response" effect of body size on cognition functioning. When test scores <2 s.d. from mean were defined as "poor," the odds of poor performance in visuospatial organization and general mental ability were doubled and tripled, respectively among at risk and overweight children, compared to their normal-weight peers.

In this study, AP was assessed by WRAT-R, a brief and widely used instrument designed to measure basic school performances rather than comprehension, reasoning, and judgment processes. Both reading and arithmetic subtests reflect large part of the social, economic, and cultural knowledge and are strongly influenced by the parental or familial SES characteristics. This might be the major reason that age–gender-adjusted effect sizes of weight status were significant but adjustment for SES reduced these effect sizes substantially to a level without statistical significance. Our observation is consistent with a previous study which found that among American kindergartners and first-grade students, overweight was a marker for but not a cause of poor AP and that worse AP can contribute to parent or family SES characteristics (6). It was found, however, that lower educational achievement among adults is associated with obesity and obese adolescents consider themselves worse students (25). It is unknown whether the findings from adults apply to children or in instances in which objective measures of school performance, as we did in this study, are used.

The finding that decreased CF was associated with increased weight status is consistent with studies demonstrating decrements in memory, abstract reasoning, and attention in adults with increased body weight. It has been observed that a significant portion of obese individuals between the ages of 20 and 64 years reported "some difficulty thinking" (26). Cognitive deficits on tests of motor speed, diminished performance on tests of motor speed and manual dexterity, and executive function have been identified among middle-aged and older obese adults (27). Poor performance on memory tasks is common among obese individuals across the adult lifespan (28). Admittedly, part of the association observed among adults is explainable by a reverse causation. Those with poorer cognitive ability to begin with may both do worse in school and select a lifestyle (i.e., high TV watching, poor dietary intake, low physical activity) that promotes weight gain. This study, however, further demonstrated that this association may exist among overweight children or children at risk of overweight without clinically diagnosed diabetes mellitus or the multiple medical comorbidities such as vascular disease and cardiac disease that often characterize adult patients. The significant relationship with decreased block-design subtest captured in both linear and logistic regression was particularly intriguing. Block design, a measure of visuospatial organization and general mental ability (29), has been shown to be sensitive to brain damage, particularly nondominant right hemisphere lesions with parietal lobe involvement. The importance of these findings can be judged by noting that the adverse effects of increased body weight status on cognition functioning start playing as early as in childhood. The general assumption does not hold true that increased body status is not a primary risk factor for poor cognitive performance, but merely predisposes or exacerbates other risk factors for cardiovascular disease. Cognitive decline may occur in younger persons without the pathophysiological vascular changes typically associated with aging. Indeed, there may be factors other than atherosclerosis and stroke implicated in the cognitive decline associated with increased body status, such as low-degree inflammation of blood vessels in the brain because obesity or overweight has been identified as a proinflammatory state.

Other mechanisms to explain the declined CF have been suggested, with recent attention being paid to impaired insulin receptor signaling, low levels of leptin in brain, and altered glucose metabolism (30,31). Physiologically, hyperinsulinemia is linked to disturbances in glucose metabolism and insulin signaling that affect several brain regions, including those (e.g., frontal lobes, hippocampus) involved in planning and organizing, which are elements of the block-design task. It is unclear whether these mechanisms may apply to the associations we observed among children and adolescents overweight or at risk of overweight. It has been reported, however, that even in the absence of diabetes mellitus, insulin resistance associated with accelerated age-related cognitive decline (32–34). Another potential explanation is related to the effects of sleep apnea. As is well known, increased BMI is related to an increased risk of obstructive sleep apnea in children and adolescents (35). As is true for adults, children with obstructive sleep apnea have detectable cognitive deficits presumably due to hypoxemia in addition to the general effects of sleep disruption (36–39). Some authors have speculated that psychosocial factors within the family may play a role in both the origins of obesity and its cognitive consequences (40), and the learning difficulties and poor cognitive performance present in overweight children may reflect parental psychopathology or SES rather than problems that result from the child's increased weight status. This study demonstrated that controlling for parental SES diminished the association between overweight and APs but such factors did not account for poor performance in areas of visuospatial organization and general mental ability.

Perhaps the greatest limitation of this study was that due to its cross-sectional design, a causal relationship between weight status and AP/CF could not be determined. Both weight status and AP/CF are strongly influenced by genetic factors, and any observed covariation could have been due to the concomitant expression of genotype without weight status and AP/CF being causally related to one another. The samples of the study may represent only "normal" children, as "abnormal" children who had been institutionalized or in special schools (classes) were excluded. Therefore, the ability to identify a strong association may have been constrained by not sampling those who were emotionally, cognitively, or behaviorally abnormal. Thanks to computer technology, the AP/CF tests can be administered in a carefully controlled fashion with extremely accurate measurement in NHANES III, making this study able to detect the subtle effects of increased body size on important elements of neuropsychological functioning. Interpretation requires caution at this point given the nature of the study design. Our findings, however, trigger important questions—chief among them being whether the associations observed in our sample during childhood lead to larger deficits during adulthood or make persons more vulnerable to biologic perturbation, and thus lead to decreased social functioning, and make difference to survival in later life? Seeking answers to these questions invites further detailed and sustained investigation in large prospective settings with a more comprehensive battery of tests. Today's schools face intense pressure to focus on standardized test and consequently have placed less emphasis on the broader view of a healthy mind in a healthy body. This study provides additional evidence indicating that physical health and learning success are interrelated; our education cannot achieve its mission if children are not healthy and fit physically, mentally, and socially.

ACKNOWLEDGMENT

This work was carried out when Y.L. and J.Z. were with the University of South Carolina.

DISCLOSURE

The authors declared no conflict of interest.

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