Epidemiology Publish Ahead of Print

DOI: 10.1097/EDE.0000000000001799

State Schooling Policies and Cognitive Performance Trajectories: A Natural Experiment in a National US Cohort of Black and White Adults

Min Hee Kim [a*], Sze Yan Liu[b], Willa D. Brenowitz[c,d], Audrey R. Murchland[e], Thu T. Nguyen[f] Jennifer J. Manly[g], Virginia J. Howard[h], Marilyn D. Thomas[d], Tanisha Hill-Jarrett[i], Michael Crowe [j], Charles F. Murchison[k], M. Maria Glymour[d,l]

[a] University of California San Francisco, Philip R. Lee Institute for Health Policy Studies, San Francisco, California, USA

[b] Montclair State University, Public Health Department, Montclair, New Jersey, USA

[c] Center for Health Research, Kaiser Permanente Northwest, Oregon, Portland, USA

[d] University of California San Francisco, Department of Epidemiology and Biostatistics, San Francisco, California, USA

[e] Harvard T.H. Chan School of Public Health, Boston, Massachusetts, USA

[f] Department of Epidemiology and Biostatistics, University of Maryland School of Public Health, College Park, MD USA

[g] Columbia University, Department of Neurology and Taub Institute for Research on Alzheimer's Disease and the Aging Brain, Vagelos College of Physicians and Surgeons, New York City, New York, USA

[h] University of Alabama at Birmingham, Department of Epidemiology, School of Public Health, Birmingham, Alabama, USA

[i] University of California San Francisco, Department of Neurology, Memory and Aging Center San Francisco, California, USA

Downloaded from http://journals.lww.com/epidem by BhDMf5ePHKav1zEoum1tQfN4a+kJLhEZgbsIHo4XMi0hCywCX1AWnYQp/IlQrHD3i3D0OdRyi7TvSFl4Cf3VC4/OAVpDDa8KKGKV0Ymy+78= on 11/19/2024

ACCEPTED

Copyright © Wolters Kluwer Health, Inc. All rights reserved. Unauthorized reproduction of this article is prohibited

[j] University of Alabama at Birmingham, Department of Psychology, Birmingham, Alabama, USA

[k] University of Alabama at Birmingham, Department of Neurology, Alzheimer's Disease Research Center, and Department of Biostatistics, School of Public Health, Birmingham, Alabama, USA

[l] Boston University, Department of Epidemiology, School of Public Health, Boston, Massachusetts, USA

Corresponding author Min Hee Kim Mailing address: Rutgers Center for Health Services Research, 112 Paterson Street, 3rd Floor, New Brunswick, NJ 08901Email: minhee.kim214@rutgers.edu | Phone: 734-358-3069

Suggested running head: US State Schooling Policies and Cognitive Trajectories

Ethics approval

This study did not require ethics approval as it used de-identified data.

Funding

This work was supported by the National Institute of Health [K99AG078405-01 to Kim; K01AG062722 to Brenowitz; T32AG078115 to Hill-Jarrett; K99AG076973-01 and UL1GM118985 to Thomas; P20AG068024 to Murchison; R01AG039588 to V. Howard; R00MD012615 and R01MD015716 to Ngyuen]. The REGARDS research project is supported by cooperative agreement U01 NS041588 co-funded by the National Institute of Neurological Disorders and Stroke (NINDS) and the National Institute on Aging (NIA), National Institutes of Health, Department of Health and Human Service. The content is solely the responsibility of the authors and does not necessarily represent the official views of the funders. Representatives of

ACCEPTED

Copyright © Wolters Kluwer Health, Inc. All rights reserved. Unauthorized reproduction of this article is prohibited

the NINDS were involved in the review of the manuscript but were not directly involved in the collection, management, analysis or interpretation of the data.

Acknowledgment

The authors thank the other investigators, the staff, and the participants of the REGARDS study for their valuable contributions. A full list of participating REGARDS investigators and institutions can be found at: https://www.uab.edu/soph/regardsstudy/. Authors also like to thank anonymous reviewers for their invaluable feedback.

Conflict of Interest

None declared

Data and Coding Availability

The REGARDS data are accessible through the official website contingent upon the policies and procedures in place. Other data are available from the corresponding and senior authors on reasonable request. The Stata code for the analyses is available on the following repository: https://github.com/kminhee/education_cognition_TSIV.

Word counts for Abstract: 250

Word counts for Main text: 4023

ACCEPTED

Copyright © Wolters Kluwer Health, Inc. All rights reserved. Unauthorized reproduction of this article is prohibited

Abstract

Background

Education is strongly associated with cognitive outcomes at older ages, yet the extent to which these associations reflect causal effects remains uncertain due to potential confounding.

Methods

Leveraging changes in historical measures of state-level education policies as natural experiments, we estimated the effects of educational attainment on cognitive performance over 10 years in 20,248 non-Hispanic Black and non-Hispanic White participants, aged 45+ in the REasons for Geographic and Racial Disparities in Stroke (REGARDS) cohort (2003-2020) by (1) using state- and year- specific compulsory schooling laws, school-term length, attendance rate, and student-teacher ratio policies to predict educational attainment for US Census microsample data from 1980 and 1990, and (2) applying policy-predicted years of education (PPYEd) to predict memory, verbal fluency, and a cognitive composite. We estimated overall and race- and sex-specific effects of PPYEd on level and change in each cognitive outcome using random intercept and slope models, adjusting for age, year of first cognitive assessment, and indicators for state of residence at age 6.

Results

Each year of PPYEd was associated with higher baseline cognition (0.11 standard deviation [SD] increase in composite measure for each year of PPYEd, 95% confidence interval [CI]: 0.07, 0.15). Subanalyses focusing on individual cognitive domains estimate the largest effects of PPYEd on memory. PPYEd was not associated with rate of change in cognitive scores. Estimates were similar across Black and White participants and across sex.

Copyright © Wolters Kluwer Health, Inc. All rights reserved. Unauthorized reproduction of this article is prohibited

Conclusions

Historical policies shaping educational attainment are associated with better later life memory, a major determinant of dementia risk.

Keywords: natural experiment, longitudinal analysis, health disparities, cognition, cognitive aging, education

ACCEPTED

Copyright © Wolters Kluwer Health, Inc. All rights reserved. Unauthorized reproduction of this article is prohibited

Introduction

Education is a potentially powerful modifiable resource for dementia prevention and population health. Education predicts better cognitive performance, memory function, life expectancy free of cognitive symptoms due to Alzheimer's Disease and Related Dementias (ADRD), and delayed onset of ADRD.[1-5] However, the extent to which these associations are causal remains uncertain. Most evidence on education and cognition associations may be biased, because many unmeasured individual and family characteristics influence both educational attainment and cognitive performance.[5] To avoid this bias, prior research has adopted natural experiments such as changes in compulsory schooling laws affecting specific birth cohorts.[6] Improvements in these laws have been shown to increase educational attainment in many countries and can be used as instrumental variables (IVs) to circumvent correlation of individual or family level confounders with education and later life cognition. Prior studies using changes in compulsory schooling laws have found mixed evidence around their relationship with dementia risk[7,8] but have consistently demonstrated higher educational attainment to be associated with later life memory performance.[9-11]

Despite persuasive evidence from compulsory schooling laws on the causal effects of education on cognition in older adults, several gaps remain. In the US, prior work focused on older adults who were self-identified as White;[12] this work was not extended to Black adults due to evidence that school mandates were not consistently enforced for Black children across the US.[13] Given the racial inequalities in cognitive outcomes in older Americans,[14] accurate understanding of causal effects of education on Black Americans' later life cognitive health is necessary to guide efforts to narrow disparities. Research using policy or contextual determinants of educational attainment, in addition to CSLs, is needed. Further, no prior study to our knowledge has

ACCEPTED

Copyright © Wolters Kluwer Health, Inc. All rights reserved. Unauthorized reproduction of this article is prohibited

evaluated whether quasi-experimental variation in educational attainment is associated with memory decline. Observational studies find inconsistent evidence on the link between education and cognitive change, but such analyses may be spuriously attenuated by measurement error when using self-reported education as an explanatory variable.[15] The IV analytic methods that avoid confounding can also correct for bias due to random measurement error in education. Older Black Americans received schooling prior to Brown v. Board decision. Schools in the US South that were designated to serve Black children averaged shorter term lengths, higher student-teacher ratios, and lower attendance ratios, among other indicators of lower-quality education.[16,17] These characteristics varied at the state level and influenced educational attainment of both Black and White children.[21]

In the current study, we evaluated the association of state policy changes that served to increase quantity and quality of education with levels and changes in cognitive performance in a large national sample of non-Hispanic Black and non-Hispanic White older adults. We leveraged geographic and temporal variations in educational policies and contexts, including compulsory schooling laws and other state-level measures of educational quality, and applied IV methods. We analyzed the association within race and sex groups, hypothesizing that Black men in particular may not have been provided the opportunities to impart educational gains into occupational or health benefits comparable to those accessible to Black women or White men and women.[18,19]

Methods

This study involved analysis of de-identified, publicly available data and did not meet the criteria for human subjects research; thus, it was exempt from ethical oversight by Institutional Review Board.

Copyright © Wolters Kluwer Health, Inc. All rights reserved. Unauthorized reproduction of this article is prohibited

ACCEPTED

Data

The REasons for Geographic and Racial Differences in Stroke (REGARDS) study is a prospective cohort of 30,239 US community-dwelling non-Hispanic Black and White individuals. REGARDS oversampled Blacks and residents of the southern Stroke Belt, who may have remained living in those states throughout their lifetime. Participants were 45 years or older at enrollment in 2003-2007 and subsequently followed.[20] Since 2006, the study fielded a battery of three cognitive tests biennially. A residential history questionnaire was used to link state of residence at age 6 with historical state policies on school quality and compulsory schooling that prevailed in that state in the year the individual turned 6. Among 24,570 respondents who provided complete residential history with information on state they lived in at age 6, our final analytical sample consisted of 20,248 participants (born between 1910 and 1962), who were stroke-free at the first cognitive assessment with non-missing values for covariates and outcomes (Details in the Supplementary Appendix, eFigure 1; http://links.lww.com/EDE/C188). Respondents had a median of four cognitive assessments over 8.6 years (range: 0-14.7 years), for n=85,705 total observations. Our school policy data, covering 1910-1968, came from previously complied data on Compulsory Schooling Laws[12,13,21] and the Federal Digest of Educational Statistics.

Variables

Exposure: Our exposure of interest is self-reported number of years of schooling. Participants reported either years of schooling (if less than high school) or college attendance and degree completion (if high-school or more). We converted reported degrees to typical years of schooling required for that degree as: 12 (high school), 13 (some college but no degree), 14 (Associate's degree), 16 (Bachelor's degree), or 18 (any graduate degree).

Copyright © Wolters Kluwer Health, Inc. All rights reserved. Unauthorized reproduction of this article is prohibited

ACCEPTED

IVs: We constructed a summary measure of state- and year-specific indicators of educational context, including number of years mandated to attend school before dropping out; number of years mandated to attend school before obtaining a work permit; days in academic year (term length); average days of attendance among enrolled children divided by term length (attendance rate); and ratio of students to instructional staff (student-teacher ratio). For states/years with *de jure* segregation (where we created an indicator for whether the state had legal racial segregation in that year), we constructed separate quality measures (i.e., one quality indicator for schools serving Black children and the other quality indicator for schools serving White children). We used both groups of quality measures to predict educational attainment. We estimated the summary measure referred to as Policy Predicted Years of Education (PPYEd) from a linear regression model in US Census data, which we described below.

Outcomes: REGARDS administered a three-test battery of domain-specific assessments by telephone every 2 years from January 2006. In the current analyses, we used the learning and memory assessments by the Word List Learning (WLL) and Word List Delayed Recall (WLDR) from the Consortium to Establish a Registry for Alzheimer's Disease (CERAD) and the Animal Fluency Test (AFT). We used three learning trials of WLL, each assessing whether respondents recalled a list 10 semantically unrelated words (the score range is 0-30), followed by WLDR, where participants recalled as many words as possible after a 5-minute delay (the score range is 0-10). The AFT asked participants to name as many animals as they could in 1 minute (range 0-59). During the first 2 years of data collection, some participants had multiple assessments per domain collected unevenly across the period; for these cases, we averaged an individual participant's scores for each measure across 2006-2007 to obtain a domain-specific score during this time frame (the more recent assessment date was used as participant's baseline). To improve

Copyright © Wolters Kluwer Health, Inc. All rights reserved. Unauthorized reproduction of this article is prohibited

interpretability, we standardized domain-specific cognitive measures at baseline values creating three z-scores. We averaged those z-scores to create a composite measure.

Covariates: State of residence at age 6 years, year of birth, race, age at first cognitive assessment (i.e., baseline), and baseline year were recorded. State-level time-varying covariates compiled from Statistical Abstracts of the United States (1919-1970) included proportion of residents who were Black (according to the US Census's classification of race[22]), urban living, and foreign-born (when the respondents were age 6); manufacturing jobs per capita and manufacturing wages per manufacturing job when the respondents were age 14 (We assumed respondents resided in the same state at age 14 that they resided in at age 6).

Analytic method

Two-Sample Instrumental Variable Analysis

We used a quasi-experimental method to estimate a causal effect of educational attainment on baseline cognitive function and cognitive change over time. Following prior work in REGARDS,[23] we used a two-sample, two-stage least squares IV estimator. This method uses separate data sources to estimate the instrument–exposure association and the instrument–outcome association with the advantage of avoiding overfitting the first stage, therefore avoiding weak instruments bias.[24,25]

The first-stage estimates were developed and reported previously,[23] using the 1980 and 1990 US Census 5% microsample from Integrated Public Use Microdata Series (IPUMS) USA (N= 11,160,031).[23] We predicted educational attainment using all the state level measures of educational context described above, moderated by race to reflect racialized educational system.[13] We matched educational context measures for each birth state cohort to US Census

ACCEPTED

Copyright © Wolters Kluwer Health, Inc. All rights reserved. Unauthorized reproduction of this article is prohibited

reports based on year the cohort would have been affected, e.g., year when turned age 6 for defining age at school entry; year turned age 14 for defining year of dropout; and year of age 14 for defining quality measures. Covariates included were race, birth year, birth year-race interaction, sex, and state indicators. This model fit was used to predict PPYEd for each race, sex, birth year, and birth state stratum. Conditional on the covariates, PPYEd is assumed to be unrelated to the individual-level confounders of the exposure-outcome association. (See Supplemental Methods for details.) The association of all school policy variables with years of education yielded an F statistic of 2,615, indicating IVs are strong exogenous estimators.

In the second stage, we assigned PPYEd values estimated from the census sample to our REGARDS analytical sample based on an individual's combination of state, race, sex, and birth year and used this PPYEd value as the exposure in predicting cognitive performance (composite measure, WLL, WLDR, AFT) at baseline and over time. We fitted mixed-effects models with random intercepts and slopes for the pooled sample and by race and sex. We used time since first cognitive assessment (scaled to decades) as the time scale in the analysis of change.[26] In linear models, we included baseline age, age squared, baseline year (to account for secular time trends), fixed effects of state of residence at age 6 (to reduce any confounding across states), and time interaction terms with these covariates. In the pooled sample model, we also adjusted for race and sex as well as race and age (and age squared) interaction terms, and sex and age (and age squared) interaction terms. We centered PPYEd at 12 months and re-scaled to 1-year increments to improve interpretation of coefficients. We reported results from mixed models using self-reported years of schooling as the exposure for cognitive outcomes. Stata 15.0 (StataCorp, 2017) code is posted on https://github.com/kminhee/education_cognition_TSIV.

Copyright © Wolters Kluwer Health, Inc. All rights reserved. Unauthorized reproduction of this article is prohibited

IV Assumptions and Validation.

Unbiased estimates in IV analyses hinge upon key assumptions, including relevance, exogeneity, exclusion restriction, and monotonicity. We implemented a series of sensitivity analyses to evaluate the plausibility of such assumptions and to validate our approach: (1) overidentification tests indicated no evidence of violation of the exclusion restriction assumption (eTable 1; http://links.lww.com/EDE/C188); (2) e-values for IV and reduced form estimates ranged 0.2 to 0.4 (eTable 2; http://links.lww.com/EDE/C188); and (3) graphical assessments for violations of the monotonicity assumption found no deviations beyond what would be expected by chance (eFigure 2; http://links.lww.com/EDE/C188). Also, we found (4) two data sources used in the first and second stages roughly comparable (eTable 3; http://links.lww.com/EDE/C188); (5) the application of a non-parametric bootstrap procedure demonstrated that uncertainty from the first stage contributes negligibly to the overall precision of estimates (eTable 4; http://links.lww.com/EDE/C188); and (6) although non-differential errors in the exposure measurement would introduce bias, within a plausible range of error, the bias would be quite small (eTable 5; http://links.lww.com/EDE/C188). As with all observational analyses, unproven assumptions remain, for example, there remains the possibility that the exclusion restriction assumptions might not be fully satisfied.

Secondary analysis

We carried out two types of secondary analysis to ensure robustness of our main findings. First, we estimated models adjusting for state characteristics during childhood to ensure the conditional independence of the IV. Second, we reported mixed model results using the exposure PPYEd where only state policies regarding educational quality were used in the first stage.

ACCEPTED

Copyright © Wolters Kluwer Health, Inc. All rights reserved. Unauthorized reproduction of this article is prohibited

Results

The average baseline age of REGARDS participants was 66.9 (SD 9.2) and 36.2% self-identified as Black (Table 1). The average self-reported years of education was 14.3 (SD 2.5), whereas the average PPYEd was 12.1 (SD 1.0). PPYEd was approximately a year less for Black adults than White individuals (Black males: 11.4; Black females: 11.4 vs. White males: 12.5; White females 12.4), reflecting a combination of lower quality in schools designated for Black children and the REGARDS study design, which oversampled from states with worse educational contexts overall.

Instrumental Variable Analysis

In the REGARDS samples, a 1-year difference in PPYEd was associated with a 0.61-year (95% confidence interval (CI): 0.58, 0.64) increase in self-reported schooling years (F statistic = 1387.40). Among Black men, a 1-year difference in PPYEd was associated with 0.44 years additional self-reported schooling; (CI: 0.34, 0.53, F=80.07); among Black women, the coefficient was 0. 50 (CI: 0.44, 0.57, F=217.72); among White men, the coefficient was 0.55 years (CI: 0.47, 0.62, F=209.29); and among White women, the coefficient was 0.63 years (CI: 0.56, 0.70, F= 321.67).

A one-unit increase in PPYEd was associated with 0.11 SD higher average composite cognition score in the pooled sample (CI: 0.07, 0.15) (Table 2). PPYEd was also associated with better Word List Learning ($\beta_{intercept}$=0.15; CI: 0.10, 0.20), Word List Delayed Recall ($\beta_{intercept}$=0.10, CI: 0.05, 0.15), and Animal Fluency ($\beta_{intercept}$=0.08; CI: 0.03, 0.13). In race/sex-specific models, PPYEd was associated with higher composite scores, with overlapping confidence intervals across race/sex groups (Table 3): Black men ($\beta_{intercept}$=0.11; CI: -0.01, 0.24), Black women ($\beta_{intercept}$=0.11; CI: 0.03, 0.20), White men ($\beta_{intercept}$=0.14; CI: 0.04,

Copyright © Wolters Kluwer Health, Inc. All rights reserved. Unauthorized reproduction of this article is prohibited

0.25), and White women ($\beta_{intercept}$= 0.08; CI: -0.03, 0.18). PPYEd estimates for domain-specific outcome levels were generally similar but had wide confidence intervals.

PPYEd was not associated with the rate of cognitive change over time in the pooled sample for either the composite or specific domain measures (Tables 2 & 3); estimates were generally small and most confidence intervals could not establish direction of effect. The exception was that higher PPYEd was associated with a slower decline in WLDR among White women (β_{slope}=0.16; CI: 0. 02, 0. 29).

Secondary analysis

In models using self-reported education as an exposure, years of schooling were associated with levels of cognition in race- and sex-stratified samples for both composite and domain-specific cognitive measures, where it was also associated with a faster decline in the composite and animal fluency measures (Table 2 & eTable 8; http://links.lww.com/EDE/C188). In models controlling for time-varying state covariates, estimates of the associations between PPYEd and levels of cognitive performance remained similar or were strengthened albeit with wider confidence intervals (Table 2 & eTable 6; http://links.lww.com/EDE/C188). Estimates between PPYEd, generated from only state educational quality variables, and levels of cognitive performance remained very similar to the main models (eTable 9; http://links.lww.com/EDE/C188), consistent with the reduced form results showing the relative strength of the quality variables in predicting the outcome (eTable 3; http://links.lww.com/EDE/C188).

Copyright © Wolters Kluwer Health, Inc. All rights reserved. Unauthorized reproduction of this article is prohibited

ACCEPTED

Discussion

Our analyses expanded on prior literature on the effect of education on later-life cognitive outcomes by using a natural experiment to circumvent confounding. In a large US sample of older Black and White adults, differences in years of education attributable to state differences in mandatory schooling and educational quality were associated with better overall cognitive performance decades later including better performance in memory and verbal fluency. Educational benefits were found for Black and White men and women, with little evidence that effects differed substantially by race or sex groups. IV-based estimates were moderately larger than estimates based on self-reported educational attainment. There was limited evidence that education slowed cognitive decline for any group.

Our findings confirm and extend previous analyses in the US Health and Retirement Study (HRS) reporting that increased education induced by states' mandatory schooling laws were associated with better memory performance[12] and lower dementia risk,[7] and in the Kaiser beneficiaries in Northern California, finding that residing in states in the top-tertile of education quality as a child, compared to bottom-tertile, was associated a lower dementia risk.[27] Our IVs included school quality measures, making the IVs more objectively relevant for older Black individuals, a critical feature because REGARDS includes more Black Americans than does HRS. The expanded set of IVs is an important advance compared to prior research based only on compulsory schooling laws, which were not uniformly enforced for Black children.[13] The IV effect estimates that we captured are a more holistic reflection of the educational benefits of investment in schools, beyond the effect measured by education attainment alone.

Previous literature on racialized group differences in effects of educational attainment on cognitive impairment, cognitive levels, and cognitive changes over time has been inconsistent.[28-

Copyright © Wolters Kluwer Health, Inc. All rights reserved. Unauthorized reproduction of this article is prohibited

[32] Mixed findings may reflect unmeasured aspects of educational quality influencing benefits of schooling.[33,34] Current generations of older Black adults were systematically denied access to high-quality educational opportunities due to de facto and de jure racial segregation, and racism within educational environments. Historical stratification of occupational and income opportunities by race and sex may modify potentially beneficial returns on education. [35,36] For example, the estimated associations between years of education and mental health were larger and had narrower confidence intervals for Black women than White men in the National Longitudinal Survey of Youth 1979 cohort.[18] Longer school term length predicted lower prevalence of hypertension and lower blood pressure among Black women, but not Black men or in White people overall in NHANES I and II.[19] Although we did not find evidence of differential effects of education on cognitive levels or changes within race and sex strata, confidence intervals were generally wide. Even if individual-level benefits of education for later-life cognitive outcomes are similar across racial groups, the potential population impact of improvements to educational access and quality is likely to be larger for Black Americans because a greater proportion of the Black population is exposed to limited educational resources. Prior work on the associations between education and change in cognition over time is limited due to its reliance on self-reported educational attainment, which has the potential for measurement error and unmeasured confounding that could attenuate education effects. While reported education was associated with a faster decline in the verbal fluency measure, our IV estimates were almost null in relation to cognitive change across all groups (although we estimated small protective effects for White women). This finding is consistent with prior observational estimates, reporting null or very small effect estimates for indicators of education on cognitive change.[4,5,37-40]

Copyright © Wolters Kluwer Health, Inc. All rights reserved. Unauthorized reproduction of this article is prohibited

ACCEPTED

We implemented a robust set of sensitivity analyses evaluating the validity of our approach and potential violations of the IV assumptions. Among other assumptions, IV estimates would be biased if there were unmeasured common aspects of state schooling policies associated with late-life memory performance. Yet, our adjustment for time-varying state characteristics strengthened the PPYEd estimates (eTable 6; http://links.lww.com/EDE/C188) and the adjusted e-value for the PPYEd estimate was 0.4 (eTable 2; http://links.lww.com/EDE/C188; a relatively large value given a year of education increases the average outcome by only about 0.10). Unmeasured confounders of the IV and outcome are unlikely to fully account for our results. Nonetheless, the political appetite for increases in schooling duration and quality is plausibly influenced by social and economic features of the population. Communities characterized by financial security, already high levels of education, occupational opportunities that require more education, and strong social cohesion states with greater wealth, social and economic redistributive measures for equity, or less structural racism may have invested more in public education earlier, influencing our estimates.[41]

Furthermore, IV estimates may be biased if schooling policies affect cognitive outcomes via mechanisms other than educational attainment. Estimated e-values for policy instruments ranged from 0.2 to 0.4 (eTable 3; http://links.lww.com/EDE/C188) and the inclusion of self-reported education did not fully attenuate estimates of the association between PPYEd and cognition (eTable 7; http://links.lww.com/EDE/C188); despite caveats in interpreting this attenuation, the finding suggests the exclusion restriction assumption may be violated. For example, education quality improvement over time could have spillover effects on community health or economic opportunity, which in turn would provide positive health benefits to residents regardless of each individual's formal schooling. Measurement error in attained schooling may also contribute to

Copyright © Wolters Kluwer Health, Inc. All rights reserved. Unauthorized reproduction of this article is prohibited

these results. Conversely, discrimination against Black students during and after the adoption of school integration policies (applicable to ~25% of our Black older adult sample born after 1946) could have a direct negative health impact.[42] In addition, school quality may have influenced later life memory function directly (e.g., developing brain or cognitive reserve), not indirectly through educational attainment. If so, the IV estimate does not correspond precisely to the effect of years of education but a combination of improved quality and quantity of education, i.e., longer duration of attendance at a higher quality school. Most research on the effects of educational attainment does not separate out the distinct contribution of school quality, so conventional estimates of education's effects may similarly correspond to the combined effects of longer school duration at higher quality schools. In theory, with a sufficiently large sample and a measure school quality as experienced by individual students, these two constructs could be disentangled with multivariable IV.

Our study has some limitations. First, selective mortality may mask the association between education and change in cognitive performance.[43,44] We found cumulative mortality rates were substantially higher for those with low education across race and sex groups because of the strong confounding by age (eTables 10-11; http://links.lww.com/EDE/C188). PPYEd was not associated with mortality risk in Cox models and PPYED and self-reported education was not differentially associated with mortality by baseline cognition level in logistical models (eTable 12; http://links.lww.com/EDE/C188), suggesting survival bias is likely to be minimal. Second, the instruments we used were chosen because they would influence years of schooling in primary and secondary schools,[7] but this limits our ability to offer insight into effects of college attendance. Additional work on potential effects of college attendance is needed: access to college has historically expanded and the effects of additional years of education after high

ACCEPTED
Copyright © Wolters Kluwer Health, Inc. All rights reserved. Unauthorized reproduction of this article is prohibited

school may differ from pre-college years.[45] Third, we assumed education has a linear effect on cognition levels and changes. This assumption is approximately supported by prior research,[46] but our findings should not be extrapolated to the extremes of education (e.g., primary schooling or college education), where our IVs are unlikely to influence educational experiences. Fourth, our IV estimates reflect a weighted average of causal effects, with weights corresponding to the influence of the policies on educational attainment. Estimates do not reflect the effects of education on outcomes of individuals whose level of schooling was insensitive to instruments. Children whose parents completed higher education for example may have been less influenced by the policies. To draw general conclusions about the effects of education, we must assume that additional education – attained for any reason – has the same benefit for cognition. This limitation in the current analysis is shared with prior observational studies as well: when contrasting health outcomes for people with differing levels of education, researchers implicitly assume the health effects of education do not vary depending on the reason for variations in educational attainment. The magnitudes of our IV estimates were similar to findings reported in robust previous studies using different designs.[47] Overall, these findings may be generalizable to U.S. Black and White older adults born prior to 1956. A valuable direction for future research would be exploring heterogeneity in the effects of education, including by region or individual characteristics associated with the degree of responsiveness to school policies. Future work may also apply robust IV approaches for the two sample setting like MR-Egger, weighted median, and weighted modal regression to evaluate IV assumptions.[48,49] Finally, we used PPYEd to capture the effects of multiple correlated schooling policies;[50] our findings do not lead to endorsement of specific policy options but rather suggest that policies which serve to increase quantity or quality of schooling are likely to have long-term benefits on cognitive outcomes in

ACCEPTED

Copyright © Wolters Kluwer Health, Inc. All rights reserved. Unauthorized reproduction of this article is prohibited

older adults. Future studies should focus on assessing individual school policies to provide specific policy recommendations.

Our study has major strengths. We included the use of geographic and temporal variations in state educational policies with the state-level quality measures accounting for racially segregated schools and we employed two-sample IV analyses to circumvent confounding and measurement errors in self-reported educational attainment. Using a large cohort of Black and White people, our causal estimates are reassuringly similar to estimates from other observational studies.[5,40] These findings provide convincing evidence– in combination with prior work – in support of the hypothesis that historical investments in delivering high-quality schooling to Black and White children in the US improved their memory performance later in life.

ACCEPTED

Copyright © Wolters Kluwer Health, Inc. All rights reserved. Unauthorized reproduction of this article is prohibited

References

1. Zahodne LB, Stern Y, Manly JJ. Differing effects of education on cognitive decline in diverse elders with low versus high educational attainment. *Neuropsychology.* 2015;29(4):649.
2. Clouston SA, Smith DM, Mukherjee S, et al. Education and cognitive decline: An integrative analysis of global longitudinal studies of cognitive aging. *The Journals of Gerontology: Series B.* 2020;75(7):e151-e160.
3. Meng X, D'arcy C. Education and dementia in the context of the cognitive reserve hypothesis: a systematic review with meta-analyses and qualitative analyses. *PloS one.* 2012;7(6):e38268.
4. Lövdén M, Fratiglioni L, Glymour MM, Lindenberger U, Tucker-Drob EM. Education and cognitive functioning across the life span. *Psychological Science in the Public Interest.* 2020;21(1):6-41.
5. Seblova D, Berggren R, Lövdén M. Education and age-related decline in cognitive performance: Systematic review and meta-analysis of longitudinal cohort studies. *Ageing Research Reviews.* 2020;58:101005.
6. Hamad R, Elser H, Tran DC, Rehkopf DH, Goodman SN. How and why studies disagree about the effects of education on health: A systematic review and meta-analysis of studies of compulsory schooling laws. *Social Science & Medicine.* 2018;212:168-178.
7. Nguyen TT, Tchetgen EJT, Kawachi I, et al. Instrumental variable approaches to identifying the causal effect of educational attainment on dementia risk. *Annals of epidemiology.* 2016;26(1):71-76. e73.

ACCEPTED
Copyright © Wolters Kluwer Health, Inc. All rights reserved. Unauthorized reproduction of this article is prohibited

8. Seblova D, Fischer M, Fors S, et al. Does prolonged education causally affect dementia risk when adult socioeconomic status is not altered? A Swedish natural experiment in 1.3 million individuals. *American Journal of Epidemiology*. 2021;190(5):817-826.

9. Banks J, Mazzonna F. The effect of education on old age cognitive abilities: evidence from a regression discontinuity design. *The Economic Journal.* 2012;122(560):418-448.

10. Crespo L, López-Noval B, Mira P. Compulsory schooling, education, depression and memory: New evidence from SHARELIFE. *Economics of Education Review.* 2014;43:36-46.

11. Huang W, Zhou Y. Effects of education on cognition at older ages: Evidence from China's Great Famine. *Social Science & Medicine.* 2013;98:54-62.

12. Glymour MM, Kawachi I, Jencks CS, Berkman LF. Does childhood schooling affect old age memory or mental status? Using state schooling laws as natural experiments. *Journal of Epidemiology & Community Health.* 2008;62(6):532-537.

13. Lleras-Muney A. Were compulsory attendance and child labor laws effective? An analysis from 1915 to 1939. *The Journal of Law and Economics.* 2002;45(2):401-435.

14. Mayeda ER, Glymour MM, Quesenberry CP, Whitmer RA. Inequalities in dementia incidence between six racial and ethnic groups over 14 years. *Alzheimer's & Dementia.* 2016;12(3):216-224.

15. Foverskov E, Glymour MM, Mortensen EL, Holm A, Lange T, Lund R. Education and cognitive aging: Accounting for selection and confounding in linkage of data from the Danish Registry and Survey of Health, Ageing and Retirement in Europe. *American Journal of Epidemiology.* 2018;187(11):2423-2430.

ACCEPTED

Copyright © Wolters Kluwer Health, Inc. All rights reserved. Unauthorized reproduction of this article is prohibited

16. Ashenfelter O, Collins WJ, Yoon A. Evaluating the Role of Brown v. Board of Education in School Equalization, Desegregation, and the Income of African Americans. *American Law and Economics Review.* 2006;8(2):213-224.

17. Margo RA. Race Differences in Public School Expenditures: Disfranchisement and School Finance in Louisiana, 1890-1910. *Social Science History.* 1982;6(1):9-33.

18. Vable AM, Cohen AK, Leonard SA, Glymour MM, dP Duarte C, Yen IH. Do the health benefits of education vary by sociodemographic subgroup? Differential returns to education and implications for health inequities. *Annals of epidemiology.* 2018;28(11):759-766. e755.

19. Liu SY, Manly JJ, Capistrant BD, Glymour MM. Historical differences in school term length and measured blood pressure: Contributions to persistent racial disparities among US-born adults. *PloS one.* 2015;10(6).

20. Howard VJ, Cushman M, Pulley L, et al. The reasons for geographic and racial differences in stroke study: objectives and design. *Neuroepidemiology.* 2005;25(3):135-143.

21. Acemoglu D, Angrist J. How large are the social returns to education? Evidence from compulsory schooling laws. In: National bureau of economic research Cambridge, Mass., USA; 1999.

22. Lee SM. Racial classifications in the US Census: 1890–1990. *Ethnic and racial studies.* 1993;16(1):75-94.

23. Brenowitz WD, Manly JJ, Murchland AR, et al. State school policies as predictors of physical and mental health: a natural experiment in the REGARDS cohort. *American journal of epidemiology.* 2020;189(5):384-393.

ACCEPTED

Copyright © Wolters Kluwer Health, Inc. All rights reserved. Unauthorized reproduction of this article is prohibited

24. Angrist JD, Krueger AB. The Effect of Age at School Entry on Educational Attainment: An Application of Instrumental Variables with Moments from Two Samples. *Journal of the American Statistical Association.* 1992;87(418):328-336.

25. Angrist JD, Krueger AB. Split-sample instrumental variables estimates of the return to schooling. *Journal of Business & Economic Statistics.* 1995;13(2):225-235.

26. Mendes de Leon CF. Aging and the elapse of time: a comment on the analysis of change. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences.* 2007;62(3):S198-S202.

27. Soh Y, Whitmer RA, Mayeda ER, et al. State-Level Indicators of Childhood Educational Quality and Incident Dementia in Older Black and White Adults. *JAMA neurology.* 2023;80(4):352-359.

28. Wilson R, Hebert L, Scherr P, Barnes L, De Leon CM, Evans D. Educational attainment and cognitive decline in old age. *Neurology.* 2009;72(5):460-465.

29. Walsemann KM, Kerr EM, Ailshire JA, Herd P. Black-White variation in the relationship between early educational experiences and trajectories of cognitive function among US-born older adults. *SSM-Population Health.* 2022:101184.

30. Quiñones AR, Chen S, Nagel CL, et al. Trajectories of cognitive functioning in later life: Disparities by race/ethnicity, educational attainment, sex, and multimorbidity combinations. *SSM-population health.* 2022;18:101084.

31. Thomas MD, Calmasini C, Seblova D, et al. Postsecondary Education and Late-life Cognitive Outcomes Among Black and White Participants in the Project Talent Aging Study: Can Early-life Cognitive Skills Account for Educational Differences in Late-life Cognition? *Alzheimer Disease & Associated Disorders.* 2022; 36(3):215-221..

ACCEPTED

Copyright © Wolters Kluwer Health, Inc. All rights reserved. Unauthorized reproduction of this article is prohibited

32. Jean KR, Lindbergh CA, Mewborn CM, Robinson TL, Gogniat MA, Miller LS. Education differentially buffers cognitive performance in black and white older adults. *The Journals of Gerontology: Series B.* 2019;74(8):1366-1375.

33. Sisco S, Gross AL, Shih RA, et al. The role of early-life educational quality and literacy in explaining racial disparities in cognition in late life. *J Gerontol B Psychol Sci Soc Sci.* 2015;70(4):557-567.

34. Carvalho JO, Tommet D, Crane PK, et al. Deconstructing Racial Differences: The Effects of Quality of Education and Cerebrovascular Risk Factors. *The Journals of Gerontology: Series B.* 2014;70(4):545-556.

35. Khalatbari-Soltani S, Maccora J, Blyth FM, Joannès C, Kelly-Irving M. Measuring education in the context of health inequalities. *International Journal of Epidemiology.* 2022; 51(3): 701-708.

36. Pager D, Shepherd H. The sociology of discrimination: Racial discrimination in employment, housing, credit, and consumer markets. *Annual review of sociology.* 2008;34:181-209.

37. Karlamangla AS, Miller-Martinez D, Aneshensel CS, Seeman TE, Wight RG, Chodosh J. Trajectories of cognitive function in late life in the United States: demographic and socioeconomic predictors. *American journal of epidemiology.* 2009;170(3):331-342.

38. Wilson RS, Yu L, Lamar M, Schneider JA, Boyle PA, Bennett DA. Education and cognitive reserve in old age. *Neurology.* 2019;92(10):e1041-e1050.

39. Lenehan ME, Summers MJ, Saunders NL, Summers JJ, Vickers JC. Relationship between education and age-related cognitive decline: a review of recent research. *Psychogeriatrics.* 2015;15(2):154-162.

ACCEPTED

Copyright © Wolters Kluwer Health, Inc. All rights reserved. Unauthorized reproduction of this article is prohibited

40. Gross AL, Mungas DM, Crane PK, et al. Effects of education and race on cognitive decline: An integrative study of generalizability versus study-specific results. *Psychology and aging*. 2015;30(4):863.

41. Goldin C, Katz LF. Human capital and social capital: The rise of secondary schooling in America, 1910 to 1940. In: National Bureau of Economic Research Cambridge, Mass., USA; 1998.

42. US Commission on Civil Rights. *Southern school desegregation, 1966-67: A Report.* 1967. Retreived from https://eric.ed.gov/?id=ED028876. Accessed August 1st, 2023.

43. Mayeda ER, Tchetgen Tchetgen EJ, Power MC, et al. A simulation platform for quantifying survival bias: an application to research on determinants of cognitive decline. *American journal of epidemiology*. 2016;184(5):378-387.

44. Mayeda ER, Filshtein TJ, Tripodis Y, Glymour MM, Gross AL. Does selective survival before study enrolment attenuate estimated effects of education on rate of cognitive decline in older adults? A simulation approach for quantifying survival bias in life course epidemiology. *International journal of epidemiology*. 2018;47(5):1507-1517.

45. Montez JK, Hummer RA, Hayward MD. Educational attainment and adult mortality in the United States: A systematic analysis of functional form. *Demography*. 2012;49(1):315-336.

46. Burgess S, Davies NM, Thompson SG. Instrumental variable analysis with a nonlinear exposure–outcome relationship. *Epidemiology (Cambridge, Mass).* 2014;25(6):877.

47. Harrati A, Glymour MM. Lifecourse epidemiology matures: commentary on Zhang et al.“Early-life socioeconomic status, adolescent cognitive ability, and cognition in late midlife”. *Social Science & Medicine*. 2020;244:112645.

ACCEPTED

Copyright © Wolters Kluwer Health, Inc. All rights reserved. Unauthorized reproduction of this article is prohibited

48. Labrecque J, Swanson SA. Understanding the assumptions underlying instrumental variable analyses: a brief review of falsification strategies and related tools. *Current epidemiology reports.* 2018;5:214-220.

49. Skrivankova VW, Richmond RC, Woolf BA, et al. Strengthening the reporting of observational studies in epidemiology using mendelian randomisation (STROBE-MR): explanation and elaboration. *bmj.* 2021;375.

50. Stephens Jr M, Yang D-Y. Compulsory education and the benefits of schooling. *American Economic Review.* 2014;104(6):1777-1792.

ACCEPTED

Copyright © Wolters Kluwer Health, Inc. All rights reserved. Unauthorized reproduction of this article is prohibited

Figure. Directed acyclic graph for the effects of state school policies on cognition performance. It depicts how leveraging geographic and temporal variations in state school policies (influencing both quality and compulsory schooling laws) affects cognition via educational experience and life course socioeconomic, social-behavioral, and future downstream (e.g., biological responses to stress, cognitive reserve) mediators. These state policies are not influenced by individual characteristics; therefore, they help reduce the impact of unmeasured confounding (e.g., individual characteristics such as intelligence). Yet, school policies are influenced by state characteristics, which could also influence later life cognition; we conceptualized blocking this potential pathway by controlling for the state of childhood residence. Still, state school policies might affect later life cognition via time-varying state characteristics in social and political domains (i.e., ecological mediators—dashed lines), which often move in tandem with state schooling policies.

ACCEPTED

Copyright © Wolters Kluwer Health, Inc. All rights reserved. Unauthorized reproduction of this article is prohibited

Table 1. Baseline Characteristics According to Race and Sex, REasons for Geographic and Racial Differences in Stroke, United States, 2003-2020

Variables	Total (N=20,248)	Black Men (N= 2,505)	Black Women (N=4,818)	White Men (N= 6,272)	White Women (N= 6,653)
Word List Learning (0-30), mean (SD)	17.4 (5.1)	15.2 (4.8)	17.1 (5.1)	16.7 (4.9)	19.2 (4.8)
Word List Delayed Recall (0-10), mean (SD)	6.5 (2.1)	5.6 (2.1)	6.4 (2.2)	6.2 (2.0)	7.2 (2.0)
Animal Fluency Scores (0-59), mean (SD)	17.2 (5.8)	15.7 (5.2)	14.8 (5.1)	18.5 (5.8)	18.2 (5.7)
Policy-predicted years of education (PPYEd), mean (SD)	12.1 (1.0)	11.4 (1.1)	11.4 (1.1)	12.5 (0.8)	12.4 (0.8)
Self-reported years of education, mean (SD)	14.3 (2.5)	13.7 (2.6)	13.7 (2.5)	14.9 (2.4)	14.4 (2.4)
Age at the first cognitive assessment, mean (SD)	66.9 (9.2)	66.6 (8.8)	65.8 (9.0)	68.3 (9.0)	66.6 (9.4)
Region of residence at age 6 years, %					
South	63	79	78	50	57
Northeast	13	7	6	18	14
Midwest	19	13	12	25	21
West	6	2	4	7	8
Number of cognitive assessments, mean (SD)	4.2 (2.1)	3.9 (2.1)	4.0 (2.1)	4.3 (2.1)	4.4 (2.1)

Note: Abbreviation: SD, standard deviation

ACCEPTED

Copyright © Wolters Kluwer Health, Inc. All rights reserved. Unauthorized reproduction of this article is prohibited

Table 2. Estimated Associations of Self-Reported Education or Policy Predicted Years of Education with Composite- and Domain-Specific Cognitive Performance Levels and Change from the REasons for Geographic and Racial Differences in Stroke Cohort (2003-2020)

	Composite		Word List Learning		Word List Delayed Recall		Animal Fluency	
Model	Estimate	95% CI	Estimate	95% CI	Estimate	95% CI	Estimate	95% CI
Estimated Effect on Cognitive Level								
Self-reported education	0.09	[0.09, 0.09]	0.09	[0.09, 0.10]	0.08	[0.07, 0.08]	0.10	[0.10, 0.11]
PPYEd	0.11	[0.07, 0.15]	0.15	[0.10, 0.20]	0.10	[0.05, 0.15]	0.08	[0.03, 0.13]
PPYEd, adjusted for state covariates	0.12	[0.07, 0.18]	0.14	[0.07, 0.21]	0.11	[0.04, 0.17]	0.09	[0.03, 0.15]
Estimated Effect on Cognitive Change per Decade								
Self-reported education	0.00	[-0.01, 0.00]	0.00	[-0.01, 0.00]	0.00	[-0.01, 0.00]	-0.02	[-0.02, 0.01]
PPYEd	0.00	[-0.06, 0.05]	0.01	[-0.07, 0.08]	0.05	[-0.02, 0.13]	-0.01	[-0.06, 0.05]
PPYEd, adjusted for state covariates	-0.08	[-0.15, -0.01]	-0.06	[-0.15, 0.03]	-0.04	[-0.14, 0.05]	-0.01	[-0.09, 0.06]

Note: Abbreviations: CI, confidence interval; PPYEd, policy-predicted years of education.
Sample included 20,248 older Black and White Americans. Pooled estimates based on random intercept and random slope models for the cognitive performance over time. All models included adjustment for baseline age, age squared, race, sex, age and race interaction terms, age and sex interaction terms, state of residence at age 6 years, and baseline assessment year. PPYEd, adjusted for state covariates, models added time-varying state covariates in mixed models.

ACCEPTED

Copyright © Wolters Kluwer Health, Inc. All rights reserved. Unauthorized reproduction of this article is prohibited

Table 3. Estimated Associations of Policy Predicted Years of Education with Composite and Domain Specific Cognitive Performance Levels and Change, Race- and Sex- Specific Sample of REasons for Geographic and Racial Differences in Stroke (2003-2020)

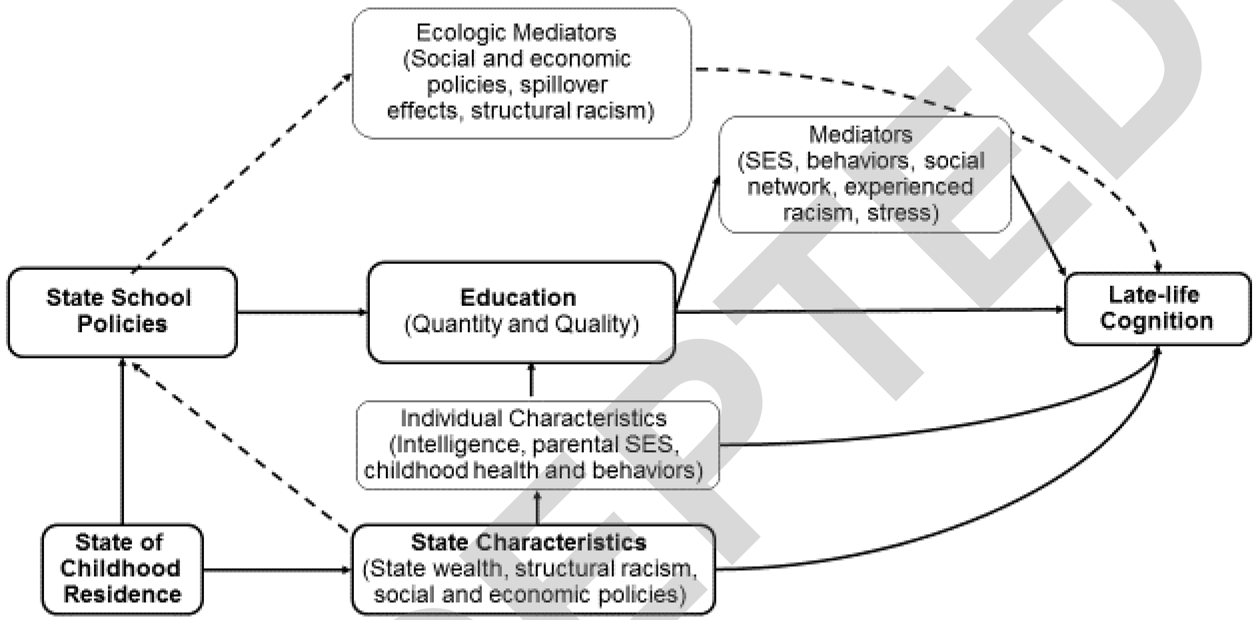
	Composite		World List Learning		Word List Delayed Recall		Animal Fluency	
Model	Estimate	95% CI	Estimate	95% CI	Estimate	95% CI	Estimate	95% CI
Estimated Effect on Cognitive Level								
Black Men	0.11	[-0.01, 0.24]	0.08	[-0.09, 0.24]	0.14	[-0.03, 0.31]	0.07	[-0.08, 0.22]
Black Women	0.11	[0.03, 0.20]	0.22	[0.10, 0.33]	0.20	[0.09, 0.32]	0.00	[-0.10, 0.10]
White Men	0.14	[0.04, 0.25]	0.24	[0.11, 0.37]	0.07	[-0.06, 0.20]	0.17	[0.04, 0.30]
White Women	0.08	[-0.03, 0.18]	0.03	[-0.10, 0.15]	-0.01	[-0.13, 0.11]	0.17	[0.04, 0.29]
Estimated Effect on Cognitive Change per Decade								
Black Men	-0.05	[-0.22, 0.12]	0.12	[-0.10, 0.35]	0.02	[-0.23, 0.26]	-0.02	[-0.21, 0.16]
Black Women	0.06	[-0.05, 0.18]	0.03	[-0.14, 0.19]	0.05	[-0.11, 0.22]	0.08	[-0.03, 0.19]
White Men	0.09	[-0.05, 0.24]	0.01	[-0.18, 0.19]	0.20	[0.01, 0.40]	0.02	[-0.14, 0.18]
White Women	0.16	[0.02, 0.29]	0.15	[-0.03, 0.33]	0.23	[0.05, 0.41]	-0.03	[-0.18, 0.12]

Note: Abbreviations: CI, confidence interval.
Samples included 2,505 Black men, 4,818 Black women, 6,272 White Men, and 6,653 White women. Estimation based on random intercept and random slope models for the cognitive performance over time. All models included adjustment for baseline age, age squared, state of residence at age 6 years, and baseline assessment year.

ACCEPTED

Copyright © Wolters Kluwer Health, Inc. All rights reserved. Unauthorized reproduction of this article is prohibited

Figure 1



ACCEPTED

Copyright © Wolters Kluwer Health, Inc. All rights reserved. Unauthorized reproduction of this article is prohibited