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Does academic achievement during childhood and adolescence benefit later health?

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Abstract

Purpose—Educational disparities in health persist after adjustment for income and occupation, suggesting that other purely cognitive and psychosocial mechanisms may be involved. Unlike occupation- or income-mediated effects, effects of cognitive and psychosocial gains—as reflected in academic achievement—may be apparent even before schooling is completed.

Methods—We used data spanning 10 years on a national U.S. cohort of 2,546 children aged 3–14 at baseline to estimate effects of academic achievement, measured by standardized tests of cognitive achievement, on future health. We used marginal structural models to address potential mutual influence of achievement and health on each other over time.

Results—One standard deviation higher academic achievement 1997–2002 was associated with a lower prevalence of poorer health status in 2007 in girls (prevalence ratio [PR] = 0.87 [(95% confidence interval) 0.78–0.97]) but not in boys (PR = 0.96 [0.86–1.08]). Higher achievement was also weakly associated with lower BMI and less psychological distress among girls only.

Conclusions—Academic achievement may benefit future health but a number of questions remain unanswered, including reasons for the gender differences and how academic-achievement-related health disparities may progress over the life course and interact with other social determinants of health.

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Keywords

academic achievement; body mass index; children and adolescents; education; gender; health status; marginal structural models; mental health

It is often hypothesized that education affects health through its effects on occupation and income [1, 2]. However, education-related health disparities persist after adjustment for income and occupation [3]. This suggests that other processes, including purely cognitive and psychosocial benefits of the learning process, may be involved. If these mechanisms are important, students who more successfully make cognitive and psychosocial gains—for example, as reflected in their academic achievement—may enjoy better health even before they complete their schooling and socioeconomic sequelae manifest. Higher academic achievement may reflect cognitive gains that help students better understand and act on information about healthy behaviors such as eating a healthy diet, exercising, not smoking, or hand washing [3, 4]. It may also benefit health through psychosocial mechanisms by fostering higher self-esteem, a greater sense of personal control, the patience and time preference to invest in healthier behaviors, more social integration and social support, or a peer group with more healthful behavioral norms [5–7].

These mechanisms are in contrast to occupation- or income-mediated effects, which would not appear until students enter the workforce. Understanding them could be an important tool for reducing health disparities by fostering educational practices that maximize future health benefits regardless of students' future economic circumstances. Yet relatively few studies have investigated how academic achievement relates to health, and most have used cross-sectional data or short follow-up times [8–16]. We used three waves of data spanning 10 years on a national cohort of children aged 3–14 at baseline to estimate effects of academic achievement on health during the schooling process.

Our primary health outcome was self-rated global health status, a relevant health measure for young populations among whom serious medical conditions are rare [17–19]. Self-rated health status is correlated in adolescents and young adults with disability, health services use, physical and mental health, and health behaviors [19–22]. In secondary analyses we examined two additional health outcomes, body mass index (BMI) and psychological distress, which might contribute to an association between academic achievement and health status. Low or high BMI and psychological problems have both been associated with poorer self-rated health status in national samples of young people [17, 19, 21], as well as with poorer academic achievement [9, 11, 12, 16].

An important challenge is the possibility of reverse causation: students' health may influence their success in school. Poor health may affect students' ability to attend school regularly, pay attention in classes, complete assignments, interact with peers and teachers, or invest in long-term educational goals [23–25]. Figure 1 shows this theorized mutual influence of health and academic achievement on each other over time. This presents a methodological challenge in longitudinal analyses because health during follow-up (Health at Time 2 in Figure 1) both mediates the health effect of prior achievement and confounds the effect of future achievement (i.e., is a time-dependent confounder). Therefore, adjusting

for health during follow-up may create overadjustment bias while failing to do so may create confounding bias. We addressed potential time-dependent confounding in academic achievement–health associations by using marginal structural models (MSMs) [26].

We hypothesized that a history of higher academic achievement decreases the risk of poor health among adolescents and young adults. We also hypothesized that conventional models adjusting for health during follow-up underestimate the effect of academic achievement on health. Finally, based on stronger associations observed among girls in previous studies on this topic [8, 14, 16], we hypothesized that there are sex differences in effects of academic achievement on health.

METHODS

Study population

We used publicly available data from two supplementary studies to the Panel Study of Income Dynamics (PSID), a longitudinal study of a representative (after weighting) sample of U.S. families started in 1968 [27]. The Child Development Supplement (CDS) began in 1997 with a sample of 3,563 children drawn from PSID families with a child aged 0–12 in calendar year 1997, with up to two children chosen per family. Black and low-income families were oversampled. Subsequent study waves were conducted in 2002–2003 and 2007–2008. The primary interviewee is the participant’s primary caregiver, in over 90% of cases the child’s biological mother. The children themselves are also interviewed; interview content varies by the child’s age. The Transition Into Adulthood Study (TA), started in 2005, comprises young adults who “aged out” of the CDS by turning 18 and finishing or leaving high school. All questions in the TA are answered by the participants themselves. We combined data from the 1997 CDS, the 2002–2003 CDS (“2002 CDS”), and either the 2007–2008 CDS (“2007 CDS”) or the 2007 TA to create a longitudinal sample with three waves of interviews spanning 10 years. The analysis sample, including only children who were at least 3 years old and enrolled in a childcare center or school at baseline, was 2,546 children aged 3–14 years by the time their baseline interviews were completed and 14–24 years at the third interview (Figure 2).

Measures

The primary outcome was 2007 health status, with prior health status treated as a time-dependent confounder (Figure 1). We dichotomized the 5-point scale into “very good” (excellent/very good) and “poorer” (good/fair/poor). We chose this dichotomization instead of excellent/very good/good vs. fair/poor because the number of participants with fair or poor health was very small, particularly in the earlier study waves (e.g., 3% in 1997). Ordinal logistic regression models provided consistent results but the data violated the proportional odds assumption. Because the survey questionnaire content varied depending on the age of the participant, the measure was reported by the participant in 2007 but by the primary caregiver in 1997 and 2002. We also included measures of perinatal health (low birth weight [< 88 ounces] and the primary caregiver’s assessment of the child’s health at birth) as baseline confounders.

As with health status, the outcomes of interest for the secondary analyses of BMI and psychological distress were the 2007 measures, with prior measures treated as time-dependent confounders. BMI (kg/m^2) was calculated from height and weight. Baseline height was reported by the participant's caregiver; baseline weight, 2002 height and weight, and 2007 height and weight for CDS participants were measured by the interviewer; 2007 height and weight for TA participants were self-reported. Psychological distress was measured using the K6 non-specific psychological distress scale developed for use in the U.S. National Health Interview Survey (NHIS) [28]. Because the K6 was administered in the TA but not the CDS, analyses using the K6 were limited to participants aged 18 or over in 2007 ($n = 1475$). For the same reason, the K6 measure was not available in 2002 to serve as a time-dependent confounder; instead we used the Children's Depression Inventory (CDI) Short Form, the measure of mental health administered in the 2002 CDS [29]. The correlation between 2002 CDI and 2007 K6 scores was 0.21 ($p < .001$). No scale of mental health was available at baseline.

The exposure variable was average academic achievement over five years. We characterized academic achievement using the Letter-Word Identification and Applied Problems subtests of the Woodcock-Johnson Psycho-Educational Battery-Revised Achievement Tests (WJ-R ACH), administered in the 1997 and 2002 CDS. These subtests, part of a battery of 39 tests of intellectual processing, test aspects of the test-taker's stores of acquired knowledge in language and math, respectively [29, 30]. The Letter-Word Identification test asks participants to identify or correctly pronounce letters or words without context; it is not necessary to know the meanings of the words. The Applied Problems test consists of math questions ranging from counting a number of objects to word problems. In both tests, participants complete progressively more difficult questions until they reach a "ceiling" in which they are unable to complete a set number of questions in a row; the raw score equals the number of correct responses, with a possible range of 0–57 for Letter-Word Identification and 0–60 for Applied Problems [29]. The tests have standardized administration and scoring protocols, were norm-referenced to a nationally standardized sample of 6,359 people aged 2–90, and have been widely used in a variety of populations [29, 30]. To create the cumulative measure of average 5-year academic achievement, we averaged each child's age-standardized Letter-Word Identification and Applied Problems scores to create a measure of overall academic achievement in each wave, then averaged the 1997 and 2002 scores. This measure was normally distributed with a mean of 101.9 and ranged 42.0–169.5; higher scores indicate better achievement.

In addition to the time-dependent confounding effects of prior health, we also considered a range of potential time-invariant and time-varying confounders. We capitalized on the richness of the PSID data to incorporate information from nine broad domains that may influence both schooling and future health in young people: demographic characteristics, family composition, family socioeconomic status, neighborhood characteristics, geographical characteristics, perinatal health, health care use, schooling characteristics, and caregiver academic ability. The variables we used corresponding to these domains are listed in Appendix Table A1.

Analysis

To handle missing information, multiple imputation with 25 imputations was carried out using the sequential regression method with IVEware software, simultaneously including information from all three study waves and including auxiliary variables predictive of analysis variables with large amounts of missing information (Table A1) [31–33].

We contrasted three types of models, each estimating the effect of one standard deviation (approximately 15 points; calculated separately in each imputed data set) higher average achievement 1997–2002 on health in 2007. First, we estimated models adjusted only for baseline confounders. In the presence of time-dependent confounding, these models may produce biased estimates because of confounding by health during follow-up. Second, we estimated “naively time-varying-confounder-adjusted” models that were additionally adjusted for 2002 values of time-varying confounders. These models may produce biased estimates because of inappropriate adjustment for mediators of academic achievement. Third, we estimated marginal structural models (MSMs) that addressed possible time-dependent confounding through inverse-probability-of-exposure weighting rather than adjustment [26]. We tested interactions between academic achievement and sex in all models; in sensitivity analyses, separate sex-specific models produced very similar findings. All models were estimated with robust standard error estimates, which account for correlations between siblings. In sensitivity analyses, models additionally incorporating CDS sampling weights produced nearly identical estimates, as did models using quintiles of academic achievement.

To estimate the MSMs, a stabilized treatment (i.e., exposure) weight sw_i was constructed for each participant using linear regression and the normal probability density function to estimate probability densities of observed academic achievement conditional on covariates [34] (see Appendix for details). Final marginal structural outcome models of 2007 health with average academic achievement 1997–2002 as the exposure were estimated incorporating the exposure weights and adjusting for baseline characteristics [34, 35].

We used Poisson regression to calculate prevalence ratios for poorer health status and being in the highest quartile of the K6 scale (“serious psychological distress”) in 2007 [36]. We log-transformed the BMI measure because of its skewed distribution and modeled it using linear regression. In a sensitivity analysis, analyses of the BMI outcome excluding observations underweight in 1997 (< 5th percentile according to the Centers for Disease Control & Prevention 2000 growth chart [37]) produced nearly identical results.

RESULTS

There was substantial and nonmonotonic case missingness in the data: 67% of participants completed all three study waves, 23% missed either wave 2 or wave 3, and 10% missed both wave 2 and wave 3 (Figure 2). Twenty-nine percent and 27% of participants were missing academic achievement scores in 1997 and 2002, respectively. In 2007, 26% of participants were missing information for health status, 28% for BMI, and 21% for psychological distress.

Variable distributions were very similar in the original and imputed data sets (Appendix table A2). About two-thirds of the participants had a sibling in the sample. At baseline, 21% lived below the Federal poverty line and 18% had no caregiver with a high school degree (Table 1). The majority of participants had good overall health status, were of normal weight, and reported few mental distress symptoms, but over a third were overweight or obese and 43% reported less than excellent or very good health status in 2007 (Table 1). Academic achievement was positively associated with family income and caregiver education, caregiver achievement score, living with two parents, supportiveness of the home environment, neighborhood quality, residence in the Northeast, private school attendance, health status, and normal BMI status; and negatively associated with low birth weight, hospital stays, behavior problems, changing schools, repeating a grade, and mental distress symptoms (Table 1; not all variables shown). Poorer 2007 self-rated health status was associated with female sex, lower family income and caregiver schooling, poorer previous caregiver-rated health status, high BMI in all waves and underweight BMI status in 2007, poorer mental health, more problem behaviors, poorer perinatal health, and more overnight hospital stays (Table 1; not all shown).

In models, average academic achievement 1997–2002 was inversely associated with poorer health status in 2007 (Table 2) but the overall association was driven by results among girls (p for interaction = 0.12 in the MSM). In the MSM, each standard deviation higher academic achievement was related to a 13% lower prevalence of poorer 2007 health status among girls (prevalence ratio [PR] = 0.87 [95% confidence interval] 0.78–0.97) but negligibly less poorer health status among boys (PR = 0.96 [0.86–1.08]). The MSMs produced only minimally different point estimates than the baseline- and naively time-varying-confounder-adjusted models.

Models of the other health outcomes produced results generally consistent with the ones for health status. In the MSM, each standard deviation higher academic achievement was weakly associated with a 1.4% lower BMI (Table 3; % difference = -1.36 [$-3.12, 0.44$]) among girls but a negligible difference among boys (% difference = -0.14 [$-1.60, 1.35$]). In the combined models and among girls, estimates from the models of BMI were indicative of the pattern we would expect in the presence of time-dependent confounding: the MSM estimates were smaller in magnitude than those from the unweighted baseline-adjusted model but larger than those from the naively time-varying-confounder-adjusted model. Among participants aged 18 and over in 2007, in the MSM, each standard deviation higher achievement was weakly associated with a lower prevalence of serious psychological distress among girls (Table 4; PR = 0.82 [0.64–1.05]) but not among boys (PR = 0.98 [0.79–1.22]). Similar to the models of health status, point estimates were very similar between the different adjusted models.

DISCUSSION

In a national sample of U.S. youth aged 3–14 at baseline, higher average academic achievement 1997–2002 was associated with better health in 2007 (better health status, lower BMI, less serious psychological distress) among girls but consistently less so for boys. The gender pattern we observed mirrors results from studies of similar outcomes in adults,

where associations between more schooling and better self-rated health status, less depression, and less obesity have been stronger in women than in men [3, 38, 39]. Studies of gender differences in associations between academic achievement and health among youth are rarer and their evidence is mixed. School performance was slightly more strongly associated with subjective health complaints in girls than boys among Hungarian 9th-graders [8] and school grades were more predictive of depressive symptoms a year later in girls than boys among adolescents in Norway [16]. On the other hand, gender differences were not reported in associations between lower school performance and worse self-rated health among students in Hungary [14] or overweight among American adolescents [12]. Future research examining gender differences in how academic achievement relates to health is needed. These differences may reflect objective mechanistic differences in how schooling influences health, as well as gender differences in how people incorporate information when reporting their health [40].

Contrary to our hypothesis, accounting for mutual influence of academic achievement and health over time with MSMs did not produce meaningfully different results, particularly for the health status and psychological distress outcomes. One explanation is that there may not have been substantial time-dependent confounding in these associations. Appendix Table A3 and Figure A1 list four preconditions for the potential usefulness of MSMs for a given research question and demonstrate how these preconditions apply to our question for the health status outcome [34]. Although our measures met the preconditions when tested in unadjusted models, many of the associations were weak—although in expected directions—after adjustment for relevant covariates.

The reliance on self- and proxy-reported information, a limitation of this analysis, may have resulted in large and/or correlated errors in measurement of different variables. However, exposure information came from validated and interviewer-administered academic achievement tests. In adults, self-rated health status is predictive of morbidity and mortality [41, 42] but it can be unreliable [43] and its predictive power tends to be lower among individuals with lower socioeconomic status [44]. The properties of self-rated health status in adolescents have been less examined but studies have found that the measure is correlated with physical and psychological health conditions, pain, and family socioeconomic status, and is relatively stable over time [21, 22, 45]. Another consideration is that 2007 health status was reported by the participant while the earlier measures were reported by the caregiver; the two sources may have based their assessments on different facets of health. In a sensitivity analysis, restricting the sample to participants aged 5 years or older in 1997 (those old enough to self-report their own health status in 2002) and replacing the 2002 caregiver-reported measure with the self-reported measure in the MSM did not affect our results. Our results may also have been affected by missing data and attrition if missing values were related to unobserved variables, particularly given the large volume of missing exposure and outcome information.

This analysis was, to our knowledge, the first to investigate whether academic achievement affects future adolescent and young adult health while accounting for time-dependent confounding. Although small, the associations we observed are consistent with the hypothesis that—at least among girls—schooling may benefit health through mechanisms

related to the learning process that are distinct from income-mediated mechanisms associated with educational attainment. A number of questions remain unanswered, including the reasons for the gender differences, the specific mechanisms for these effects and the health outcomes for which they are most important, and how these academic-achievement-related health disparities may progress over the life course and interact with other social determinants of health.

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Appendix

MULTIPLE IMPUTATION

Table A1

Variables used in multiple imputation and estimation of treatment weights

Variables	<u>Multiple imputation</u> Years used	<u>Treatment weights</u> Years used
Demographic		
Sex	1997	1997
Age	1997, 2002, 2007	1997
Race	1997	1997
Family composition		
Family size	1997, 2002	
Head of household's marital status	1997	
Number of parent figures/guardians lives with	1997, 2002, 2007	1997, 2002
Lives with a partner (age ≥ 18)	2007	
Birth order to mother	1997	
Sibling in 1997 CDS	1997	
Family socioeconomic status & environment		
Maximum of parents' years schooling at birth	1997	
Maximum of caregivers' years schooling	1997, 2002	1997
Family poverty threshold	1996, 2002, 2006	
ln(Family income-to-poverty ratio)	1996, 2002, 2006	1996, 2002
HOME scale	1997	1997
Neighborhood characteristics		
Years lived in current neighborhood	1997, 2002	
Rating of neighborhood as a place to raise children	1997, 2002	1997, 2002
Neighborhood dangerous to walk around alone after dark	1997, 2002	
Geographical characteristics		
Urbanicity	1997, 2001, 2003, 2007	1997
Region	1997, 2001, 2003, 2007	1997
Perinatal health		
Birth weight	1997	
Low birth weight		1997
Spent time in neonatal intensive care unit	1997	
Primary caregiver's rating of health at birth	1997	1997
Current physical health and health care use		
Primary caregiver's rating of health status	1997, 2002	1997, 2002
Self-rated health status	2002, 2007	
Body mass index	1997, 2002, 2005 (TA), 2007	1997, 2002
Number of overnight hospital stays	1997, 2002, 2007	1997, 2002
Routine physician check-up in past 2 years	1997, 2002	1997, 2002
Primary caregiver's self-rated health status	1997, 2002	

Variables	Multiple imputation	Treatment weights
	Years used	Years used
Mental health and well-being		
Children's Depression Inventory (age 12+)	2002, 2007	2002
K-6 Nonspecific Psychological Distress Scale (TA only; age 18+)	2005, 2007	
Physician diagnosis of serious emotional disturbance	1997, 2002	
Physician diagnosis of depression (TA only; age 18+)	2007	
Global self-concept (CDS version; age 8+ in 1997, age 10+ in 2002, 2007)	1997, 2002, 2007	
Global self-concept compared to others (TA version; age 18+)	2005, 2007	
Emotional well-being subscale (age 12+)	2002, 2007	
Psychological well-being subscale (age 12+)	2002, 2007	
Social well-being subscale (age 12+)	2002, 2007	
Behaviors		
Behavior Problems Index (age 19)	1997, 2002, 2007	1997, 2002
Internalizing Behaviors subscale	1997, 2002, 2007	
Externalizing Behaviors subscale	1997, 2002, 2007	
Categories of # arrests (age 12+)	2002, 2005 (TA), 2007	
Drunk driving past 6 mos (age 12+)	2007	
Rode w/drunken driver past 6 mos (age 12+)	2007	
How often wear seatbelt (age 10+)	2002	
Did something dangerous past 6 mos just for thrill (TA only)	2005, 2007	
Regular smoker (age 11+)	2002, 2007	
Friend influences (CDS version; 9.5 age 19)	2002, 2007	
Friend influences (TA version; age 18+)	2005, 2007	
Friend influences (CDS & TA combined)	2007	
Schooling		
Years completed schooling	1997, 2002, 2007	
Degrees completed	2007	
Ever repeated a grade	1997	1997
Whether in school	2002, 2007	2002
Type of school	1997, 2002	1997, 2002
Changed school during current school year	1997, 2002	1997, 2002
Academic achievement		
Academic achievement score	1997, 2002	1997, 2002
Primary caregiver's achievement score	1997	1997

Table A2

Distributions of characteristics in original and imputed samples

Characteristic	Original sample		Imputed sample
	N or range	% ^a or mean (SE ^b)	% or mean (SE ^b)
Total	2546	---	63,650
Female	1248	51	51
Age in years 1997	3.0–13.9	8.5 (0.059)	8.5 (0.059)
Missing	0	0	---
Age in years 2002	7.8–19.3	14.0 (0.068)	14.0 (0.068)
Missing	679	679	---
Age in years 2007	12.8–24.0	19.0 (0.068)	18.9 (0.059)
Missing	671	671	---
Race/Hispanicity			
non-Hispanic white	1160	46	46
non-Hispanic black	1063	42	42
Hispanic	193	8	8
Other race	127	5	5
Missing	3	<1	---
Number of parent figures live with 1997			
0	24	1	1
1	756	30	30
2	1762	69	69
Missing	4	<1	---
Number of parent figures live with 1997			
0	3	<1	7
1	621	30	31
2	1438	70	62
Missing	484	19	---
Marital status of head of household 1997			
Married	1606	63	63
Never married	406	16	16
Divorced/Separated/Widowed	533	21	21
Missing	1	<1	---
HOME scale 1997	8.8–24.0	18.9 (0.058)	18.7 (0.058)
Family income/poverty ratio 1996	0–36.9	2.9 (0.068)	2.9 (0.068)
Missing	0	0	---
Family income/poverty ratio 2002	0–111.6	3.7 (0.13)	3.4 (0.13)
Missing	186	7	---
Maximum of caregivers' completed years education 1997	3–17	13.2 (0.062)	13.2 (0.061)
<9	84	3	3
9–11	234	9	9
12	897	36	35

Characteristic	Original sample		Imputed sample
	N or range	% ^a or mean (SE ^b)	% or mean (SE ^b)
13–15	694	28	28
16	613	24	24
Missing	24	1	---
Caregiver achievement score	4–43	30.6 (0.16)	30.4 (0.14)
Missing	631	25	---
Neighborhood as place to raise children 1997			
Excellent	427	27	27
Very good	481	30	30
Good	408	26	27
Fair/Poor	263	17	17
Missing	967	38	---
Neighborhood as place to raise children 2002			
Excellent	621	30	31
Very good	633	31	29
Good	450	22	22
Fair/Poor	345	17	17
Missing	497	20	---
Urbanicity 1997			
Central county, metropolitan area 1M	754	30	30
County, metropolitan area 250K	1044	41	41
Area <250K	748	29	29
Region 1997			
Northeast	362	14	14
North Central	624	25	25
South	1152	45	45
West	407	16	16
Missing	1	<1	---
Primary caregiver-rated health compared to other babies at birth			
Same	1633	65	65
Better	662	26	26
Worse	225	9	9
Missing	26	1	---
Low birth weight (<2500 g)	219	9	9
Missing	62	2	---
Spent time in NICU after birth	313	12	12
Missing	38	1	---
Number overnight hospital stays birth–1997			
0	1912	75	75
1–2	519	20	20
3	107	4	4

Characteristic	Original sample		Imputed sample
	N or range	% ^a or mean (SE ^b)	% or mean (SE ^b)
Missing	8	<1	---
Number overnight hospital stays 1997–2002			
0	1859	90	89
1–2	171	8	9
3	31	2	2
Missing	485	19	---
Routine physician check-up 1996–1997	1952	78	78
Missing	40	2	---
Routine physician check-up in 2001–2002	1713	84	83
Missing	507	20	---
Primary caregiver-rated health 1997			
Excellent	1237	49	49
Very good	814	32	32
Good	410	16	16
Fair	65	3	3
Poor	5	<1	<1
Missing	15	<1	---
Primary caregiver-rated health 2002			
Excellent	1090	53	47
Very good	653	32	32
Good	257	12	13
Fair	56	3	3
Poor	6	<1	5
Missing	484	19	---
Self-rated health 2007			
Excellent	464	25	25
Very good	725	39	32
Good	518	28	28
Fair	152	8	10
Poor	14	1	5
Missing	673	26	---
BMI percentile 1997	0–100	59 (0.78)	59 (0.78)
<5 (underweight)	271	12	13
5–84.9 (normal)	1238	54	52
85–94.5 (overweight)	325	14	14
95 (obese)	459	20	21
Missing	253	10	---
BMI percentile 2002	0–100	66 (0.75)	66 (0.79)
< 5 (underweight)	49	3	5
5–84.9 (normal)	1102	60	55

Characteristic	Original sample		Imputed sample
	N or range	% ^a or mean (SE ^b)	% or mean (SE ^b)
85–94.5 (overweight)	288	16	17
95 (obese)	399	22	23
Missing	708	28	---
BMI status 2007 (age < 21/age 21+)			
< 5 th percentile/<18.5 (underweight)	60	3	5
5–84.9 th percentile/18.5–24.9 (normal)	1035	56	53
85–94.5 th percentile/25–29.9 (overweight)	394	21	22
95 th percentile/ 30 (obese)	347	19	20
Missing	710	28	---
Children's Depression Inventory 2002 (age 12+)	0–18	3.0 (0.092)	3.5 (1.27)
Missing	566	22	---
Too young to be asked question ^c	725	28	21
K-6 Non-Specific Psychological Distress Scale 2007 (age 18+)	0–23	5.2 (0.11)	5.2 (0.17)
Missing	522	21	---
Too young to be asked question ^c	911	36	35
Behavior Problems Index 1997	0–27	8.0 (0.13)	8.0 (0.13)
Missing	102	4	---
Behavior Problems Index 2002	0–30	8.7 (0.16)	8.7 (0.15)
Missing	509	20	---
Ever repeated a grade 1997	159	6	7
Missing	67	3	---
Changed school during current school year 1997	129	5	5
Missing	49	2	---
Changed school during current school year 2002	122	6	6
Not in school	29	1	8
Missing	513	20	---
Type of school 1997			
Public	1867	90	81
Private	188	9	8
Home	17	1	11
Missing	474	19	---
Type of school 2002			
Public	1784	91	78
Private	126	6	5
Home	28	1	9
Not in school	29	1	8
Missing	579	23	---
Academic achievement 1997	40.5–163.0	104.3 (0.42)	104.4 (0.40)
Missing	745	29	---
Academic achievement 2002	42.0–169.5	102.2 (0.42)	101.9 (0.39)

Characteristic	Original sample		Imputed sample
	N or range	% ^a or mean (SE ^b)	% or mean (SE ^b)
Missing	691	27	---
Mean academic achievement 1997–2002	42.0–169.5	103.1 (0.37)	103.1 (0.36)
Missing	316	12	---
Change in academic achievement 1997–2002	–48.0–72.5	–2.6 (0.35)	–2.5 (0.32)
Missing	1120	44	---

^aTo facilitate comparison with the imputed sample, the denominators for percents for nonmissing categories include only observations with nonmissing information. To facilitate interpretation, denominators also exclude participants ineligible to be asked the question because of age.

^bStandard error of the mean.

^cEstimated from age in 1997 for participants missing from this wave

CONSTRUCTION OF TREATMENT WEIGHTS

To estimate the marginal structural models, each participant was assigned a treatment weight sw_i that was constructed using the equation:

$$sw_i = \prod_{t=1}^2 \frac{f(A(t)=a_i(t) | A(t-1)=a_i(t-1), V=v_i)}{f(A(t)=a_i(t) | A(t-1)=a_i(t-1), L(t)=l_i(t))}$$

where each term's numerator $f(A(t)=a_i(t) | A(t-1)=a_i(t-1), V=v_i)$ is the probability density of participant i 's academic achievement score at time-point t , conditional on his or her history of academic achievement through time-point $t-1$ (so $A(1)$ was 1997 academic achievement and $A(0)$ was set to zero) and values of time-invariant baseline covariates V . In the denominator, V is replaced by $L(t)$, the history of both baseline and time-varying covariates through time t (V is included in $L(1)$) [26, 35].

Included in V were sex, race, baseline age, perinatal health (whether the child was low birth weight [< 88 ounces] and the primary caregiver's assessment of the child's health at birth), an interviewer-assessed scale of cognitive stimulation and emotional support provided in the participant's home at baseline (using selected items from Caldwell and Bradley's Home Observation for the Measurement of The Environment [HOME] scale) [46], whether the participant had ever repeated a grade in school, and the primary caregiver's achievement score. In addition, the following variables with time-varying information but very high correlation or agreement between 1997 and 2002 were treated as time invariant and therefore also included in V : the maximum of the child's caregivers' years of schooling, geographical region, and urbanicity. In addition to the variables included in V , $L(t)$ also included time-varying information on family income (measured as a family income-to-poverty-level ratio in which the annual household income was divided by the corresponding annual U.S. Census Bureau poverty threshold, which takes into account family size and the ages of family members [47]), whether the child lived with two parent figures, a caregiver-rated measure of how good a place the neighborhood where the family resided was to raise

children, health (global health status, body mass index [BMI], number of overnight hospital stays), whether the child had a routine physician check-up in the previous two years, a scale of the caregiver's report of problem behaviors (including both aggressive and withdrawn or sad behaviors), school type (public, private, home, not in school), and whether the child changed schools during the current school year. In models of psychological distress, the log of the 2002 CDI score was additionally included as a time-dependent confounder. Since academic achievement was a normally distributed continuous measure, the conditional numerator and denominator probability densities were estimated using linear regression and the normal probability density function [26, 34].

In order to produce a reasonable distribution of weights for the MSMs of global health status and BMI, (i.e., mean approximately 1 and reasonable range), we trimmed the weights separately for each imputation at their 3rd-highest and 3rd-lowest values, resulting in a total range of 0.07–32.97 and imputation-specific means ranging 1.00–1.05. Because the distribution of weights for the psychological distress models was more unstable, we trimmed them at the 1st and 99th percentiles, resulting in imputation-specific means ranging 0.99–1.01 and a total range 0.25–2.73. Further trimming the weights produced nearly identical estimates.

Table A3

Tests of preconditions for the outcome of 2007 poorer self-rated health status

Precondition	In This Case	Tests	Conclusions
Key time-varying covariates predict exposure	Does health predict academic achievement?	Adjusted linear regression of 1997 academic achievement on perinatal health (low birth weight, spent time in NICU, caregiver-rated health compared to other babies) & 1997 health (caregiver-rated health status, nights spent in hospital birth-1997). Adjusted linear regression of 2002 academic achievement on perinatal health, 1997 health, and 2002 health (caregiver-rated health status, nights spent in hospital 1997-2002).	In general, poorer health predicts lower academic achievement. For 1997 achievement, point estimates are driven by NICU and are stronger for perinatal health than 1997 health. For 2002 achievement, perinatal health is stronger predictor than 1997 or 2002 health.
Exposure predicts key time-varying covariates	Does academic achievement predict future health?	Adjusted logistic regression of 2002 poorer caregiver-rated health status on 1997 academic achievement. Adjusted logistic regression of 2007 poorer self-rated health status on 1997 and 2002 academic achievement.	In general, higher academic achievement predicts lower odds of poorer health. Stronger evidence for 2007 self-rated health status than 2002 caregiver-rated health status.
Key time-varying covariates predict outcome independent of exposure	Does past health predict 2007 health independent of academic achievement?	Adjusted logistic regression of 2007 poorer self-rated health status on perinatal, 1997, and 2002 health measures, with average 1997–2002 academic achievement included as a covariate	Poorer previous health weakly predicts 2007 poorer self-rated health independent of academic achievement.
Exposure and key time-varying	Do academic achievement and	Correlation between 1997 and 2002 academic achievement.	Academic achievement and health status do vary over time.

Precondition	In This Case	Tests	Conclusions
covariates vary over time	health vary over time?	Agreement between 1997, 2002, and 2007 poorer health status measures.	

Figure A1. Empirical support for hypothesized causal paths linking academic achievement and health status

Results are from tests described in Table A3 and describe the direction and strength of associations. Parentheses indicate weak associations.

Figure 1.

Assumed causal structure of health and academic achievement

Academic achievement is assumed to be influenced by health at each time-point, and in turn to influence health at future time-points.

Figure 2.

Study sample from Child Development Supplement (CDS) and Transition into Adulthood (TA) supplemental studies to the Panel Study of Income Dynamics, 1997–2007

Table 1

Mean academic achievement score and 2007 health status by category of selected predictors (N = 2546)^a

	Sample percent	Mean academic achievement 1997–2002		Poorer self-rated health status 2007 ^b	
		Mean	p ^c	Percent	p ^d
Total	--	101.9	--	43	--
Sex			0.28		0.05
Male	51	102.8		40	
Female	49	103.5		46	
Age at 1997 interview (years)			0.20		0.21
3–5	18	103.1		47	
6–8	31	103.0		43	
9–11	31	103.9		39	
12–14	20	102.0		44	
Race/Hispanicity			<0.001		0.33
non-Hispanic white	46	108.4		42	
non-Hispanic black	42	97.7		42	
Hispanic	8	100.5		47	
Other	5	104.4		50	
Number of parent figures live with 1997			<0.001		0.40
0	1	96.2		50	
1	30	98.7		45	
2	69	105.1		42	
Primary caregiver achievement score quartile 1997			<0.001		0.59
1 (4.0–26.99)	23	96.3		43	
2 (27.0–30.99)	25	100.7		44	
3 (31.0–34.27)	27	105.2		43	
4 (34.28–43.0)	25	109.6		40	
Family income/poverty ratio 1996			<0.001		0.003
0–0.9	21	96.8		48	
1–1.9	22	99.9		46	

	Sample percent	Mean academic achievement 1997–2002		Poorer self-rated health status 2007 ^b	
		Mean	p ^c	Percent	p ^d
2–4.9	44	104.9		42	
5	13	112.2		33	
Maximum of caregivers' completed years schooling 1997			<0.001		0.03
<9	3	97.1		51	
9–11	9	96.0		51	
12	35	99.7		44	
13–15	28	103.1		40	
16	24	111.7		39	
Primary caregiver-rated health compared to other babies at birth			<0.001		0.34
Better	26	105.2		41	
Same	65	102.8		43	
Worse	9	99.6		48	
Low birth weight (<2500 g)			<0.001		0.68
Yes	9	98.6		41	
No	91	103.6		43	
Primary caregiver-rated health 1997			<0.001		0.03
Very good	81	104.1		42	
Poorer	19	99.1		48	
Primary caregiver-rated health 2002			<0.001		0.03
Very good	78	104.1		41	
Poorer	22	99.7		49	
Self-rated health 2007			0.001		--
Very good	57	104.3		--	
Poorer	43	101.6		--	
BMI percentile 1997			<0.001		0.008
< 5 (underweight)	13	99.8		41	
5–84.9 (normal)	52	104.6		40	
85–94.5 (overweight)	14	103.3		41	
95 (obese)	21	101.2		50	

	Sample percent	Mean academic achievement 1997–2002		Poorer self-rated health status 2007 ^b	
		Mean	p ^c	Percent	p ^d
BMI percentile 2002			0.001		<0.001
< 5 (underweight)	5	101.7		38	
5–84.9 (normal)	55	104.1		37	
85–94.5 (overweight)	17	103.6		46	
95 (obese)	23	100.7		56	
BMI status 2007 (age 21/21+)			<0.001		<0.001
< 5th percentile/<18.5 (underweight)	5	102.4		45	
5–84.9th percentile/18.5–24.9 (normal)	53	104.6		36	
85–94.5/25–29.9 (overweight)	22	101.8		46	
95th percentile/ 30 (obese)	20	100.9		57	
Children's Depression Inventory quartile 2002 (age 12+)			0.03		0.04
1	19	105.5		36	
2	31	103.7		39	
3	24	103.0		44	
4	25	101.8		47	
K-6 Non-Specific Psychological Distress Scale quartile 2007 (age 18+)			0.03		<0.001
1	25	103.0		34	
2	27	104.9		40	
3	23	102.6		45	
4	25	101.7		52	

^aUses imputed data.^bGood/fair/poor (vs. excellent/very good).^cFrom unadjusted linear regression with clustering by sibling pair.^dFrom unadjusted logistic regression with clustering by sibling pair.

Table 2

Prevalence ratios of poorer self-rated health 2007 for 1-standard-deviation^a higher average academic achievement 1997–2002, by sex

Model Type	Covariates	Combined			Boys			Girls			Interaction p
		PR	95% CI	p	PR	95% CI	p	PR	95% CI	p	
Unweighted	None	0.90	(0.84, 0.97)	0.004	0.94	(0.85, 1.03)	0.20	0.86	(0.78, 0.95)	0.002	0.17
Unweighted	Baseline ^b	0.91	(0.84, 0.99)	0.03	0.95	(0.85, 1.06)	0.35	0.87	(0.79, 0.97)	0.01	0.20
Unweighted	Baseline and time-varying ^c	0.93	(0.85, 1.01)	0.08	0.96	(0.86, 1.07)	0.47	0.89	(0.81, 0.99)	0.04	0.27
MSM	Baseline ^b	0.91	(0.83, 1.00)	0.05	0.96	(0.86, 1.08)	0.49	0.87	(0.78, 0.97)	0.01	0.12

^aStandard deviation was calculated separately for each imputation. Values ranged 14.7–15.1, with a mean of 14.9.

^bModel includes baseline age, sex, race, perinatal health, caregiver education, number of parents in household, HOME scale, household income, region, urbanicity, whether the child had repeated a grade, and the primary caregiver's achievement score as covariates.

^cModel includes baseline adjustment variables + time-varying measures of family income, neighborhood rating, health status, overnight hospital stays, BMI percentile, problem behaviors, school type, and whether the child switched schools in the current year.

Table 3

Percent difference in 2007 BMI associated with 1-standard-deviation higher average academic achievement 1997–2002^a, by sex

Model Type	Covariates	Combined			Boys			Girls		
		Diff	95% CI	p	Diff	95% CI	p	Diff	95% CI	p
Unweighted	None	-1.83	(-2.89, -0.77)	<0.001	-1.08	(-2.51, 0.37)	0.14	-2.70	(-4.13, -1.24)	<0.001
Unweighted	Baseline ^b	-0.88	(-2.07, 0.31)	0.15	-0.26	(-1.76, 1.25)	0.73	-1.58	(-3.07, -0.07)	0.04
Unweighted	Baseline and time-varying ^c	-0.52	(-1.51, 0.50)	0.30	-0.19	(-1.35, 0.97)	0.74	-0.90	(-2.13, 0.35)	0.16
MSM	Baseline ^b	-0.71	(-1.98, 0.58)	0.28	-0.14	(-1.60, 1.35)	0.86	-1.36	(-3.12, 0.44)	0.14
										0.24

^a Calculated from coefficients and 95% confidence intervals from linear regression of the natural log of BMI using the formula: % difference = $100 \times (\exp(b) - 1)$. Standard deviation of average academic achievement was calculated separately for each imputation. Values ranged 14.7–15.1, with a mean of 14.9.

^b Model includes baseline age, sex, race, perinatal health, caregiver education, number of parents in household, HOME scale, household income, region, urbanicity, whether the child had repeated a grade, and the primary caregiver's achievement score as covariates.

^c Model includes baseline adjustment variables + time-varying measures of family income, neighborhood rating, health status, overnight hospital stays, BMI percentile, problem behaviors, school type, and whether the child switched schools in the current year.

Table 4

Prevalence ratios of serious psychological distress for 1-standard-deviation higher average academic achievement 1997–2002^a, by sex

Model Type	Covariates	Combined			Male			Female			Interaction p
		PR	95% CI	p	PR	95% CI	p	PR	95% CI	p	
Unweighted	None	0.84	(0.73, 0.97)	0.02	0.92	(0.76, 1.12)	0.39	0.77	(0.61, 0.95)	0.02	0.24
Unweighted	Baseline ^b	0.89	(0.76, 1.05)	0.16	0.95	(0.77, 1.17)	0.65	0.82	(0.65, 1.04)	0.10	0.34
Unweighted	Baseline and time-varying ^c	0.91	(0.77, 1.07)	0.26	0.97	(0.78, 1.20)	0.76	0.85	(0.67, 1.07)	0.17	0.40
MSM	Baseline ^b	0.91	(0.76, 1.07)	0.25	0.98	(0.79, 1.22)	0.85	0.82	(0.64, 1.05)	0.12	0.28

^aIncludes only participants aged at least 18 years in 2007: N = 36,293 in imputed sample, including information for 1475 participants. Standard deviation was calculated separately for each imputation based on the entire sample. Values ranged 14.7–15.1, with a mean of 14.9.

^bModel includes baseline age, sex, race, perinatal health, caregiver education, number of parents in household, HOME scale, household income, region, urbanicity, whether the child had repeated a grade, and the primary caregiver's achievement score as covariates.

^cModel includes baseline adjustment variables + time-varying measures of family income, neighborhood rating, health status, overnight hospital stays, BMI percentile, problem behaviors, childhood depression scale (2002), school type, and whether the child switched schools in the current year.