I Z A Institute
of Labor Economics
Initiated by Deutsche Post Foundation

DISCUSSION PAPER SERIES

IZA DP No. 17466

School Racial Segregation and Late-Life Cognition

Zhuoer Lin
Yi Wang
Thomas M. Gill
Xi Chen

NOVEMBER 2024

I Z A Institute of Labor Economics

Initiated by Deutsche Post Foundation

DISCUSSION PAPER SERIES

IZA DP No. 17466

School Racial Segregation and Late-Life Cognition

Zhuoer Lin
University of Illinois Chicago

Yi Wang
Yale University

Thomas M. Gill
Yale University

Xi Chen
Yale University and IZA

NOVEMBER 2024

ISSN: 2365-9793

IZA – Institute of Labor Economics

Schaumburg-Lippe-Straße 5–9
53113 Bonn, Germany

Phone: +49-228-3894-0
Email: publications@iza.org

www.iza.org

ABSTRACT

School Racial Segregation and Late-Life Cognition

Disparities in cognition persist between non-Hispanic Black (hereafter, Black) and non-Hispanic White (hereafter, White) older adults, and are possibly influenced by early educational differences stemming from structural racism. However, the relationship between school racial segregation and later-life cognition remains underexplored. We examined a nationally sample of older Americans from the Health and Retirement Study. Utilizing childhood residence data and cognitive assessment data (1995-2018) for Black and White participants aged 65 and older, Black-White dissimilarity index for public elementary schools measuring school segregation, multilevel analyses revealed a significant negative association between school segregation and later-life cognitive outcomes among Black participants, but not among White participants. Potential mediators across the life course, including educational attainment, explained 58-73% of the association, yet the associations remained large and significant among Black participants for all outcomes. Given the rising trend of school segregation in the US, educational policies aimed at reducing segregation are crucial to address health inequities. Clinicians can leverage patients' early-life educational circumstances to promote screening, prevention, and management of cognitive disorders.

JEL Classification: I14, I24, I10, J14, J15, H75

Keywords: early-life circumstances, school segregation, quality of education, racial disparity, cognition, dementia, health equity

Corresponding author:
Xi Chen
Department of Health Policy and Management
Department of Economics
Yale University
60 College St, New Haven, CT 06520
USA

E-mail: xi.chen@yale.edu

1. Introduction

Cognitive impairment poses considerable challenges for older adults,[1] with Alzheimer's disease and related dementias affecting millions of Americans and the burden escalating as the population ages. Notably, marked racial/ethnic disparities persist.[2] Cognitive disorders disproportionally impact disadvantaged populations, diminishing individual well-being and imposing substantial burdens on caregivers and families, thereby exacerbating societal racial/ethnic disparities.[3]

Emerging evidence underscores the profound influence of adverse early-life circumstances on brain development and cognitive decline over the lifespan.[4–6] Racial differences in early educational environments, particularly those rooted in structural racism, appear pivotal in shaping cognition in later life.[7–9]

School racial segregation (school segregation hereafter), a significant aspect of US education systems, may exert particularly profound impacts on cognition.[10] This practice physically segregates students in educational institutions based on racial backgrounds, resulting in vastly unequal educational experiences, qualities, and opportunities between White and minoritized populations. Despite the historic *Brown v. Board* ruling, US schools continue to struggle with heightened levels of segregation,[11,12] with more than half of students attending schools in districts that are predominantly White or non-White, and approximately 40% of Black students attending schools that are 90% to 100% non-White.[13,14]

Understanding the long-term relationship between school segregation and later-life cognition is crucial, as the school environment not only influences educational outcomes but shapes the quality of educational experience.[15] Individuals exposed to school segregation typically experience higher rates of discriminatory discipline that may contribute to elevated stress levels. Their limited access to educational resources can adversely affect learning opportunities and activities. These disadvantaged school environments may hinder neurological development through mechanisms like chronic stress or metabolic dysregulation and processes that impair cognitive ability into later life.[16,17] However, school segregation could also impact the health of Black children by reducing their exposure to interpersonal racism from White peers, staff, parents or teachers, especially in predominantly White schools.[18–20] Overall, segregated schools often entail more exposure to discrimination, racism, reduced school resources, and other adversities for Black children, which exacerbate their gaps in cognitive outcomes with White children.[21,22]

Studies evaluating the association between US school segregation and health outcomes in later life have been limited by a singular focus on indirect measures of segregation,[23] reliance on self-reported data,[24–26] lack nationally representative samples,[24,27,28] and inattention to later-life cognitive outcomes.[18,29,30] To bridge these gaps, we examine how childhood contextual exposure to school segregation is associated with cognitive outcomes in later life, and explore the potential mediating role of early- and mid-life modifiable risk factors for dementia. Linking historical data on Black-White school segregation in public elementary schools from the late 1960s and early 1970s to a nationally representative sample of American older adults – the Health and Retirement Study (HRS), we hypothesized that childhood exposure to high levels of school segregation is associated with poorer later-life cognitive outcomes, especially among Black Americans. We also hypothesized that the associations can be partially mediated by important modifiable factors such as educational attainment.

2. Methods

This study was waived from institutional board review by the Human Research Protection Program at Yale University, because it did not involve human participation. The study adhered to the STROBE reporting guideline.

2.1 Data and Study Participants

Data were derived from two primary sources: 1) school segregation data from the Office of Civil Rights (OCR); and 2) longitudinal survey data from the HRS.[31,32]

The school segregation data were obtained from OCR files that included school enrollment statistics and segregation index for American school districts across non-Hispanic Black (hereafter, Black) and non-Hispanic White (hereafter, White) populations. Previous studies have thoroughly cleaned and validated the OCR data, constructing segregation index measures at the metropolitan level from the late 1960s.[31,32] These metropolitan-level public elementary school enrollment and segregation index data, spanning 328 US metropolitan areas, were used to construct a segregation index for each state.[32]

The HRS is a nationally representative longitudinal survey of Americans aged 50 years and older, with consistent collection of data on cognition and individual-level sociodemographic and health characteristics since 1995. For this study, we focused on Black and White participants aged 65 or older surveyed during 1995-2018 (i.e., the most recent wave pre-COVID[33]).

The sample selection process is shown in **Figure 1**. Over the study period (1995-2018), 39,958 HRS participants underwent cognitive assessments. We excluded 6,614 participants self-identified as Hispanic or other racial/ethnic groups other than Black or White, and 11,087 participants aged below 65, resulting in 22,257 Black or White participants aged 65 or older. Among them, 21,307 participants with childhood residence in the U.S. and linked measures of school segregation were included. After excluding 186 participants with any missing data (<1% of the sample), the final sample comprised 21,121 (3,566 Black and 17,555 White) participants aged 65 or older with complete data and measurements, contributing to a total of 106,978 observations (16,104 Black and 90,874 White).

2.2 Cognitive Outcomes

Cognition was assessed using the Telephone Interview for Cognitive Status, a 27-point cognitive scale encompassing a series of cognitive questions evaluating memory, working memory, and speed of mental processing. The scale reflects global cognitive function, with higher score indicating better cognitive performance. Cognitive impairment and dementia status were determined based on established criteria: a score below 12 indicated cognitive impairment (with or without dementia), and a score below 7 indicated dementia.[34,35]

For participants unable to complete the cognitive assessment by themselves, a 11-point proxy cognitive scale was constructed to determine cognitive status, with a higher score indicating poorer cognitive function. Cognitive impairment (with or without dementia) was determined if the proxy score was above 2, and dementia status was identified if the proxy score was above 5.[34,35]

2.3 School Segregation

School segregation was assessed using the Black-White dissimilarity index (hereafter, dissimilarity index), which measures the extent of segregation between Black and White students in public elementary schools. Scores on this index, ranging from 0 to 100, indicate the percentage of Black children who would need to move to a different school to achieve an equal distribution of Black and White students across schools in a metropolitan area. Higher scores indicate more segregation. The dissimilarity index primarily relied on enrollment data from public elementary schools reported by the OCR in 1968, supplemented by data from 1969 to 1971.[31,32]

Since all study participants attended elementary schools prior to 1970, a period during which segregation levels saw minimal changes, using late 1960s data to calculate the dissimilarity index is highly relevant.[32,36] Participants were asked to report the state where they lived at age 10. An average dissimilarity index score was then calculated for each state in the late 1960s, weighted by the enrollment numbers of Black and White students in public elementary schools within the metropolitan areas.

Due to the skewed distribution of index scores (Supplementary eFigure 1), states were categorized based on quintile of scores, a commonly used cut-off in prior contextual-level research in older Americans.[37] States in the highest quintile (dissimilarity index ≥ 83.6) were classified as "high segregation", while the others were classified as "low segregation".

2.4 Covariates and Mediators

Age, sex, parental education, and childhood residence in U.S. Southern States were included as key sociodemographic covariates.[38,39] Additionally, we incorporated regional indicators for childhood residence, a birth-year trend indicator, and region-specific birth-year trend interactions to account for potential unobserved geographic and temporal confounders.

Building on prior research, we also included a series of early- and mid-life mediators that are potentially shaped by childhood experiences and may impact cognition across the life course. Drawing on the *Lancet Commission Report* on Dementia Prevention,[6] we selected educational attainment as the primary early-life mediator. For mid-life, we incorporated several leading modifiable risk factors for dementia and exhibited minimal missing data in the HRS, including hypertension, diabetes, heart diseases, psychiatric conditions, obesity, and smoking.[6,40] The selection is further supported by emerging evidence linking school segregation with educational attainment and health factors. Examining these mediators may therefore imply pivotal mechanisms through which school segregation influences cognition later in life.[5,27,41,42]

2.5 Statistical Analyses

Descriptive statistics were estimated for the entire sample, as well as for subgroups with high versus low levels of segregation. Differences across subgroups were assessed using Chi-square tests for categorical variables and Welch t-tests for continuous variables.

To evaluate the association between school segregation and cognitive outcomes in later life, multilevel models were employed, with individuals at level two and childhood states of residence at level three. Random intercepts were included at the state level to account for unobserved heterogeneity and differences between states, while individual-level random intercepts addressed within-individual correlations across multiple observations.[43] Robust standard errors, clustered at the state level, were estimated.[44] Multilevel linear models were used for the continuous outcome (i.e., cognitive score) and multilevel logistic models were used for the dichotomous outcomes (i.e., cognitive impairment and dementia). Models were estimated separately for Black and White participants.

In the base model (Model A), we examined the association between school segregation and cognitive outcomes, adjusting for covariates. In subsequent models, we sequentially included early- and mid-life mediators. Model B included early-life mediators (i.e., educational attainment), while Model C additionally included mid-life mediators (i.e., health factors). Mediation was evaluated using the difference method (percentage reduction), which compares the coefficients from the mediated model (i.e., Model C) to the unmediated model (i.e., Model A). The percentage reduction of the coefficients reflects the extent to which mediators explain the association between school segregation and cognitive outcomes.[45,46]

A series of sensitivity analyses were conducted. First, we redefined high level of school segregation using a less extreme cutoff (top tertile instead of top quintile). Second, we employed a continuous measure of school segregation (i.e., dissimilarity index) instead of a dichotomous classification (i.e., low vs high). Third, we restricted sample to individuals who lived in urban areas more directly exposed to segregation during childhood. Fourth, following the literature, we used a more time-varying, self-reported measure of school segregation from the HRS life history survey (i.e., attending segregated schools during primary education) to reexamine the association. Finally, state-level birth-year trend indicators were added to further account for time-varying confounding at the state level. eAppendix A presents details of these sensitivity analyses.

To address biases from sample attrition, inverse probability-of-attrition weights were computed and applied in all models. All analyses were performed using Stata 17.0 (StataCorp LLC), and statistical significance was set at $P<0.05$ for all tests.

3. Results

The study sample included 21,121 participants (106,978 observations), with 3,566 Black (16,104 observations) and 17,555 White participants (90,874 observations) (**Figure 1**). The mean (SD) age of the sample was 75.6 (7.5) years, and 58.1% were female. **Table 1** presents descriptive statistics for the overall sample and for subgroups stratified by high vs. low level of school segregation. The two segregation groups were similar in age but differed in other characteristics. Participants from high segregation states had a higher proportion of Black participants (28.4% vs 12.7%), lower levels of educational attainment, and a greater prevalence of health conditions, such as hypertension and diabetes, compared to those from low segregation states (also see Supplementary Table S1).

The mean (SD) dissimilarity index, the measure of school segregation, was 79.9 (5.7) overall, with higher levels in participants from highly segregated states (mean: 86.9) compared to those from states with low segregation (mean: 77.5). Participants exposed to high segregation during childhood exhibited lower cognitive scores (13.6 vs 14.5) and higher likelihood of cognitive impairment (37.0% vs. 28.0%) and dementia (14.1% vs. 9.3%) compared to their low segregation counterparts. As shown in Supplementary eFigures 2-3, Black participants who experienced higher segregation consistently showed worse cognitive outcomes across ages compared to those exposed to lower segregation. This difference was most pronounced among participants in the highest quintiles of the dissimilarity index (i.e., most segregated), with less noticeable differences in the lower quintiles.

Figure 2 illustrates the inverse relationships between state-level dissimilarity index scores and cognition, adjusted for age and sex, separately for Black and White participants. States with higher levels of segregation demonstrated lower average cognitive scores and higher proportions of cognitive impairment and dementia. The fitted lines show steeper declines for Black participants compared to White participants across all cognitive outcomes. Additionally, among Black participants, the slopes were even steeper for those exposed to the highest levels of segregation, indicating a disproportionately greater impact on the most vulnerable (Supplementary eFigure 4).

Multilevel regression analyses, presented in **Figures 3-4** (with detailed estimates in Supplementary eTables 2-3), confirmed these findings. Overall, participants experienced high levels of segregation during childhood had lower cognitive scores (**Figure 3**) and higher odds of cognitive impairment and dementia (**Figure 4**) compared to those in low segregation states, after adjusting for covariates (Model A). Importantly, the associations were stronger and statistically significant for Black participants across all cognitive outcomes, while the associations for White participants were not statistically significant.

The associations observed in Model A were partially attenuated after including the early-life mediator, i.e., educational attainment (Model B), but showed no further attenuation with addition of mid-life health factors (Model C). In Model C, the associations between school segregation and cognitive outcomes for Black participants remained large and statistically significant. Mediation analysis revealed that early- and mid-life mediators collectively explained 58%-73% of these associations (**Figures 3-4** and Supplementary eTables 2-3). Our sensitivity analyses in Supplementary eFigures 5-14 confirmed the observed patterns.

4. Discussion and Conclusions

Linking a nationally representative sample of American older adults to historical administrative data on segregation, we provide new insights into the long-term association between school segregation exposure and cognitive outcomes in later life. Our findings demonstrate that childhood exposure to high levels of school segregation was associated with lower cognitive scores and a higher likelihood of cognitive impairment and dementia among Black Americans.

Despite decades of desegregation efforts, school segregation persists, [47,48] and its long-term health consequences have not been thoroughly investigated due to data constraints. By using historical administrative records of school segregation rather than relying on self-reports, our study captures a more objective contextual measure of segregation exposure. Importantly, linking these segregation measures to HRS data enabled us to evaluate important and clinically relevant cognitive outcomes in later-life in a nationally representative sample of older adults.

To our knowledge, this is the first study to use such linked data to examine the association between school segregation and various cognitive outcomes in later life. Our findings align with existing research showing that adverse educational experiences are negatively associated with later-life cognition.[9] Previous studies have also shown that higher educational quality is linked to a lower risk of dementia and improved cognitive outcomes.[49,50] By utilizing comprehensive national datasets, our analysis provides broader contextual insights into the relationship between school segregation and cognition, distinguishing it from studies relying on self-reports[24–26] or regional-specific data,[24,27] or those not focused on cognition.[18,29,30]

High levels of school segregation are often indicative of systemic educational disparities, where predominantly Black schools receive fewer resources, leading to poorer educational quality. States with higher segregation levels typically allocate less funding to schools serving Black students,[51] resulting in under-resourced schools with higher teacher turnover and larger class sizes.[52,53] This disparity may impact the educational experiences (e.g., limited learning opportunities) and physical development (e.g., inadequate nutrition and physical activity) of Black students, which may affect cognitive function later in life.[17,18] Our findings are consistent with previous research showing that Black individuals are disproportionately affected by these systemic inequities, leading to worse cognitive outcomes.[9,26,30,39] In contrast, while White participants may also experience disadvantaged environments with less social interactions across diverse racial communities, they are less exposed to the systemic racism that disproportionately impacts Black students, which may explain the lack of negative associations between segregation and cognition in this group.

We found that educational attainment mediated a significant portion of the association between school segregation and cognitive outcomes. School segregation has been shown to reduce educational opportunities for Black students, manifested in lower educational attainment.[54] As educational attainment is a key modifiable risk factor for dementia, it likely influences cognitive development in early life and affects cognitive outcomes through various pathways over the life course.[6] For example, individuals with lower education may have reduced access to healthcare or may adopt unhealthy behaviors, such as smoking, further increasing their risks of cognitive disorders. Our findings suggest that policies addressing educational inequities, particularly in highly segregated states, could reap long-term benefits for reducing health disparities. Moreover, identifying people at risk of dementia in the clinical settings, including using information on their early-life schooling, might lower the bar for cognitive screening or testing, which could help prioritize limited clinical resources for higher risk groups.

Although mid-life health conditions and behaviors, such as hypertension, diabetes, and smoking, are known to influence cognition in later life,[6] they did not further attenuate the association between school segregation and cognitive outcomes. This may be because educational attainment already encapsulates much of the impact of these mid-life risk factors on cognition. Future research should explore more detailed measures to better understand the mechanisms.

Our study has limitations. First, state-level segregation measures may not fully capture localized segregation. More granular segregation data could provide a clearer understanding of exposure, particularly considering the rural/urban differences. Second, we do not have data on educational quality, such as teacher qualifications, class sizes, and school duration, which could elucidate the mechanisms linking segregation to cognition. Additionally, lack of state-level data for cohorts prior to the 1970s limit our ability to implement more comprehensive regional controls. Third, while evaluating cognitive trajectories was beyond the scope of this study, future research should explore the relationship between school segregation and cognitive decline. Fourth, although we accounted for proxy respondents when evaluating cognitive impairment and dementia, the evaluation of cognitive scores was limited to self-respondents. Future studies should consider combining self- and proxy-reported scores for more comparable results.[55] Fifth, the HRS does not include data on early brain structure or function, limiting the exploration of biological pathways linking early-life segregation to cognitive aging. More comprehensive chain mediation analyses could further deepen understanding. Finally, while our study shows strong associations between segregation and cognition, as well as the mediating role of life course factors, it does not establish causality. Future research using causal designs could deepen our understanding of causal relationships and complex dynamics.

Our study highlights the long-term neurological consequences of school segregation. We show that high levels of school segregation are associated with poorer cognitive outcomes in later life, suggesting that structural racism in education has lasting effects on cognition. Reducing school segregation and addressing educational inequities could have profound benefits slowing cognitive aging and mitigating racial health disparities. Our findings contribute to the growing evidence on the importance of addressing systemic racism in education to promote health equity and improve health outcomes for historically marginalized populations.

Acknowledgements

Dr. Chen had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis. Drs. Lin and Wang are co–first authors who contributed equally. This study was funded by research grant R01AG077529 from the U.S. National Institute on Aging; and grant P30AG021342 from the U.S. National Institute on Aging to the Yale Claude D. Pepper Older Americans Independence Center. The funders had no role in the design and conduct of the study; collection, management, analysis, and interpretation of the data; preparation, review, or approval of the manuscript; and decision to submit the manuscript for publication. The IZA Discussion Paper Series serves as a preprint server to deposit latest research for feedback.

References

1. Manly JJ, Jones RN, Langa KM, et al. Estimating the Prevalence of Dementia and Mild Cognitive Impairment in the US: The 2016 Health and Retirement Study Harmonized Cognitive Assessment Protocol Project. *JAMA Neurology*. 2022;79(12):1242-1249. doi:10.1001/jamaneurol.2022.3543

2. Rajan KB, Weuve J, Barnes LL, McAninch EA, Wilson RS, Evans DA. Population estimate of people with clinical Alzheimer's disease and mild cognitive impairment in the United States (2020–2060). *Alzheimer's & Dementia*. 2021;17(12):1966-1975. doi:10.1002/alz.12362

3. Moon W, Han JW, Bae JB, et al. Disease Burdens of Alzheimer's Disease, Vascular Dementia, and Mild Cognitive Impairment. *Journal of the American Medical Directors Association*. 2021;22(10):2093-2099.e3. doi:10.1016/j.jamda.2021.05.040

4. Lee H, Lee MW, Warren JR, Ferrie J. Childhood lead exposure is associated with lower cognitive functioning at older ages. *Science Advances*. 8(45):eabn5164. doi:10.1126/sciadv.abn5164

5. Gilsanz P, Mayeda ER, Glymour MM, Quesenberry CP, Whitmer RA. Association Between Birth in a High Stroke Mortality State, Race, and Risk of Dementia. *JAMA Neurology*. 2017;74(9):1056-1062. doi:10.1001/jamaneurol.2017.1553

6. Livingston G, Huntley J, Liu KY, et al. Dementia prevention, intervention, and care: 2024 report of the Lancet standing Commission. *The Lancet*. 2024;404(10452):572-628. doi:10.1016/S0140-6736(24)01296-0

7. Fletcher J, Topping M, Zheng F, Lu Q. The effects of education on cognition in older age: Evidence from genotyped Siblings. *Social Science & Medicine*. 2021;280:114044. doi:10.1016/j.socscimed.2021.114044

8. Lövdén M, Fratiglioni L, Glymour MM, Lindenberger U, Tucker-Drob EM. Education and Cognitive Functioning Across the Life Span. *Psychol Sci Public Interest*. 2020;21(1):6-41. doi:10.1177/1529100620920576

9. Lin Z, Ye J, Allore H, Gill TM, Chen X. Early-Life Circumstances and Racial Disparities in Cognition Among Older Adults in the US. *JAMA Intern Med*. 2024;184(8):904-914. doi:10.1001/jamainternmed.2024.1132

10. Ghio M, Simpson JT, Ali A, et al. Association Between Markers of Structural Racism and Mass Shooting Events in Major US Cities. *JAMA Surgery*. Published online July 19, 2023. doi:10.1001/jamasurg.2023.2846

11. Orfield G, Frankenberg E, Ee J, Ayscue JB. *Harming Our Common Future: America's Segregated Schools 65 Years after Brown*. The Civil Rights Project at UCLA; 2019. Accessed December 21, 2023. https://www.civilrightsproject.ucla.edu/research/k-12-education/integration-and-diversity/harming-our-common-future-americas-segregated-schools-65-years-after-brown

12. Antman FM, Cortes KE. The Long-Run Impacts of Mexican American School Desegregation. *Journal of Economic Literature*. 2023;61(3):888-905. doi:10.1257/jel.20221704

13. Stancil W. School Segregation Is Not a Myth. *The Atlantic*. https://www.theatlantic.com/education/archive/2018/03/school-segregation-is-not-a-myth/555614/. March 14, 2018. Accessed October 1, 2023.

14. Mervosh S. How Much Wealthier Are White School Districts Than Nonwhite Ones? $23 Billion, Report Says - The New York Times. *The New York Times*. https://www.nytimes.com/2019/02/27/education/school-districts-funding-white-minorities.html. 2019. Accessed October 1, 2023.

15. Adkins-Jackson PB, Weuve J. Racially Segregated Schooling and the Cognitive Health of Black Adults in the United States—Why It Matters. *JAMA Network Open*. 2021;4(10):e2130448-e2130448. doi:10.1001/jamanetworkopen.2021.30448

16. 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):e0129673. doi:10.1371/journal.pone.0129673

17. Walsemann KM, Ureña S, Farina MP, Ailshire JA. Race inequity in school attendance across the Jim Crow South and its implications for black–white disparities in trajectories of cognitive function among older adults. *The Journals of Gerontology: Series B*. 2022;77(8):1467-1477. doi:https://doi.org/10.1093/geronb/gbac026

18. Wang G, Schwartz GL, Kim MH, et al. School Racial Segregation and the Health of Black Children. *Pediatrics*. 2022;149(5):e2021055952. doi:10.1542/peds.2021-055952

19. Wells AS, Crain RL. *Stepping over the Color Line: African-American Students in White Suburban Schools*. Yale University Press; 1997. https://books.google.com/books?id=ULuMiNb18FMC

20. Spears Brown C, Bigler RS. Children's Perceptions of Discrimination: A Developmental Model. *Child Development*. 2005;76(3):533-553. doi:10.1111/j.1467-8624.2005.00862.x

21. Mahmood N, Sanchez-Vaznaugh EV, Matsuzaki M, Sánchez BN. Racial/ethnic disparities in childhood obesity: The role of school segregation. *Obesity*. 2022;30(5):1116-1125. doi:10.1002/oby.23416

22. Walsemann KM, Hair NL, Farina MP, Tyagi P, Jackson H, Ailshire JA. State-level desegregation in the U.S. South and mid-life cognitive function among Black and White adults. *Social Science & Medicine*. 2023;338:116319. doi:10.1016/j.socscimed.2023.116319

23. Carr DC, Reynolds J. Race-Discordant School Attendance and Cognitive Function in Later Life. *Res Aging*. 2023;45(3-4):320-331. doi:10.1177/01640275221103791

24. Lamar M, Lerner AJ, James BD, et al. Relationship of Early-Life Residence and Educational Experience to Level and Change in Cognitive Functioning: Results of the Minority Aging Research Study. *The Journals of Gerontology: Series B*. 2020;75(7):e81-e92. doi:10.1093/geronb/gbz031

25. Wolinsky FD, Andresen EM, Malmstrom TK, Miller JP, Schootman M, Miller DK. Childhood school segregation and later life sense of control and physical performance in the African American Health cohort. *BMC Public Health*. 2012;12(1):827. doi:10.1186/1471-2458-12-827

26. 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;19:101184. doi:10.1016/j.ssmph.2022.101184

27. Peterson RL, George KM, Barnes LL, et al. Association of timing of school desegregation in the United States with late-life cognition in the study of healthy aging in African Americans (STAR) cohort. *JAMA Network Open*. 2021;4(10):e2129052-e2129052. doi:doi:10.1001/jamanetworkopen.2021.29052

28. Aiken-Morgan AT, Gamaldo AA, Sims RC, Allaire JC, Whitfield KE. Education Desegregation and Cognitive Change in African American Older Adults. *The Journals of Gerontology: Series B*. 2015;70(3):348-356. doi:10.1093/geronb/gbu153

29. Kim MH, Schwartz GL, White JS, et al. School racial segregation and long-term cardiovascular health among Black adults in the US: A quasi-experimental study. *PLoS medicine*. 2022;19(6):e1004031. doi:https://doi.org/10.1371/journal.pmed.1004031

30. Hahn RA. School Segregation Reduces Life Expectancy in the U.S. Black Population by 9 Years. *Health Equity*. 2022;6(1):270-277. doi:10.1089/heq.2021.0121

31. Taeuber KE, Wilson FD. The Demographic Impact of School Desegregation Policy. In: Kraft ME, Schneider M, eds. *Population Analysis*. Lexington Books; 1978:135-152.

32. Logan JR, Oakley D, Stowell J. School Segregation in Metropolitan Regions, 1970–2000: The Impacts of Policy Choices on Public Education. *American Journal of Sociology*. 2008;113(6):1611-1644. doi:10.1086/587150

33. World Health Organization. *Coronavirus Disease 2019 (COVID-19) Situation Report – 51*. World Health Organization; 2020. https://iris.who.int/bitstream/handle/10665/331475/nCoVsitrep11Mar2020-eng.pdf?sequence=1&isAllowed=y

34. Crimmins EM, Kim JK, Langa KM, Weir DR. Assessment of Cognition Using Surveys and Neuropsychological Assessment: The Health and Retirement Study and the Aging, Demographics, and Memory Study. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences*. 2011;66B(Supplement 1):i162-i171. doi:10.1093/geronb/gbr048

35. Langa KM, Larson EB, Crimmins EM, et al. A Comparison of the Prevalence of Dementia in the United States in 2000 and 2012. *JAMA Intern Med*. 2017;177(1):51-58. doi:10.1001/jamainternmed.2016.6807

36. Reber SJ. Court-Ordered Desegregation: Successes and Failures Integrating American Schools since Brown versus Board of Education. *The Journal of Human Resources*. 2005;40(3):559-590.

37. Gill TM, Zang EX, Murphy TE, et al. Association Between Neighborhood Disadvantage and Functional Well-being in Community-Living Older Persons. *JAMA Intern Med*. 2021;181(10):1297-1304. doi:10.1001/jamainternmed.2021.4260

38. Lin Z, Chen X. Place of Birth and Cognitive Function Among Older Americans: Findings From the Harmonized Cognitive Assessment Protocol. *The Journals of Gerontology: Series B*. 2024;79(9):gbae126. doi:10.1093/geronb/gbae126

39. Liu SY, Glymour MM, Zahodne LB, Weiss C, Manly JJ. Role of Place in Explaining Racial Heterogeneity in Cognitive Outcomes among Older Adults. *Journal of the International Neuropsychological Society*. 2015;21(9):677-687. doi:10.1017/S1355617715000806

40. Alzheimer's Association. 2023 Alzheimer's disease facts and figures. *Alzheimer's & Dementia*. 2023;19:1598-1695. doi:10.1002/alz.13016

41. Zhang Z, Hayward MD, Yu YL. Life Course Pathways to Racial Disparities in Cognitive Impairment among Older Americans. *J Health Soc Behav*. 2016;57(2):184-199. doi:10.1177/0022146516645925

42. Glymour MM, Manly JJ. Lifecourse Social Conditions and Racial and Ethnic Patterns of Cognitive Aging. *Neuropsychol Rev*. 2008;18(3):223-254. doi:10.1007/s11065-008-9064-z

43. Lin Z, Yin X, Levy BR, Yuan Y, Chen X. Association of Family Support With Lower Modifiable Risk Factors for Dementia Among Cognitively Impaired Older Adults. *The American Journal of Geriatric Psychiatry*. 2024;32(10):1187-1199. doi:10.1016/j.jagp.2024.05.005

44. Luke DA. *Multilevel Modeling*. 2nd ed. SAGE Publications; 2019. https://books.google.com/books?id=5_vDDwAAQBAJ

45. Tani Y, Fujiwara T, Kondo K. Association Between Adverse Childhood Experiences and Dementia in Older Japanese Adults. *JAMA Network Open*. 2020;3(2):e1920740-e1920740. doi:10.1001/jamanetworkopen.2019.20740

46. Morency MM, Reynolds AJ, Loveman-Brown M, Kritzik R, Ou SR. Structural Equality and Support Index in Early Childhood Education. *JAMA Netw Open*. 2024;7(8):e2432050. doi:10.1001/jamanetworkopen.2024.32050

47. U. S. Government Accountability Office. K-12 Education: Student Population Has Significantly Diversified, but Many Schools Remain Divided Along Racial, Ethnic, and

Economic Lines | U.S. GAO. August 30, 2022. Accessed September 5, 2023. https://www.gao.gov/products/gao-22-104737

48. Reardon SF, Owens A. 60 Years After Brown: Trends and Consequences of School Segregation. *Annual Review of Sociology*. 2014;40(Volume 40, 2014):199-218. doi:https://doi.org/10.1146/annurev-soc-071913-043152

49. Crowe M, Clay OJ, Martin RC, et al. Indicators of Childhood Quality of Education in Relation to Cognitive Function in Older Adulthood. *The Journals of Gerontology: Series A*. 2013;68(2):198-204. doi:10.1093/gerona/gls122

50. 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 Neurol*. 2023;80(4):352-359. doi:10.1001/jamaneurol.2022.5337

51. Hanushek E, Rivkin S. *School Quality and the Black-White Achievement Gap*. National Bureau of Economic Research; 2006:w12651. doi:10.3386/w12651

52. Elder TE, Figlio DN, Imberman SA, Persico CL. School Segregation and Racial Gaps in Special Education Identification. *Journal of Labor Economics*. 2021;39(S1):S151-S197. doi:10.1086/711421

53. Condron DJ, Roscigno VJ. Disparities within: Unequal Spending and Achievement in an Urban School District. *Sociology of Education*. 2003;76(1):18-36. doi:10.2307/3090259

54. Rivkin SG. School Desegregation, Academic Attainment, and Earnings. *The Journal of Human Resources*. 2000;35(2):333-346. doi:10.2307/146328

55. Wu Q, Tchetgen Tchetgen EJ, Osypuk TL, White K, Mujahid M, Maria Glymour M. Combining Direct and Proxy Assessments to Reduce Attrition Bias in a Longitudinal Study. *Alzheimer Disease & Associated Disorders*. 2013;27(3). doi:10.1097/WAD.0b013e31826cfe90

Figure 1. Flow chart of sample selection process

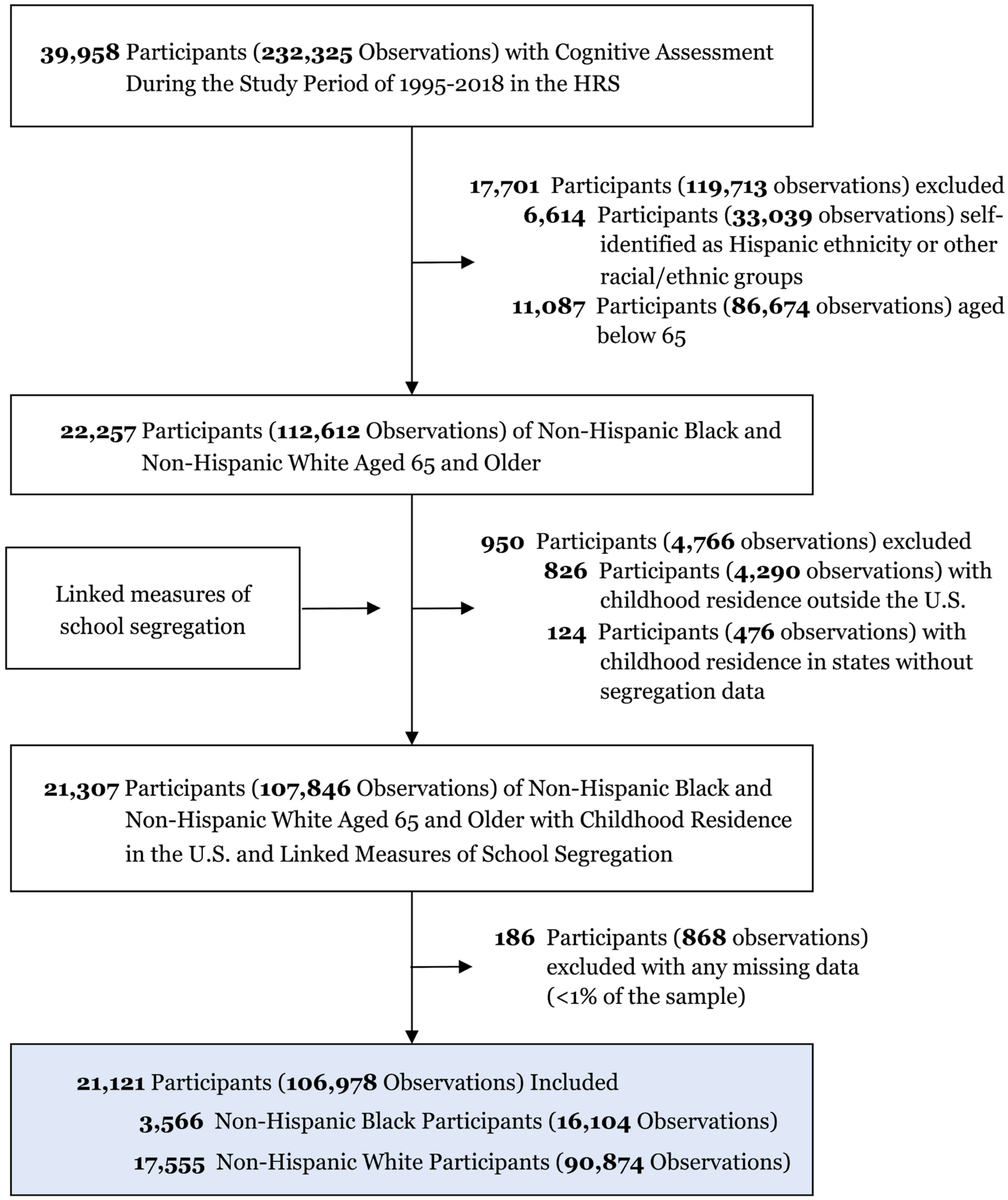
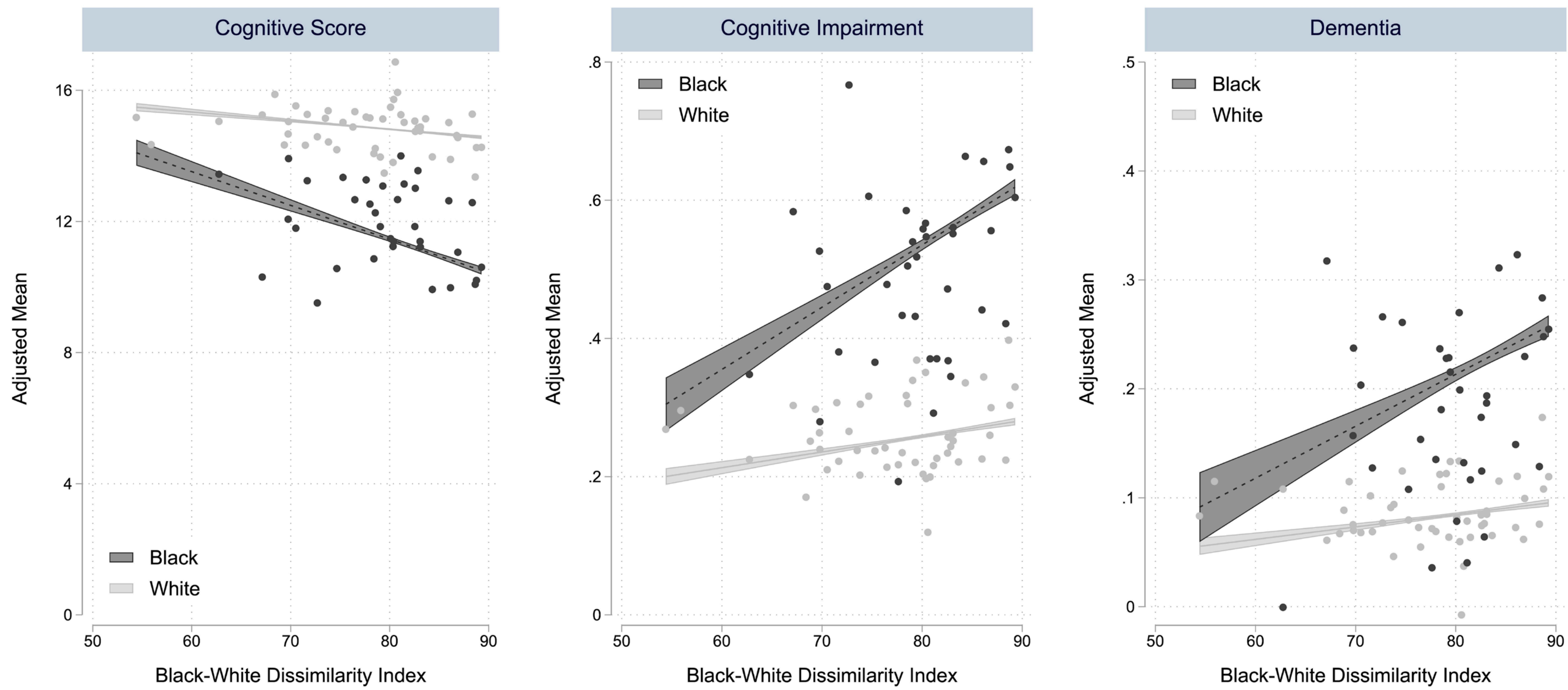
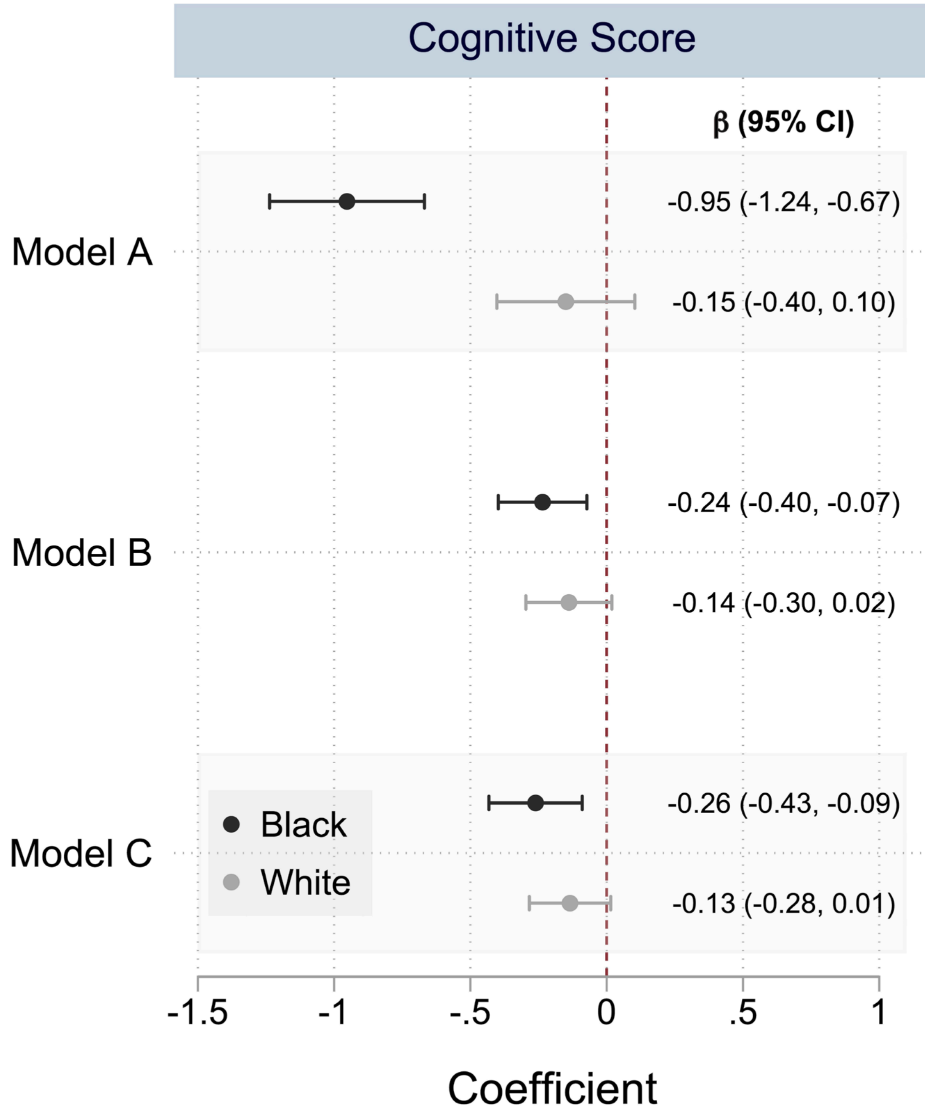


Figure 2. Relationship between Black-White dissimilarity index and cognitive outcomes for Black and White participants in the HRS (1995-2018)



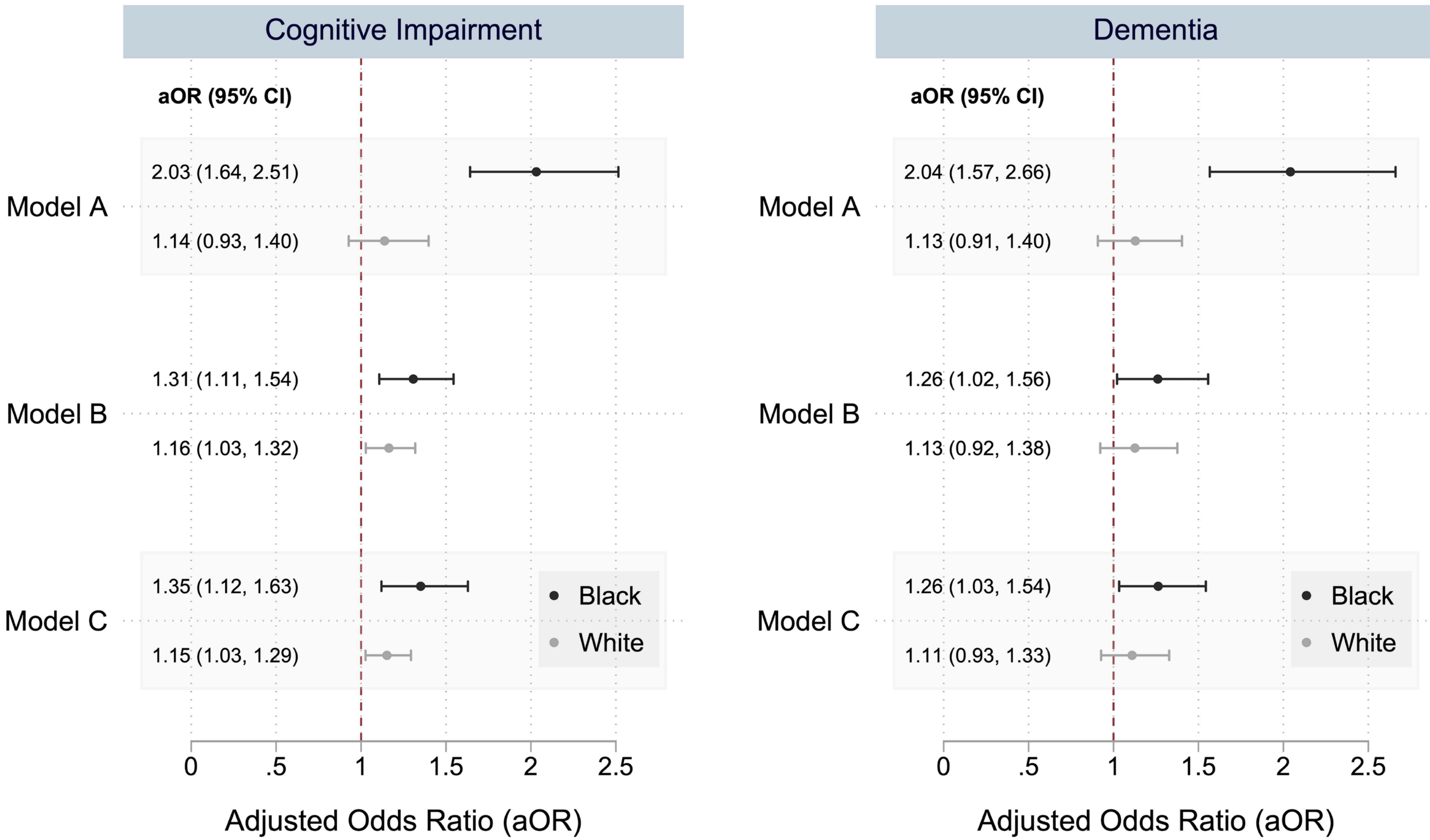
Notes: The figure presents scatterplots of US states demonstrating the inverse relationships between school segregation (measured by Black-White dissimilarity index) and cognitive outcomes in the Health and Retirement Study (HRS, 1995-2018), with dissimilarity index on the x-axis and adjusted cognitive outcomes on the y-axis. The scatterplots are stratified by Black (in black color) and White (in gray color) participants. Black refers to non-Hispanic Black, and White refers to non-Hispanic White. The average cognitive outcomes were estimated respectively for Black and White participants in each state after adjusting for age and sex; and only states with more than 10 observations are plotted. The fitted lines (with 95% CI) denote the linear relationship between Black-White dissimilarity index and adjusted average cognitive outcomes for Black participants (in black color) and White participants (in gray color). Chow cross-equation tests were performed to examine if there were statistically significant differences in fitted slopes between White and Black participants for each cognitive outcome and the results were all statistically significant with P<0.001.

Figure 3. Association between school segregation and cognitive score for Black and White participants in the HRS (1995-2018) estimated using multilevel models



Notes: Multilevel regression models were used to estimate the association between school segregation and cognitive score for Black (in black color) and White participants (in gray color) in the Health and Retirement Study (HRS, 1995-2018). Black refers to non-Hispanic Black, and White refers to non-Hispanic White. Horizontal lines represent the 95% confidence interval, and numerical estimates are displayed alongside each line. Model A adjusted for age, sex, parental education, childhood residence in U.S. Southern States, regional indicators for childhood residence, a birth-year trend indicator, and region-specific birth-year trend interactions. Model B additionally adjusted for early-life mediator, i.e., educational attainment. Model C further added mid-life mediators, including health factors involving hypertension, diabetes, heart diseases, psychiatric conditions, obesity, and smoking behaviors. Random intercepts were included at the state level to account for unobserved heterogeneity and differences between states, while individual-level random intercepts addressed within-individual correlations across multiple observations. Robust standard errors, clustered at the state level, were estimated accounting for within-state correlation. The detailed numerical estimates and mediation results are presented in Supplementary eTables 2-3.

Figure 4. Association between school segregation and cognitive impairment and dementia for Black and White participants in the HRS (1995-2018) estimated using multilevel models



Notes: Multilevel regressions were used to estimate the association between school segregation and cognitive impairment (left panel) and dementia (right panel), for Black (in black color) and White participants (in gray color) in the Health and Retirement Study (HRS, 1995-2018). Black refers to non-Hispanic Black, and White refers to non-Hispanic White. Horizontal lines represent the 95%

confidence interval, and numerical estimates are displayed alongside each line. Model A adjusted for covariates, including age, sex, parental education, childhood residence in U.S. Southern States, regional indicators for childhood residence, a birth-year trend indicator, and region-specific birth-year trend interactions. Model B additionally included early-life mediator, i.e., educational attainment. Model C further added mid-life mediators, including health factors involving hypertension, diabetes, heart diseases, psychiatric conditions, obesity, and smoking behaviors. Random intercepts were included at the state level to account for unobserved heterogeneity and differences between states, while individual-level random intercepts addressed within-individual correlations across multiple observations. Robust standard errors, clustered at the state level, were estimated accounting for within-state correlation. The detailed numerical estimates and mediation results are presented in Supplementary eTables 2-3.

Table 1. Characteristics of study sample with low and high level of school segregation in the HRS (1995-2018), No. (%)

	Overall (N=106,978)	Low Segregation (N=80,127)	High Segregation (N=26,851)
School Segregation			
Dissimilarity Index (0-100), mean (SD)	79.9 (5.7)	77.5 (4.6)	86.9 (1.9)
Cognitive Outcomes			
Cognitive Score (0-27), mean (SD)	14.3 (4.6)	14.5 (4.5)	13.6 (4.9)
Cognitive Impairment	32356 (30.2)	22432 (28.0)	9924 (37.0)
Dementia	11238 (10.5)	7448 (9.3)	3790 (14.1)
Covariates			
Age, mean (SD), y	75.6 (7.5)	75.7 (7.5)	75.6 (7.7)
Female	62187 (58.1)	46341 (57.8)	15846 (59.0)
Race			
Non-Hispanic Black	16104 (15.1)	9003 (11.2)	7101 (26.4)
Non-Hispanic White	90874 (84.9)	71124 (88.8)	19750 (73.6)
Mother's Education			
<8 years	23538 (22.0)	16358 (20.4)	7180 (26.7)
8-12 years	62909 (58.8)	48177 (60.1)	14732 (54.9)
>12 years	9640 (9.0)	7635 (9.5)	2005 (7.5)
Unknown	10891 (10.2)	7957 (9.9)	2934 (10.9)
Father's Education			
<8 years	28840 (27.0)	20373 (25.4)	8467 (31.5)
8-12 years	53643 (50.1)	41313 (51.6)	12330 (45.9)
>12 years	9549 (8.9)	7667 (9.6)	1882 (7.0)
Unknown	14946 (14.0)	10774 (13.4)	4172 (15.5)

Childhood Residence in U.S. Southern States	38340 (35.8)	22446 (28.0)	15894 (59.2)
Early-Life Mediators - Education			
Years of Educational Attainment, mean (SD)	12.4 (3.0)	12.6 (2.8)	11.8 (3.4)
Mid-Life Mediators - Health Factors			
Hypertension	65811 (61.5)	48732 (60.8)	17079 (63.6)
Diabetes	22332 (20.9)	16469 (20.6)	5863 (21.8)
Heart Diseases	34440 (32.2)	25701 (32.1)	8739 (32.5)
Psychiatric Conditions	15447 (14.4)	11450 (14.3)	3997 (14.9)
Obesity	36569 (34.2)	26917 (33.6)	9652 (35.9)
Smoking			
Never smoking	45996 (43.0)	33616 (42.0)	12380 (46.1)
Ever smoking	51214 (47.9)	39341 (49.1)	11873 (44.2)
Currently smoking	9768 (9.1)	7170 (8.9)	2598 (9.7)

Abbreviations: HRS=Health and Retirement Study, SD=standard deviation, ADL=activities of daily living, IADL=instrumental activities of daily living.
Notes: Differences in characteristics between sample with high and low level of school segregation were assessed using appropriate statistical tests: Chi-square tests for categorical variables and Welch t-tests for continuous variables. The test results are presented in Supplementary eTable 1.

Appendix

Supplementary eFigure 14. Sensitivity analysis using self-reported time-varying measures of school segregation exposure with additional adjustment for state-level geographical and temporal variations: association between school segregation and cognitive impairment and dementia by race

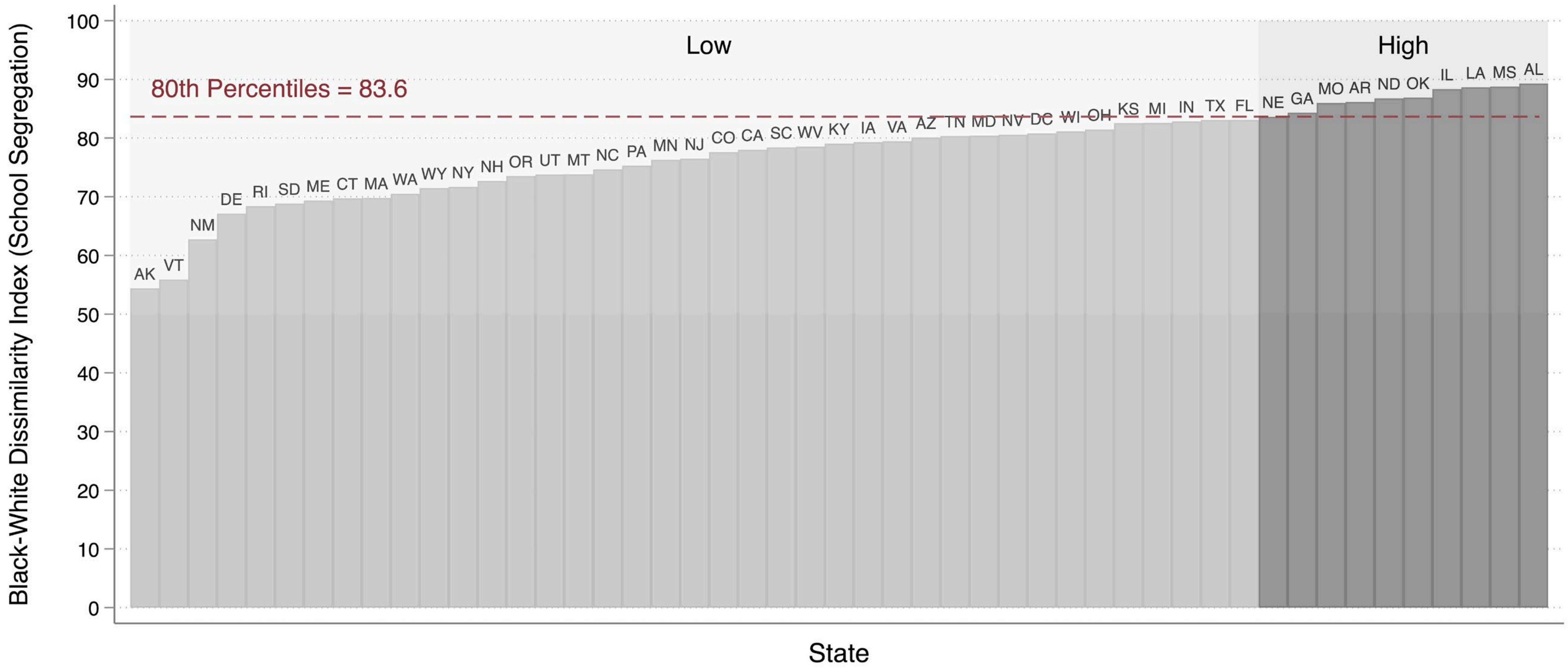
Supplementary eTable 1. Differences in characteristics between sample with high vs. low level of school segregation assessed using appropriate statistical tests

Supplementary eTable 2. Association between school segregation and cognitive outcomes for Black participants in the HRS (1995-2018)

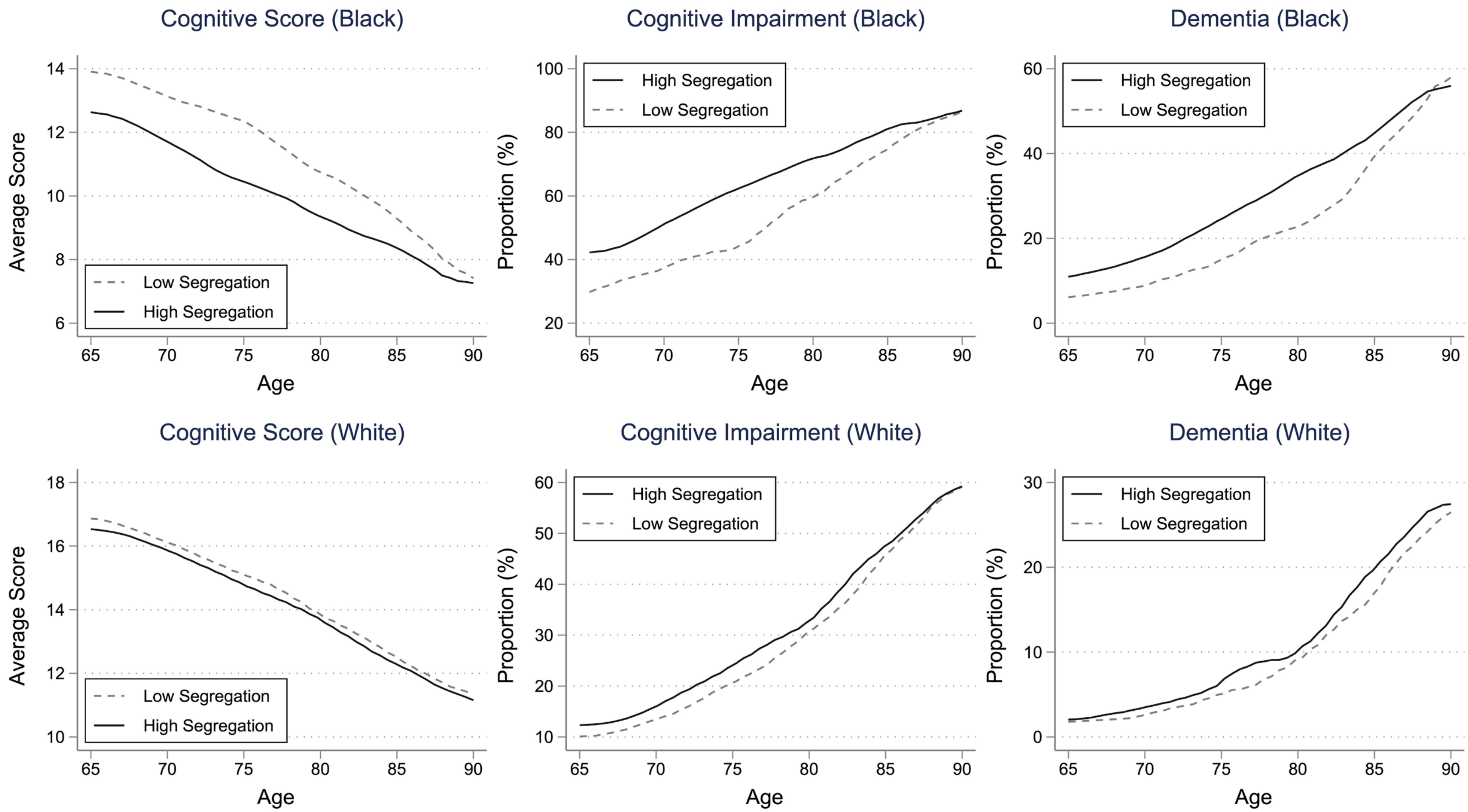
Supplementary eTable 3. Association between school segregation and cognitive outcomes for White participants in the HRS (1995-2018)

eAppendix A. Sensitivity Analyses

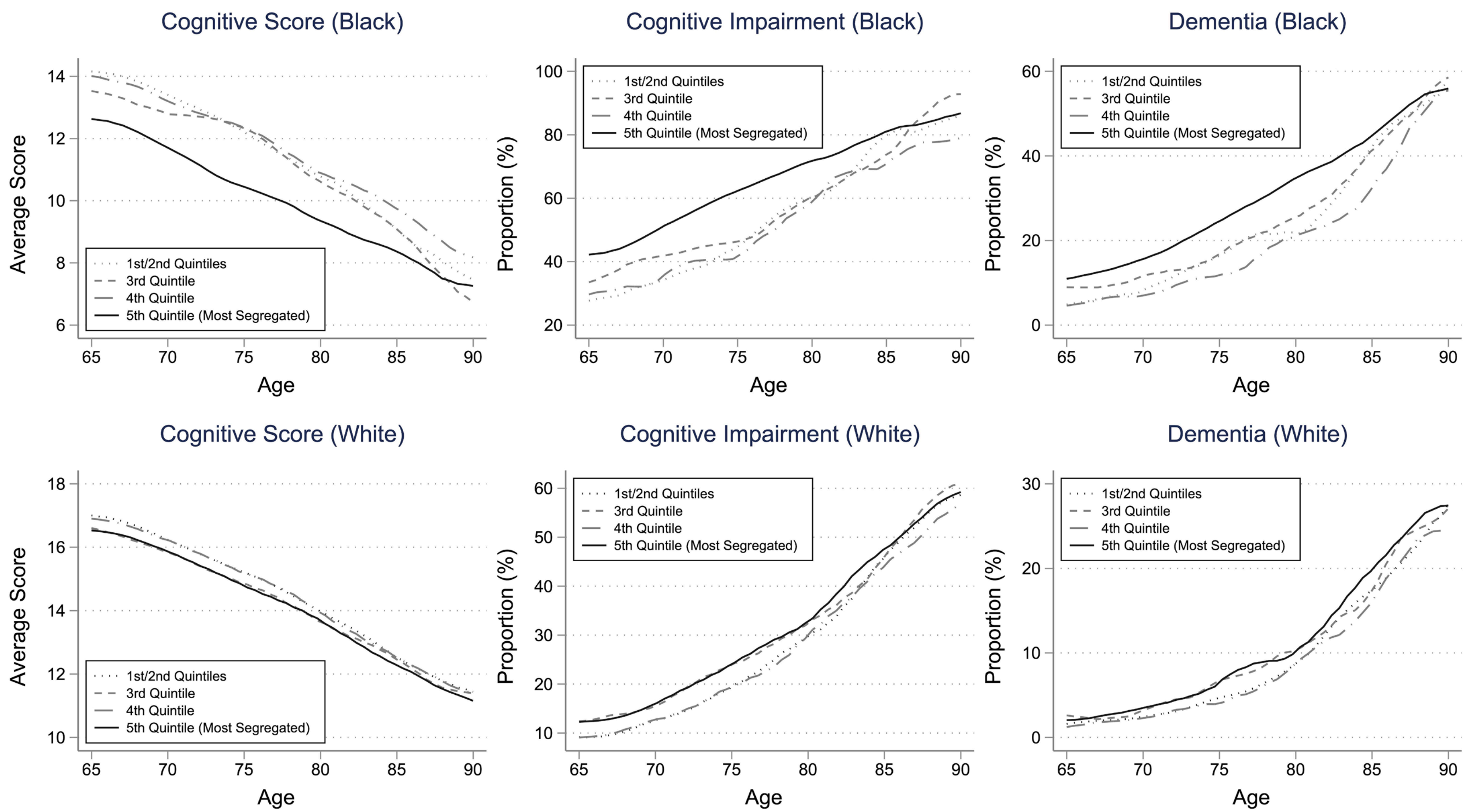
Supplementary eFigure 1. Distribution of school segregation at the state level



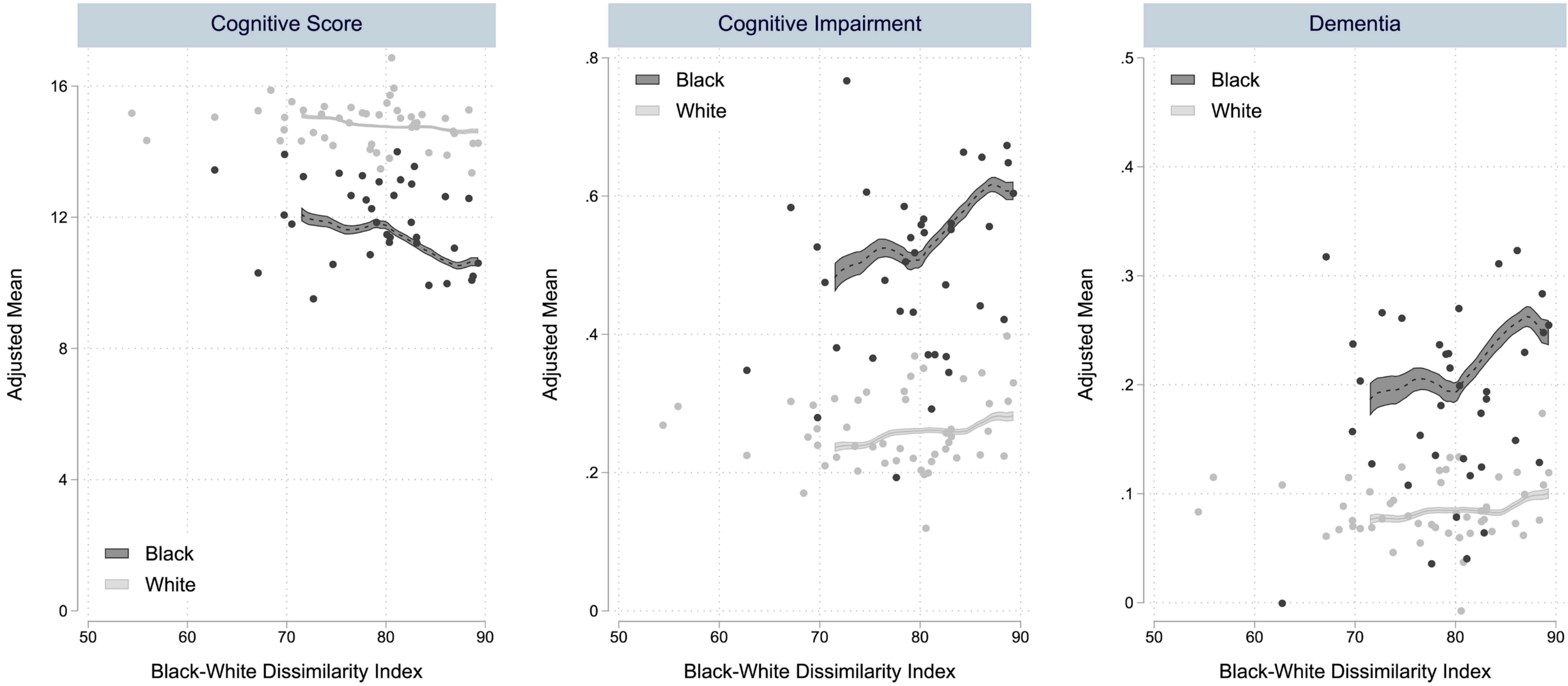
Supplementary eFigure 2. Age trend in cognitive outcomes by low vs. high levels of school segregation for Black and White participants in the HRS



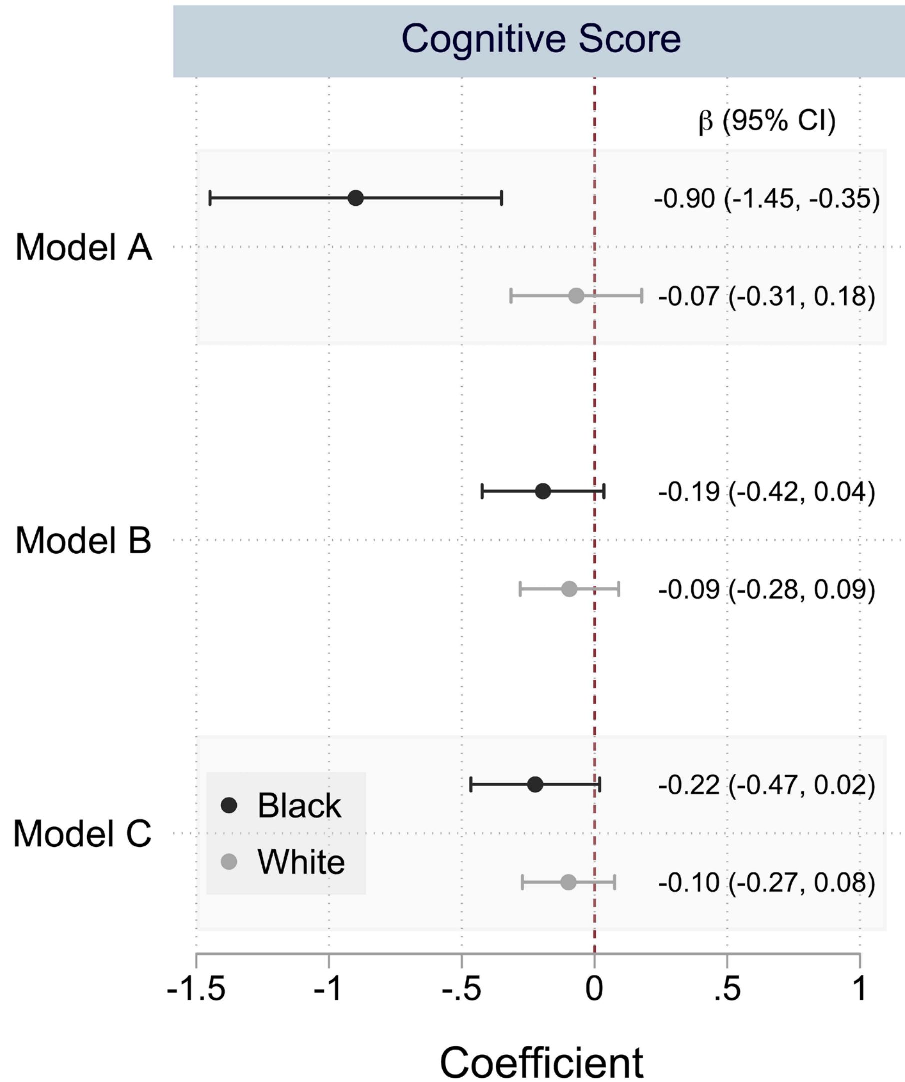
Supplementary eFigure 3. Age trend in cognitive outcomes by quintiles of segregation index for Black and White participants in the HRS



Supplementary eFigure 4. Relationship between Black-White dissimilarity index and cognitive outcomes for Black and White participants in the HRS (non-linear)

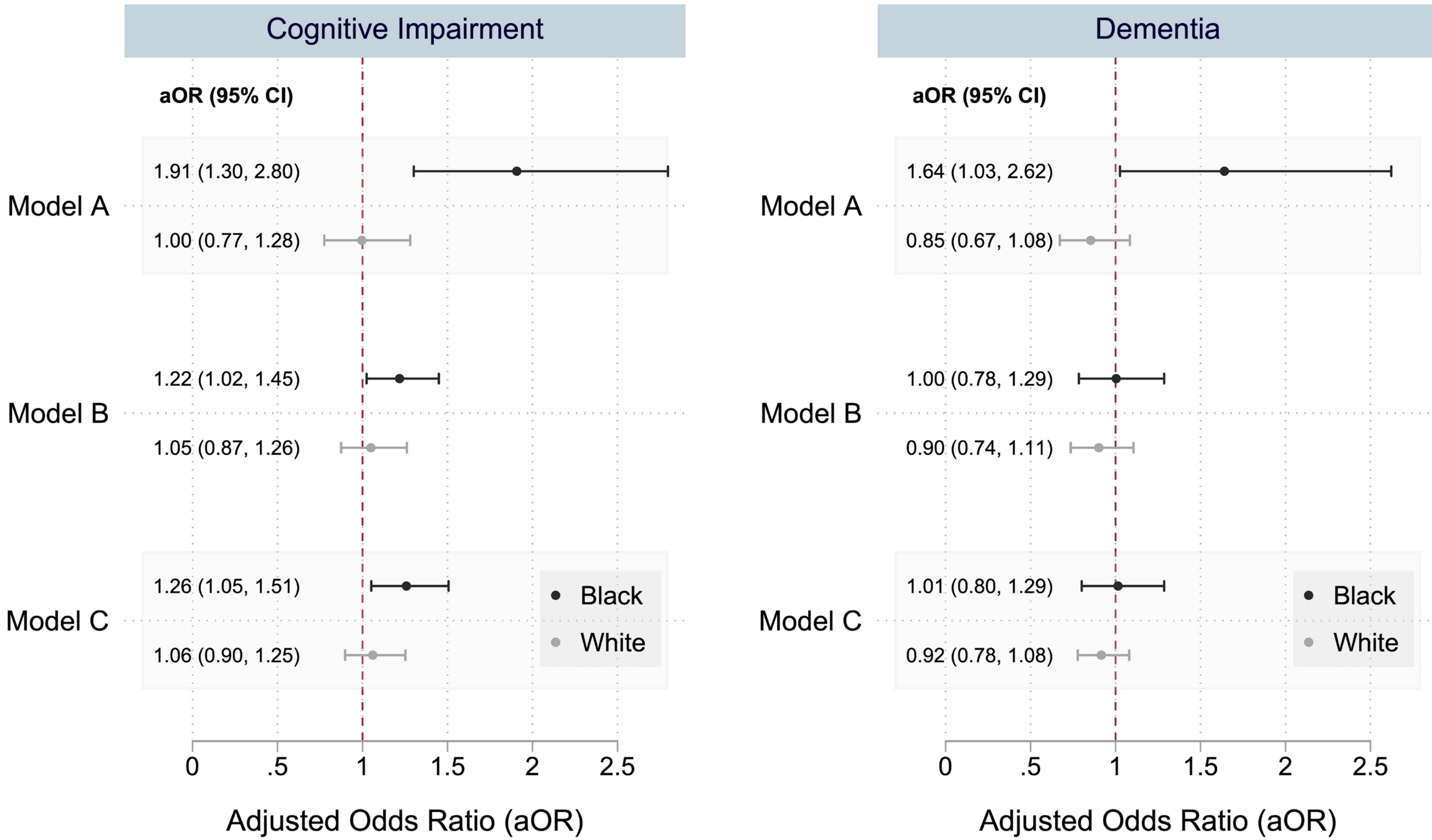


Supplementary eFigure 5. Sensitivity analysis using the highest tertile as cutoff for low vs. high level of segregation: association between school segregation and cognitive score by race



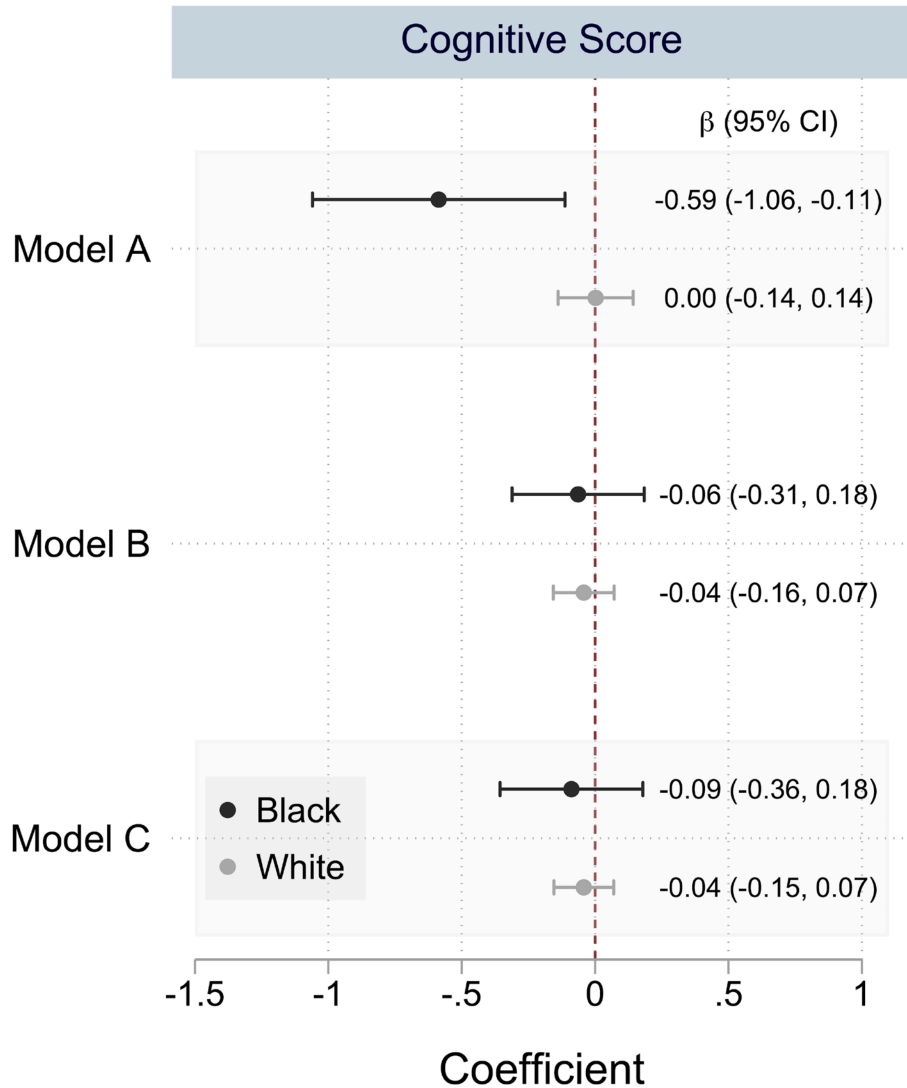
Notes: Multilevel regression models were used to estimate the association between school segregation and cognitive score for Black (in black color) and White participants (in gray color) in the Health and Retirement Study (HRS, 1995-2018). Black refers to non-Hispanic Black, and White refers to non-Hispanic White. Horizontal lines represent the 95% confidence interval, and numerical estimates are displayed alongside each line. In the sensitivity analyses, we redefined the threshold for high levels of school segregation, using a less extreme cutoff (the top tertile instead of the top quintile). Model A adjusted for covariates, including age, sex, parental education, childhood residence in U.S. Southern States, regional indicators for childhood residence, a birth-year trend indicator, and region-specific birth-year trend interactions. Model B additionally included early-life mediator, i.e., educational attainment. Model C further added mid-life mediators, including health factors involving hypertension, diabetes, heart diseases, psychiatric conditions, obesity, and smoking behaviors. Random intercepts were included at the state level to account for unobserved heterogeneity and differences between states, while individual-level random intercepts addressed within-individual correlations across multiple observations. Robust standard errors, clustered at the state level, were estimated accounting for within-state correlation.

Supplementary eFigure 6. Sensitivity analysis using the highest tertile as cutoff for low vs. high level of segregation: association between school segregation and cognitive impairment and dementia by race



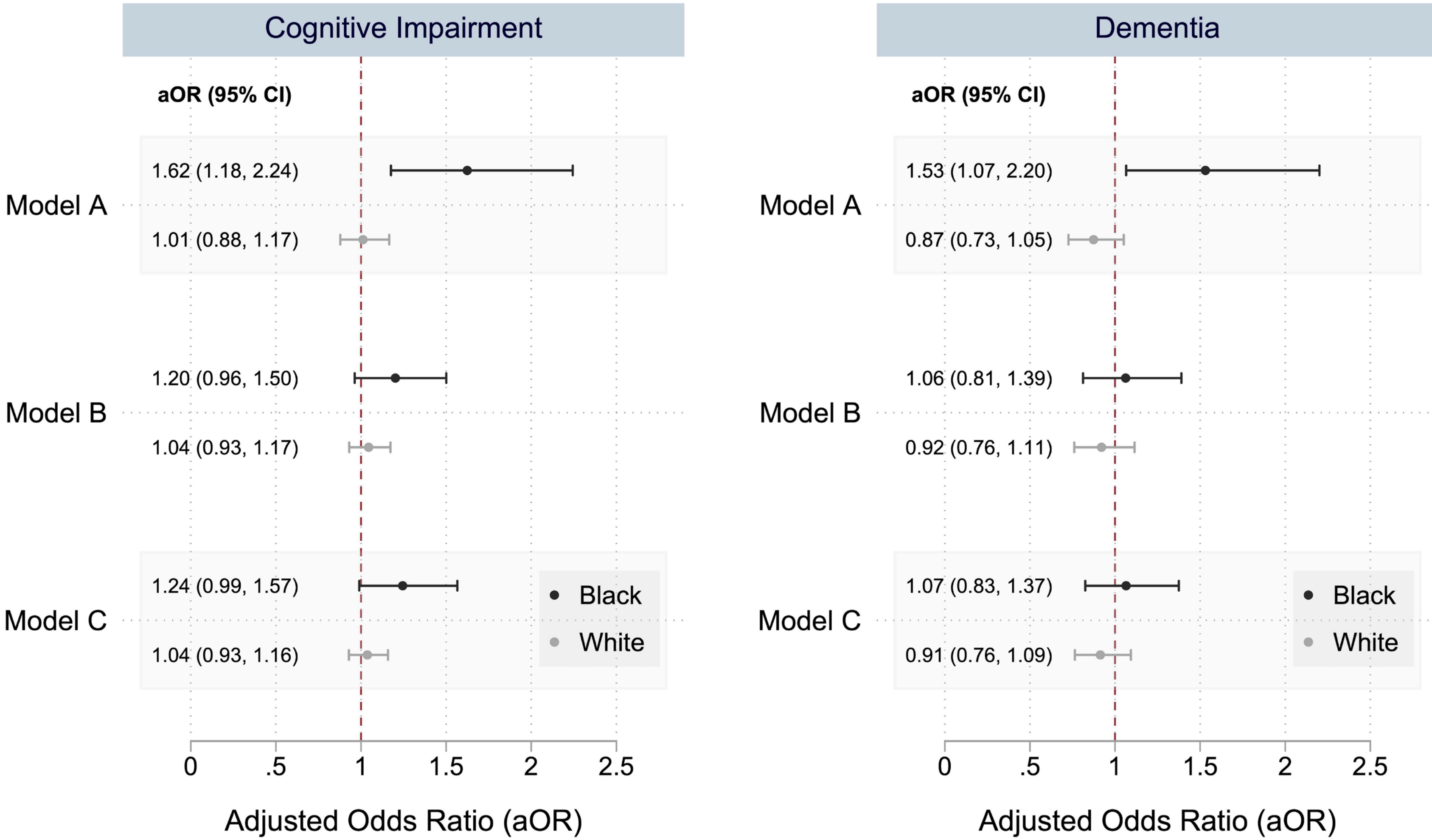
interval, and numerical estimates are displayed alongside each line. In the sensitivity analyses, we redefined the threshold for high levels of school segregation, using a less extreme cutoff (the top tertile instead of the top quintile). Model A adjusted for covariates, including age, sex, parental education, childhood residence in U.S. Southern States, regional indicators for childhood residence, a birth-year trend indicator, and region-specific birth-year trend interactions. Model B additionally included early-life mediator, i.e., educational attainment. Model C further added mid-life mediators, including health factors involving hypertension, diabetes, heart diseases, psychiatric conditions, obesity, and smoking behaviors. Random intercepts were included at the state level to account for unobserved heterogeneity and differences between states, while individual-level random intercepts addressed within-individual correlations across multiple observations. Robust standard errors, clustered at the state level, were estimated accounting for within-state correlation.

Supplementary eFigure 7. Sensitivity analysis using the continuous specification of school segregation (i.e., Black-White dissimilarity index): association between school segregation and cognitive score by race



Notes: Multilevel regression models were used to estimate the association between school segregation and cognitive score for Black (in black color) and White participants (in gray color) in the Health and Retirement Study (HRS, 1995-2018). Black refers to non-Hispanic Black, and White refers to non-Hispanic White. Horizontal lines represent the 95% confidence interval, and numerical estimates are displayed alongside each line. In the sensitivity analyses, we employed a continuous measure of school segregation, represented by the dissimilarity index, rather than using a dichotomous classification (low vs. high segregation). Model A adjusted for covariates, including age, sex, parental education, childhood residence in U.S. Southern States, regional indicators for childhood residence, a birth-year trend indicator, and region-specific birth-year trend interactions. Model B additionally included early-life mediator, i.e., educational attainment. Model C further added mid-life mediators, including health factors involving hypertension, diabetes, heart diseases, psychiatric conditions, obesity, and smoking behaviors. Random intercepts were included at the state level to account for unobserved heterogeneity and differences between states, while individual-level random intercepts addressed within-individual correlations across multiple observations. Robust standard errors, clustered at the state level, were estimated accounting for within-state correlation.

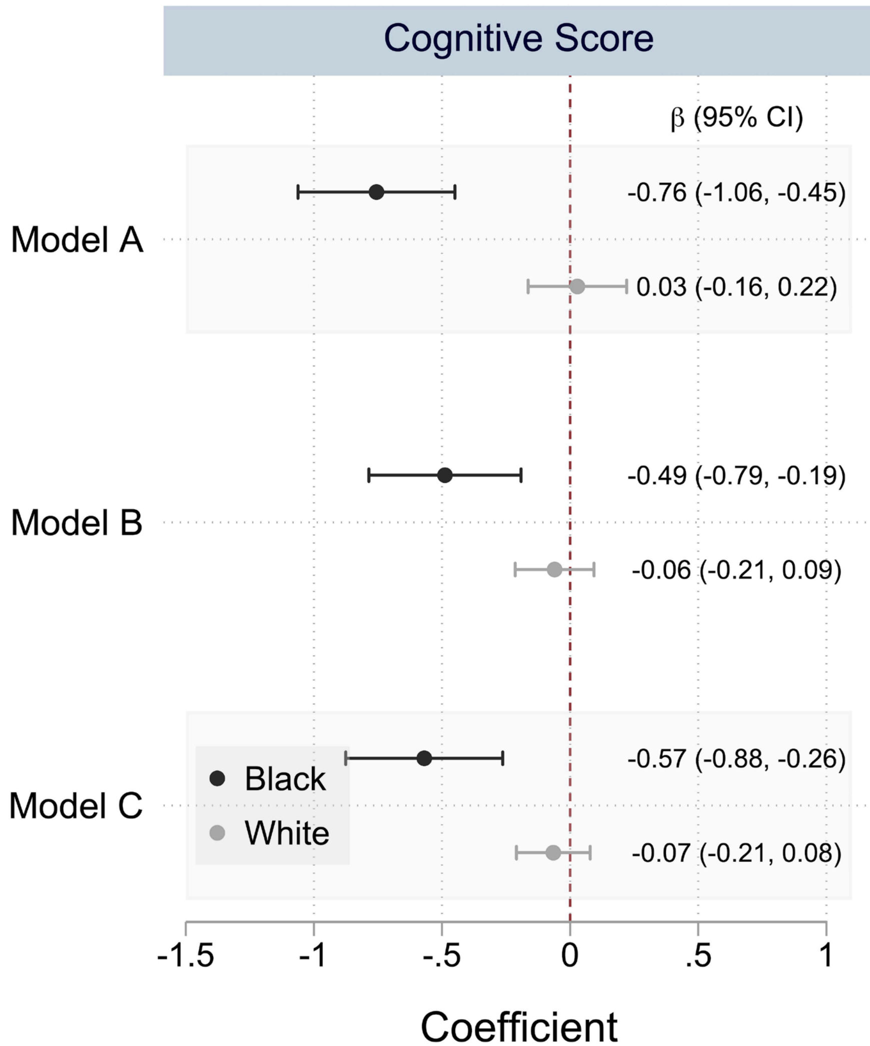
Supplementary eFigure 8. Sensitivity analysis using the continuous specification of school segregation (i.e., Black-White dissimilarity index): association between school segregation and cognitive impairment and dementia by race



Notes: Multilevel regressions were used to estimate the association between school segregation and cognitive impairment (left panel) and dementia (right panel), for Black (in black color) and White participants (in gray color) in the Health and Retirement Study (HRS, 1995-2018). Black refers to non-Hispanic Black, and White refers to non-Hispanic White. Horizontal lines represent the 95% confidence

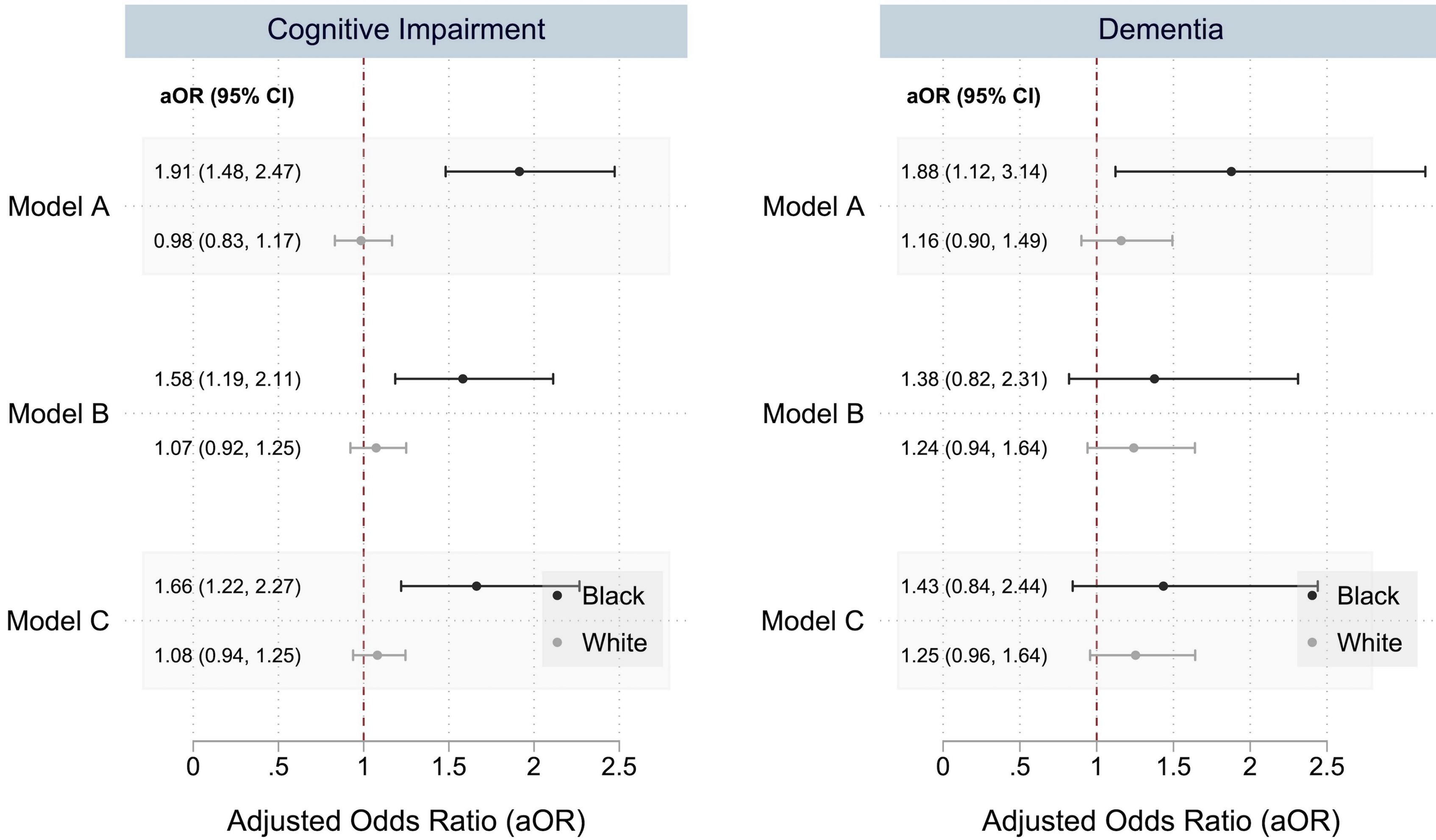
interval, and numerical estimates are displayed alongside each line. In the sensitivity analyses, we employed a continuous measure of school segregation, represented by the dissimilarity index, rather than using a dichotomous classification (low vs. high segregation). Model A adjusted for covariates, including age, sex, parental education, childhood residence in U.S. Southern States, regional indicators for childhood residence, a birth-year trend indicator, and region-specific birth-year trend interactions. Model B additionally included early-life mediator, i.e., educational attainment. Model C further added mid-life mediators, including health factors involving hypertension, diabetes, heart diseases, psychiatric conditions, obesity, and smoking behaviors. Random intercepts were included at the state level to account for unobserved heterogeneity and differences between states, while individual-level random intercepts addressed within-individual correlations across multiple observations. Robust standard errors, clustered at the state level, were estimated accounting for within-state correlation.

Supplementary eFigure 9. Sensitivity analysis with sample restricted to participants who lived in urban areas during childhood: association between school segregation and cognitive score by race



Notes: Multilevel regression models were used to estimate the association between school segregation and cognitive score for Black (in black color) and White participants (in gray color) in the Health and Retirement Study (HRS, 1995-2018). Black refers to non-Hispanic Black, and White refers to non-Hispanic White. Horizontal lines represent the 95% confidence interval, and numerical estimates are displayed alongside each line. In the sensitivity analyses, we restricted our sample to participants who lived in urban areas during childhood. The segregation measure is the same as the main setting. Model A adjusted for covariates, including age, sex, parental education, childhood residence in U.S. Southern States, regional indicators for childhood residence, a birth-year trend indicator, and region-specific birth-year trend interactions. Model B additionally included early-life mediator, i.e., educational attainment. Model C further added mid-life mediators, including health factors involving hypertension, diabetes, heart diseases, psychiatric conditions, obesity, and smoking behaviors. Random intercepts were included at the state level to account for unobserved heterogeneity and differences between states, while individual-level random intercepts addressed within-individual correlations across multiple observations. Robust standard errors, clustered at the state level, were estimated accounting for within-state correlation.

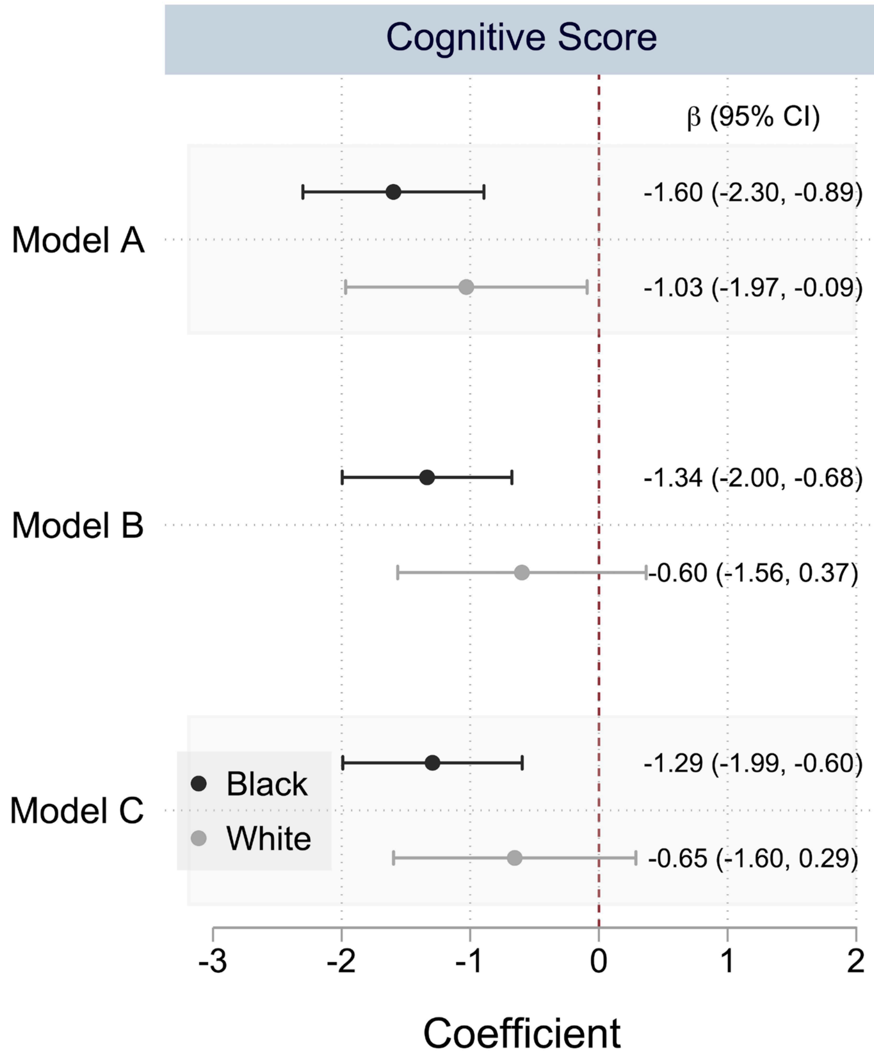
Supplementary eFigure 10. Sensitivity analysis with sample restricted to participants who lived in urban areas during childhood: association between school segregation and cognitive impairment and dementia by race



Notes: Multilevel regressions were used to estimate the association between school segregation and cognitive impairment (left panel) and dementia (right panel), for Black (in black color) and White participants (in gray color) in the Health and Retirement Study (HRS, 1995-2018). Black refers to non-Hispanic Black, and White refers to non-Hispanic White. Horizontal lines represent the 95% confidence

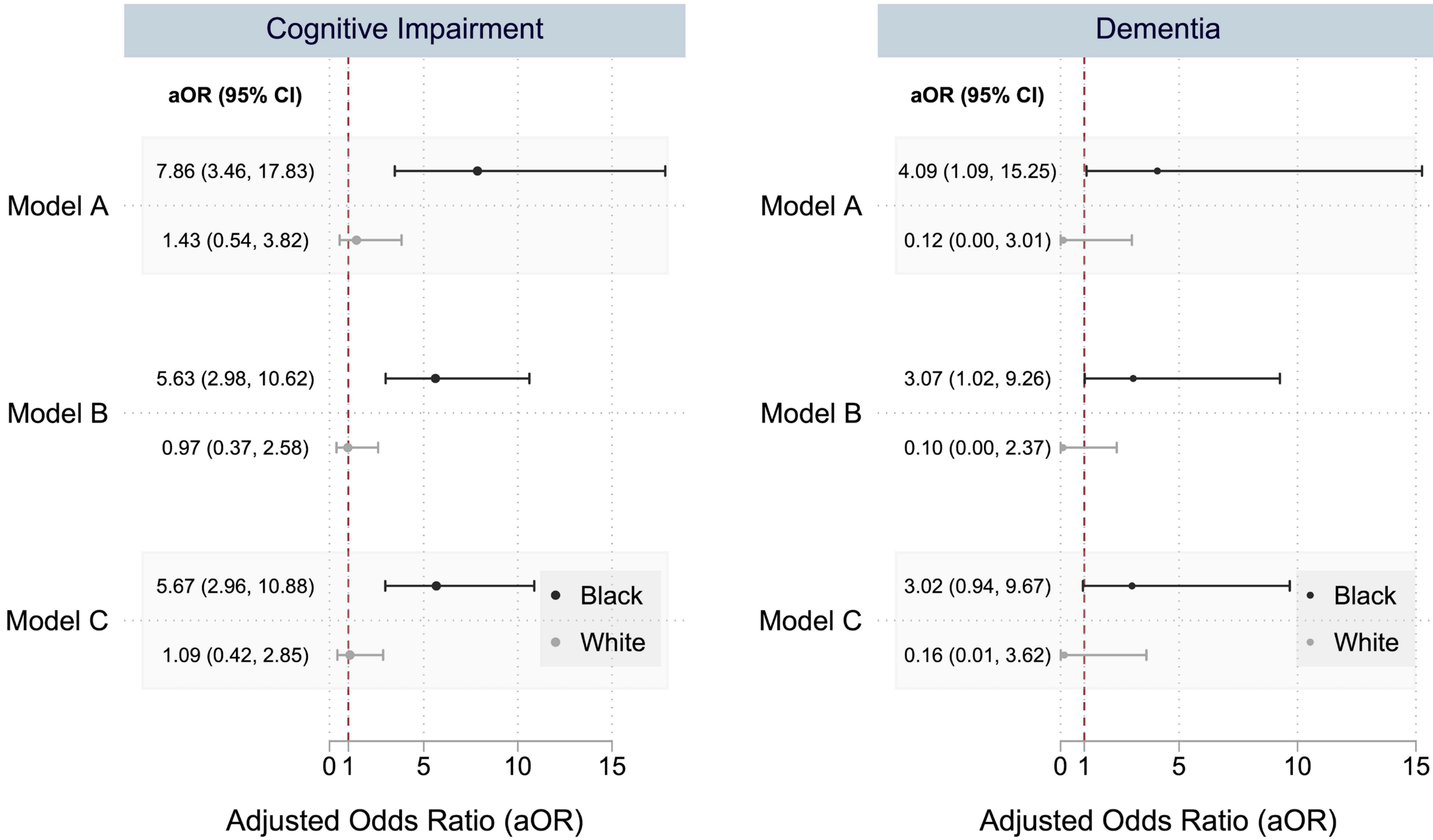
interval, and numerical estimates are displayed alongside each line. In the sensitivity analyses, we restricted our sample to participants who lived in urban areas during childhood. The segregation measure is the same as the main setting. Model A adjusted for covariates, including age, sex, parental education, childhood residence in U.S. Southern States, regional indicators for childhood residence, a birth-year trend indicator, and region-specific birth-year trend interactions. Model B additionally included early-life mediator, i.e., educational attainment. Model C further added mid-life mediators, including health factors involving hypertension, diabetes, heart diseases, psychiatric conditions, obesity, and smoking behaviors. Random intercepts were included at the state level to account for unobserved heterogeneity and differences between states, while individual-level random intercepts addressed within-individual correlations across multiple observations. Robust standard errors, clustered at the state level, were estimated accounting for within-state correlation.

Supplementary eFigure 11. Sensitivity analysis using self-reported time-varying measures of school segregation exposure: association between school segregation and cognitive score by race



Notes: Multilevel regression models were used to estimate the association between school segregation and cognitive score for Black (in black color) and White participants (in gray color) in the Health and Retirement Study (HRS, 1995-2018). Black refers to non-Hispanic Black, and White refers to non-Hispanic White. Horizontal lines represent the 95% confidence interval, and numerical estimates are displayed alongside each line. In the sensitivity analyses, we used a more time-varying, self-reported measure of school segregation from the HRS life history survey. Specifically, HRS participants who completed the life history mailed survey in 2015-2017 were asked to report the schools they attended during their primary education and whether the majority of children in each school were White, Black, Hispanic or others. School was classified as segregated if most children in the school were Black, Hispanic or others. If the schools the participants attended during primary education were segregated schools, they were coded as 1 (and 0 otherwise). Model A adjusted for covariates, including age, sex, parental education, childhood residence in U.S. Southern States, regional indicators for childhood residence, a birth-year trend indicator, and region-specific birth-year trend interactions. Model B additionally included early-life mediator, i.e., educational attainment. Model C further added mid-life mediators, including health factors involving hypertension, diabetes, heart diseases, psychiatric conditions, obesity, and smoking behaviors. Random intercepts were included at the state level to account for unobserved heterogeneity and differences between states, while individual-level random intercepts addressed within-individual correlations across multiple observations. Robust standard errors, clustered at the state level, were estimated accounting for within-state correlation.

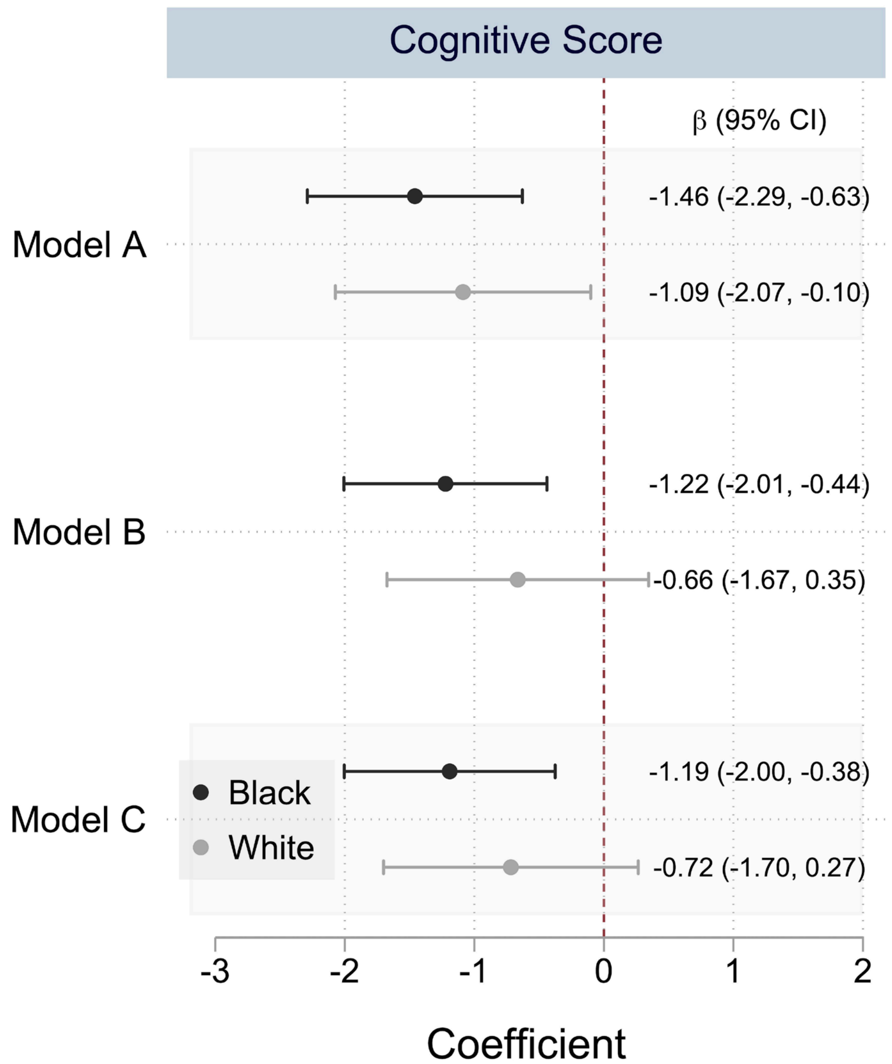
Supplementary eFigure 12. Sensitivity analysis using self-reported time-varying measures of school segregation exposure: association between school segregation and cognitive impairment and dementia by race



Notes: Multilevel regressions were used to estimate the association between school segregation and cognitive impairment (left panel) and dementia (right panel), for Black (in black color) and White participants (in gray color) in the Health and Retirement Study (HRS, 1995-2018). Black refers to non-Hispanic Black, and White refers to non-Hispanic White. Horizontal lines represent the 95% confidence

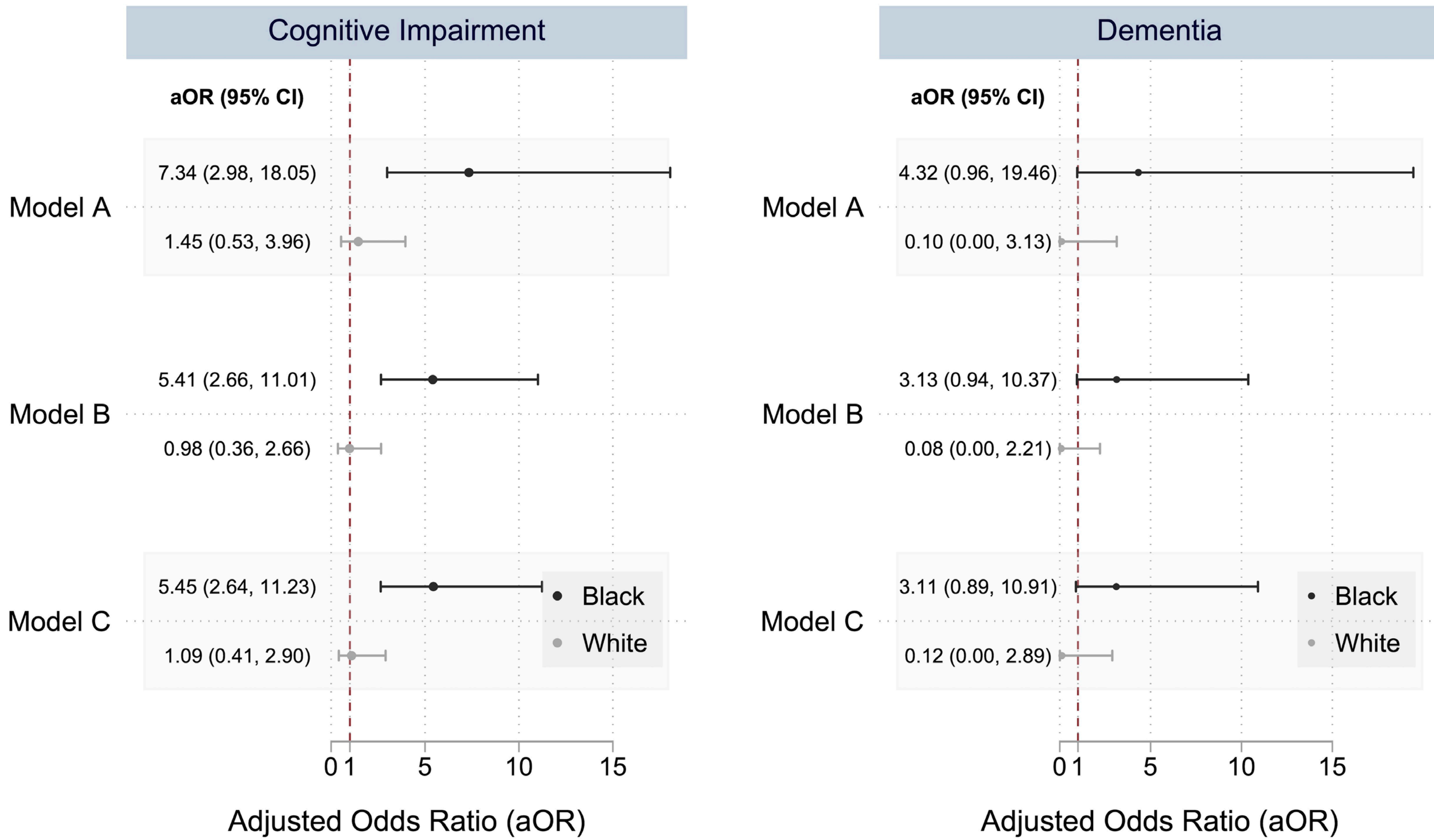
interval, and numerical estimates are displayed alongside each line. In the sensitivity analyses, we used a more time-varying, self-reported measure of school segregation from the HRS life history survey. Specifically, HRS participants who completed the life history mailed survey in 2015-2017 were asked to report the schools they attended during their primary education and whether the majority of children in each school were White, Black, Hispanic or others. School was classified as segregated if most children in the school were Black, Hispanic or others. If the schools the participants attended during primary education were segregated schools, they were coded as 1 (and 0 otherwise). Model A adjusted for covariates, including age, sex, parental education, childhood residence in U.S. Southern States, regional indicators for childhood residence, a birth-year trend indicator, and region-specific birth-year trend interactions. Model B additionally included early-life mediator, i.e., educational attainment. Model C further added mid-life mediators, including health factors involving hypertension, diabetes, heart diseases, psychiatric conditions, obesity, and smoking behaviors. Random intercepts were included at the state level to account for unobserved heterogeneity and differences between states, while individual-level random intercepts addressed within-individual correlations across multiple observations. Robust standard errors, clustered at the state level, were estimated accounting for within-state correlation.

Supplementary eFigure 13. Sensitivity analysis using self-reported time-varying measures of school segregation exposure with additional adjustment for state-level geographical and temporal variations: association between school segregation and cognitive score by race



Notes: Multilevel regression models were used to estimate the association between school segregation and cognitive score for Black (in black color) and White participants (in gray color) in the Health and Retirement Study (HRS, 1995-2018). Black refers to non-Hispanic Black, and White refers to non-Hispanic White. Horizontal lines represent the 95% confidence interval, and numerical estimates are displayed alongside each line. In the sensitivity analyses, we used a more time-varying, self-reported measure of school segregation from the HRS life history survey (If the schools the participants attended during primary education were segregated schools, they were coded as 1 and 0 otherwise). Moreover, we introduced state-level birth-year trend indicators to account for potential geographical and time-varying confounding. Model A adjusted for covariates, including age, sex, parental education, childhood residence in U.S. Southern States, regional indicators for childhood residence, a birth-year trend indicator, and region-specific birth-year trend interactions. Model B additionally included early-life mediator, i.e., educational attainment. Model C further added mid-life mediators, including health factors involving hypertension, diabetes, heart diseases, psychiatric conditions, obesity, and smoking behaviors. Random intercepts were included at the state level to account for unobserved heterogeneity and differences between states, while individual-level random intercepts addressed within-individual correlations across multiple observations. Robust standard errors, clustered at the state level, were estimated accounting for within-state correlation.

Supplementary eFigure 14. Sensitivity analysis using self-reported time-varying measures of school segregation exposure with additional adjustment for state-level geographical and temporal variations: association between school segregation and cognitive impairment and dementia by race



Notes: Multilevel regressions were used to estimate the association between school segregation and cognitive impairment (left panel) and dementia (right panel), for Black (in black color) and White participants (in gray color) in the Health and Retirement Study (HRS, 1995-2018). Black refers to non-Hispanic Black, and White refers to non-Hispanic White. Horizontal lines represent the 95% confidence interval, and numerical estimates are displayed alongside each line. In the sensitivity analyses, we used a more time-varying, self-reported measure of school segregation from the HRS life history survey (If the schools the participants attended during primary education were segregated schools, they were coded as 1 and 0 otherwise). Moreover, we introduced state-level birth-year trend indicators to account for potential geographical and time-varying confounding. Model A adjusted for covariates, including age, sex, parental education, childhood residence in U.S. Southern States, regional indicators for childhood residence, a birth-year trend indicator, and region-specific birth-year trend interactions. Model B additionally included early-life mediator, i.e., educational attainment. Model C further added mid-life mediators, including health factors involving hypertension, diabetes, heart diseases, psychiatric conditions, obesity, and smoking behaviors. Random intercepts were included at the state level to account for unobserved heterogeneity and differences between states, while individual-level random intercepts addressed within-individual correlations across multiple observations. Robust standard errors, clustered at the state level, were estimated accounting for within-state correlation.

Supplementary eTable 1. Differences in characteristics between sample with high vs. low level of school segregation assessed using appropriate statistical tests

	Low Segregation (N=80,127)	High Segregation (N=26,851)	*P*-values [a]
School Segregation			
Dissimilarity Index (0-100), mean (SD)	77.5 (4.6)	86.9 (1.9)	<0.001
Cognitive Outcomes			
Cognitive Score (0-27), mean (SD)	14.5 (4.5)	13.6 (4.9)	<0.001
Cognitive Impairment, No. (%)	22432 (28.0)	9924 (37.0)	<0.001
Dementia, No. (%)	7448 (9.3)	3790 (14.1)	<0.001
Covariates			
Age, mean (SD), y	75.7 (7.5)	75.6 (7.7)	0.13
Female, No. (%)	46341 (57.8)	15846 (59.0)	<0.001
Race			<0.001
Non-Hispanic Black, No. (%)	9003 (11.2)	7101 (26.4)	
Non-Hispanic White, No. (%)	71124 (88.8)	19750 (73.6)	
Mother's Education			<0.001
<8 years, No. (%)	16358 (20.4)	7180 (26.7)	
8-12 years, No. (%)	48177 (60.1)	14732 (54.9)	
>12 years, No. (%)	7635 (9.5)	2005 (7.5)	
Unknown, No. (%)	7957 (9.9)	2934 (10.9)	
Father's Education			<0.001
<8 years, No. (%)	20373 (25.4)	8467 (31.5)	
8-12 years, No. (%)	41313 (51.6)	12330 (45.9)	
>12 years, No. (%)	7667 (9.6)	1882 (7.0)	

Unknown, No. (%)	10774 (13.4)	4172 (15.5)	
Childhood Residence in Southern States, No. (%)	22446 (28.0)	15894 (59.2)	<0.001
Early-Life Mediators - Education			
Years of Educational Attainment, mean (SD)	12.6 (2.8)	11.8 (3.4)	<0.001
Mid-Life Mediators - Health Factors			
Hypertension, No. (%)	48732 (60.8)	17079 (63.6)	<0.001
Diabetes, No. (%)	16469 (20.6)	5863 (21.8)	<0.001
Heart Diseases, No. (%)	25701 (32.1)	8739 (32.5)	0.15
Psychiatric Conditions, No. (%)	11450 (14.3)	3997 (14.9)	0.016
Obesity, No. (%)	26917 (33.6)	9652 (35.9)	<0.001
Smoking			<0.001
Never smoking, No. (%)	33616 (42.0)	12380 (46.1)	
Ever smoking, No. (%)	39341 (49.1)	11873 (44.2)	
Currently smoking, No. (%)	7170 (8.9)	2598 (9.7)	

Abbreviations: SD=standard deviation, ADL=activities of daily living, IADL=instrumental activities of daily living.

[a] Differences in characteristics between sample with high and low level of school segregation were assessed using appropriate statistical tests: Chi-square tests for categorical variables and Welch t-tests for continuous variables.

Supplementary eTable 2. Association between school segregation and cognitive outcomes for Black participants in the HRS (1995-2018)

	Black Participants			
VARIABLES	Model A	Model B	Model C	Association mediated by early-life and mid-life factors
Panel A. Cognitive Score (0-27)		β Coefficient (95% CI)		
School Segregation	-0.95 (-1.24, -0.67)	-0.24 (-0.40, -0.07)	-0.26 (-0.43, -0.09)	73%
Observations	14,209	14,209	14,209	
Panel B. Cognitive Impairment (0/1)		Adjusted Odds Ratio (95% CI)		
School Segregation	2.03 (1.64, 2.51)	1.31 (1.11, 1.54)	1.35 (1.12, 1.63)	58%
Observations	16,104	16,104	16,104	
Panel C. Dementia (0/1)		Adjusted Odds Ratio (95% CI)		
School Segregation	2.04 (1.57, 2.66)	1.26 (1.02, 1.56)	1.26 (1.03, 1.54)	67%
Observations	16,104	16,104	16,104	
Covariates	YES	YES	YES	
Mediators: Educational Attainment	NO	YES	YES	
Mediators: Health Factors	NO	NO	YES	

Notes: Multilevel regressions were used to estimate the association associations between school segregation and cognitive outcomes, including cognitive score (0-27) (Panel A), cognitive impairment (0/1) (Panel B), and dementia (0/1) (Panel C) for Black participants in the Health and Retirement Study (HRS, 1995-2018). Black refers to non-Hispanic Black, and White refers to non-Hispanic White. Model A adjusted for covariates, including age, sex, parental education, childhood residence in U.S. Southern States, regional indicators for childhood residence, a birth-year trend indicator, and region-specific birth-year trend interactions. Model B additionally included early-life mediator, i.e., educational attainment. Model C further added mid-life mediators, including health factors involving hypertension, diabetes, heart diseases, psychiatric conditions, obesity, and smoking behaviors. Random intercepts were included at the state level to account for unobserved heterogeneity and differences between states, while individual-level random intercepts addressed within-individual correlations across multiple observations. Robust standard errors, clustered at the state level, were estimated accounting for within-state correlation. Mediation was evaluated using the difference method (percentage reduction), which compares the coefficients from the mediated model (i.e., Model C) to the unmediated model (i.e., Model A). The percentage reduction of the coefficients reflects the extent to which mediators explain the association between school segregation and cognitive outcomes, and the results are listed at the right column.

Supplementary eTable 3. Association between school segregation and cognitive outcomes for White participants in the HRS (1995-2018)

	White Participants			
VARIABLES	Model A	Model B	Model C	Association mediated by early-life and mid-life factors
Panel A. Cognitive Score (0-27)		β Coefficient (95% CI)		
School Segregation	-0.15 (-0.40, 0.10)	-0.14 (-0.30, 0.02)	-0.13 (-0.28, 0.01)	10%
Observations	83,205	83,205	83,205	
Panel B. Cognitive Impairment (0/1)		Adjusted Odds Ratio (95% CI)		
School Segregation	1.14 (0.93, 1.40)	1.16 (1.03, 1.32)	1.15 (1.03, 1.29)	-9%
Observations	90,874	90,874	90,874	
Panel C. Dementia (0/1)		Adjusted Odds Ratio (95% CI)		
School Segregation	1.13 (0.91, 1.40)	1.13 (0.92, 1.38)	1.11 (0.93, 1.33)	14%
Observations	90,874	90,874	90,874	
Covariates	YES	YES	YES	
Mediators: Educational Attainment	NO	YES	YES	
Mediators: Health Factors	NO	NO	YES	

Notes: Multilevel regressions were used to estimate the association associations between school segregation and cognitive outcomes, including cognitive score (0-27) (Panel A), cognitive impairment (0/1) (Panel B), and dementia (0/1) (Panel C) for White participants in the Health and Retirement Study (HRS, 1995-2018). Black refers to non-Hispanic Black, and White refers to non-Hispanic White. Model A adjusted for covariates, including age, sex, parental education, childhood residence in U.S. Southern States, regional indicators for childhood residence, a birth-year trend indicator, and region-specific birth-year trend interactions. Model B additionally included early-life mediator, i.e., educational attainment. Model C further added mid-life mediators, including health factors involving hypertension, diabetes, heart diseases, psychiatric conditions, obesity, and smoking behaviors. Random intercepts were included at the state level to account for unobserved heterogeneity and differences between states, while individual-level random intercepts addressed within-individual correlations across multiple observations. Robust standard errors, clustered at the state level, were estimated accounting for within-state correlation. Mediation was evaluated using the difference method (percentage reduction), which compares the coefficients from the mediated model (i.e., Model C) to the unmediated model (i.e., Model A). The percentage reduction of the coefficients reflects the extent to which mediators explain the association between school segregation and cognitive outcomes, and the results are listed at the right column.

eAppendix A. Sensitivity Analyses

A comprehensive series of sensitivity analyses were conducted to ensure the robustness of our findings and to assess the associations between exposure to school segregation and cognitive outcomes across varying levels and specifications of exposure.

1. Less Extreme Cutoff for High Segregation

First, we redefined the threshold for high levels of school segregation, using a less extreme cutoff (the top tertile instead of the top quintile). This adjustment allowed us to examine whether the associations between segregation and cognitive outcomes persisted when considering a broader range of segregation levels. The main patterns held as shown in Supplementary eFigures 5-6, though the associations were relatively smaller compared to our main specification (top quintile). Combined with the patterns shown in Supplementary eFigures 3-4, these results suggest that individuals exposed to the most extreme levels of segregation (as captured by the top quintile) tend to experience disproportionately worse cognitive outcomes.

2. Continuous Measure of School Segregation

Second, we employed a continuous measure of school segregation, represented by the dissimilarity index, rather than using a dichotomous classification (low vs. high segregation). While this approach assumes a linear relationship, it captures more granular variations in segregation. As shown in Supplementary eFigures 7-8, the results supported our finding that higher segregation levels are associated with poorer cognitive outcomes. The relatively smaller associations observed using the continuous specification further imply that the strongest effects of school segregation may occur among individuals exposed to extreme segregation, as reflected by the top quintile.

3. Restriction to Urban Sample

Third, recognizing that the dissimilarity index is based on metropolitan data, we restricted our sample to participants who lived in urban areas during childhood. This restriction allowed for a more targeted assessment of segregation. Our results remained consistent with the main findings (Supplementary eFigures 9-10), further confirming the robustness of our analysis.

4. Time-Varying Measure of Segregation

Fourth, we incorporated a more time-varying, self-reported measure of school segregation from the HRS life history survey. Specifically, HRS participants who completed the life history mailed survey in 2015-2017 were asked to report the schools they attended during their primary education and whether the majority of children in each school were White, Black, Hispanic or others. School was classified as segregated if most children in the school were Black, Hispanic or others. If the schools the participants attended during primary education were segregated schools, they were coded as 1 (and 0 otherwise). This self-reported measure, validated in previous research, provided a time-varying evaluation of participants' exposure to segregation. Although it cannot capture the relative intensity of the exposure, it offered an additional layer of temporal variation. Results from the analysis (Supplementary eFigures 11-12) aligns with our primary findings, further reinforcing the association between school segregation and cognitive outcomes.

5. Additional Adjustment for State-level Geographical and Temporal Variations

Finally, we introduced state-level birth-year trend indicators to account for potential geographical and time-varying confounding. Using the self-reported life history measure of school segregation, which incorporates temporal variation, enabled us to add state-level indicators to adjust for differences across various time periods and regions. The consistent findings shown in Supplementary eFigures 13-14 further strengthened our main results.

These sensitivity analyses collectively confirmed the robustness of our findings. Moreover, although the missing data in our study sample is minimal (<1%), we performed additional robustness checks using multiple imputation, and the estimates remained nearly identical, providing further confidence in the consistency of our results.