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Adverse Childhood Circumstances and Cognitive Function in Middle-aged and Older Chinese Adults: Lower Level or Faster Decline?

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ABSTRACT

We examine the long-term relationship between childhood circumstances and cognitive aging. In particular, we differentiate the level of cognitive deficit from the rate of cognitive decline. Applying a linear mixed-effect model to three waves of China Health and Retirement Longitudinal Surveys (CHARLS 2011, 2013, 2015) and matching cognitive outcomes to CHARLS Life History Survey (2014), we find that key domains of childhood circumstances, including family socioeconomic status (SES), neighborhood cohesion, friendship and health conditions, are significantly associated with both the level of cognitive deficit and the rate of decline. In contrast, childhood neighborhood safety only affects the level of cognitive deficit. Childhood relationship with mother only affects the rate of cognitive decline. The effects of adverse childhood circumstances are generally larger on level of cognitive deficit than on rate of cognitive decline. Moreover, education plays a more important role in mediating the relationships compared to other later-life factors. These findings suggest that exposure to disadvantaged childhood circumstances can exacerbate cognitive deficit as well as cognitive decline over time, which may be partially ameliorated by educational attainment.

Keywords: Childhood circumstances, life course factors, cognitive aging, education
JEL Classification: I14, I24, J13, J14

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1. Introduction

The varying trajectories of health and well-being of older adults may result from a complex interaction of social, environmental, and physiological factors over the life course (Chatterji et al., 2015). With the accretion of knowledge in health and aging, there is converging interest in a life course perspective on later life health trajectories from different disciplines (Burton-Jeangros et al., 2015). Cumulative evidence has suggested the lasting impacts of life course circumstances, especially those in early life (Liu et al., 2019). In particular, adverse early-life exposure may not only affect health directly, but influence individuals' ability to adapt and to exercise self-control, exacerbating vulnerability to health shocks in old age (Burton-Jeangros et al., 2015; Huber et al., 2011).

A sizable body of research has focused on the long-term health impacts of childhood circumstances to inform interventions in earlier stages. They show that during childhood, socioeconomic status (SES) (Katikireddi, 2016; Moody-Ayers et al., 2007), health and nutritional conditions (Almond and Mazumder, 2011; McEniry et al., 2008), community environment (Aneshensel and Sucoff, 1996; Shen, 2014), and other childhood exposures (Black et al., 2016; Simon, 2016) are associated with various aspects of health in later life. Although previous studies have revealed multiple pathways through which childhood circumstances may affect physical health, mental health, and frailty status in later life, direct evidence on the relationship between childhood circumstances and cognitive aging is still partial and limited.

Given the essential roles of cognitive functioning play in later-life, this knowledge gap may impede targeted interventions, thus requiring thorough investigations. In fact, the impacts of childhood

circumstances on cognitive aging can be large and profound. Several hypothetical models have implied the persisting influence childhood circumstances may have on cognition across the life course. To begin with, the *critical period model* points out the critical impacts of prenatal, postnatal, and early childhood exposures on brain development and cognitive reserve (Lynch and Smith, 2005). For example, gestational and infant undernutrition, inadequate care, and disadvantaged socioeconomic conditions in the first few years of life may cause the brain to fall short of its full potentials, which can be consequential for later-life cognitive aging (Barker, 2004; Borenstein and Mortimer, 2016a). Moreover, the *accumulation of risk model* posits that the exposures in early life may have a cumulative effect across the life course if the brain becomes vulnerable or weakened in keeping up with the accumulated damages (Kuh et al., 2003). In other words, exposure to adverse early-life circumstances may result in a faster rate of brain functioning loss, especially in later life. Finally, the *chains of risk model* argues that the exposures are linked across the life course (Kuh et al., 2003). One exposure in the early stage of life may lead to another exposure in later life, hence resulting in varying patterns of cognitive aging. Childhood SES, health and social environment, for instance, may determine the level of schooling, the patterns of socialization, and the extent to which individuals are involved in cognitively stimulating activities, which consequently change cognitive reserve and the progression of cognitive aging (Borenstein and Mortimer, 2016a; Foverskov et al., 2018; Glepawwe and Miguel, 2007).

The transition from normal cognitive functioning to cognitive impairment can be slowed with better understanding of risk factors and their mechanisms. Particularly, promoting interventions targeting key social and environmental factors across the lifespan may increase individuals' resilience to brain pathologies and therefore reduce vulnerability to cognitive impairment and

dementia (Borenstein and Mortimer, 2016b; Stern, 2012). Given the long preclinical stages of the disorder, understanding early-life risk factors for cognitive aging is especially pivotal to delaying the disease progression and alleviating burdens of an aging society (Borenstein and Mortimer, 2016c; Sayer and Gill, 2016). However, few studies explicitly examine early-life determinants of cognitive aging, among which most focus on childhood SES and health factors (Fors et al., 2009; Kaplan et al., 2001; Luo and Waite, 2005), whereas investigations on other early-life factors, such as neighborhood social environments, are very limited (Wu et al., 2015). In addition, previous work tends to investigate a single early-life factor, while evidence that simultaneously considers a comprehensive set of circumstances are largely absent. Estimation biases may reduce after accounting for other relevant early-life factors (Borenstein and Mortimer, 2016a).

Moreover, prior research rarely distinguishes between the underlying impacts of early-life circumstances on two distinctive components of cognitive aging, i.e., the level of deficit and the rate of decline. Since level and rate may have different implications, this limits our understanding of cognitive aging process. In particular, the rate of cognitive decline often signal to individuals their potential cognitive problems that may promote timely diagnosis and treatment, while the level of cognitive deficit often determines the risk of being assessed cognitive impaired or even demented. The few studies that link childhood circumstances with later-life cognitive trajectories often provide inconsistent evidence: some shows that adverse childhood circumstances can lead to higher rates of cognitive decline (Brown, 2010; Marden et al., 2017; Melrose et al., 2015; Steptoe and Zaninotto, 2020), while others offer contradictory evidence (Barnes et al., 2012; Everson-Rose, 2003). Therefore, research on adverse childhood circumstances and cognitive aging is inconclusive.

To fill the gaps, this paper investigates the long-term effects of a wide spectrum of childhood circumstances on the trajectories of cognitive aging. Using three waves of the China Health and Retirement Longitudinal Survey (CHARLS 2011, 2013, 2015) and the CHARLS Life History Survey (2014), we characterizes the varying cognitive aging patterns through four aspects of childhood circumstances: SES, neighborhood social environment, social relationships, and health conditions. Specifically, applying a linear mixed effect model to individuals' trajectories of cognitive outcomes, we separate the baseline level of cognitive deficit from the rate of cognitive decline and respectively examine their associations with childhood circumstances.

As suggested by prior literature, these four domains of childhood factors may influence cognitive aging through multiple pathways. For example, childhood SES (Kaplan et al., 2001; Marden et al., 2017), neighborhood social environment (Wu et al., 2015), social relationships (Chan et al., 2019; Crosnoe, 2000) and health conditions (Kobayashi et al., 2017; Nguyen et al., 2008; Zhang et al., 2010) have profound effects on early-life brain development, which contribute to the initial cognitive reserve and vulnerability to brain pathologies. The four childhood circumstances may also determine the completion of formal education, social status, and health or health behaviors in adulthood (Borenstein and Mortimer, 2016a; Chetty et al., 2016; Fletcher et al., 2020; Glewwe and Miguel, 2007; Luo and Waite, 2005), which in turn shape varying patterns of cognitive aging. Further, childhood SES, neighborhood social environment, and social relationships may also be linked to social support and connections in adulthood (Crosnoe, 2000), which play an important role for cognitive functioning in old age (Bassuk et al., 1999; Borenstein and Mortimer, 2016d). Therefore, this study first tests the hypothesis that exposure to more adverse childhood

circumstances is associated with faster cognitive aging. We then explore heterogeneous effects across gender, education, and rural/urban status. Finally, in light of the mechanisms discussed above, we examine the extent to which the effects are mediated through main pathways, including education, later-life family wealth, health and health behaviors, and social engagements.

This study contributes to the literature in three major aspects. First, the richness of life history data allows us to link, to our knowledge, the most comprehensive set of childhood circumstances with later life cognitive function. Second, we examine the long-term impacts of childhood circumstances on two distinctive dimensions of cognitive aging, i.e., the level of cognitive deficit and the rate of cognitive decline, which offers novel evidence on their relationships. Third, we underscore the importance of social relationships (e.g., childhood friendship and relationships with parents) and neighborhood social environments (e.g., neighborhood safety and cohesion) on cognitive deficit, which, to our knowledge, have not been thoroughly investigated in previous studies.

2. Data Sets and Methods

2.1 Data Sources and Analytical Sample

Our analytical data are mainly obtained from the China Health and Retirement Longitudinal Study (CHARLS) conducted in 2011 (national baseline), 2013 (Wave 2 follow-up), 2014 (Life History Survey), and 2015 (Wave 3 follow-up), which collects a high quality and nationally representative sample of Chinese residents age 45 and older (Zhao et al., 2014). In addition, some key background characteristics controlled for in our analysis, such as age, education, and marital status, are extracted from Harmonized CHARLS, which integrates and validates the data from all four

surveys (Beaumaster et al., 2018). The details of data sampling, collection, administration, as well as the obtainment of ethical approval and informed consent are presented in Appendix B.

We restrict our analysis to respondents aged 45 and older at baseline who have all three waves of cognitive test results, to ensure the validity of longitudinal cognitive measures. After excluding the illegible responses, 9,109 respondents are used to model and decompose the individual trajectories of cognitive aging; they contribute a total of 27,327 observations in our analytical model (n=9,109 study samples × 3 time points). Of the 9,109 respondents, 6,700 participants have complete life history data and therefore are used to examine the association between childhood circumstances and two components of cognitive aging. We also check the balance of childhood characteristics between our study sample (n=6,700) and the sample with complete cognitive test results but incomplete life history data (n=2,409). As shown in Appendix Table A1, our study sample tends to be exposed to better childhood circumstances, as measured by parental education, neighborhood social environment, friendship, and health conditions. While potential selection of respondents experiencing adverse childhood circumstances and worse cognitive aging is unlikely, and therefore our concern over overestimated effects may be mitigated, we should still interpret our results with caution in consideration of these unbalanced factors.

2.2 Measures of Childhood Circumstances

Rich information about family history, health history, and other childhood environments is drawn from the CHARLS life history survey. Four domains of childhood circumstances, i.e., childhood SES, neighborhood social environment, social relationships, and health conditions, are considered, and objective measures for each domain are selected to ensure accuracy.

First, parental education, parental work status, and architecture type of the first residence are included to measure childhood SES. Among them, architecture type of the first residence is used as an objective measure of family economic and financial status (Ghawi et al., 2015; Zhao et al., 2020). Relative to the self-reported status collected in CHARLS, the housing characteristics (i.e., architecture type) has the advantage of objectivity and accuracy, which has been increasingly used in recent studies and recognized as a good indicator of individuals' SES (Ghawi et al., 2015; Juhn et al., 2011). Secondly, neighborhood safety and neighborhood cohesion are used to measure the childhood neighborhood social environments, which could also be important for individuals' long-term cognitive development (Chan et al., 2019; Crosnoe, 2000; Wu et al., 2015; Yen et al., 2009). Third, childhood social relationships are captured by two measures: childhood friendship, childhood relationships with parents. Childhood friendship is measured by how often the respondent had a group of friends that he/she felt comfortable spending time with, which reflects the social supports and connections individuals had during the childhood. Childhood relationships with parents are intended to measure the level of family supports that individuals perceived (Borenstein and Mortimer, 2016d). Finally, childhood self-rated health, experience of serious illness, and experience of hospitalization are used to indicate childhood health status, and vaccination history and food deprivation during 0-5 years old are included as measures of childhood health resources (Kobayashi et al., 2017; Zhang et al., 2010).

The descriptive statistics of these variables are shown in Table 1; and additional details are presented in Appendix Table C1, which includes the original questions asked in the surveys and the construction and conceptualization of the variables.

2.3 Measures of Cognitive Deficit

Cognitive deficit is assessed by five cognitive tests measured in the CHARLS baseline and two follow-up surveys: immediate word recall, delayed word recall, serial 7s (correctly subtracting 7 from the prior number), date naming (correctly reporting today's date), and picture drawing. Among them, immediate and delayed word recall tests, are used to assess individuals' short-term and long-term memory, whereas serial 7's test, date naming, and picture drawing are designed to assess the respondents' ability to perform mathematical tasks, orientation, and mental intactness. All the five cognitive tests are conducted by interviewers who are trained with a standard and stringent protocol. (Zhao et al., 2020, 2014). These tests have also been recognized as valid measures for cognition (Herzog and Wallace, 1997; Zhao et al., 2020), and the details related to the cognitive tests in CHARLS can be found in Appendix D.

As our goal is to examine the cognitive aging process, we sum all these test results to form a composite score (i.e., global cognitive function; range 0-30) and reverse-code to make it more interpretable, i.e., a greater value for the level of cognitive deficit or the rate of cognitive decline indicates a severer stage of cognitive aging (Xu et al., 2015). This composite measure has been shown to have a strong relationship with defining cognitive impairment, thus is a good measure of respondents' overall cognitive functioning (Herzog and Wallace, 1997; Langa et al., 2008). The distributions of cognitive deficits in our study sample are shown in Appendix Figure A1.

To characterize the varying patterns of cognitive aging related to childhood circumstances, we plot the average trends of cognitive deficit by childhood circumstance. As shown in Figure 1, cognition

gaps exist between cohorts of diverse childhood circumstances. Those with better childhood circumstances generally have a lower level of cognitive deficit. The differences persist for all age groups from age 45 to age 80. Moreover, there are large variations across childhood characteristics. Some of the gaps are larger, such as work status of parents and childhood friendship, while others seem smaller, such as relationship with parents.

2.4 Other Variables

In addition to the childhood circumstances and cognitive outcomes, we include a set of covariates and mediators to adjust for their associations with both the exposures and outcomes. Specifically, a number of covariates are controlled for in our main analysis, including baseline age, gender, education, hukou status (rural/urban), marital status, log income, and the number of chronic diseases.

In addition, as suggested by the existing literature, several important mediators could potentially link childhood circumstances with later-life cognitive aging, including formal education, later-life family wealth, health and health behaviors, and social engagements. These factors are further examined and compared in the mediation analysis.

The definition and construction of these variables are presented in Appendix Table C2.

2.5 Empirical Strategy

The descriptive analysis only captures the average population trend, hence in our study, we model individual cognitive aging trajectories to shed light on within-subject pattern of cognitive decline.

Linear mixed-effect model (LMM) is utilized to model the individual development of health outcomes by adjusting for the correlations of the repeated measures within one subject (Burton-Jeangros et al., 2015; Laird and Ware, 1982). An emerging strand of literature in cognitive science have used the linear mixed-effect model to investigate the trajectory of cognitive aging (Hall et al., 2000; Hout et al., 2015; Wilson et al., 2011). In our study, the model used can be specified as,

$$Y_{it} = \gamma_0 + \gamma_1 Time_{it} + \gamma_2 X_i + \gamma_3 X_i \cdot Time_{it} + \mu_{0i} + \mu_{1i} Time_{it} + \epsilon_{it} \quad (1)$$

where Y_{it} is the composite score of cognitive deficit measured for individual i at time t, and γ_0 and γ_1 are the fixed intercept and fixed slope for the study population; X_i is the covariates matrix controlled in our model, including baseline age, gender and education level (Wilson et al., 2011); interaction term $X_i \times Time_{\mathrm{it}}$ is added into the model to adjust for the fixed impact of covariates on the slope. Thus, γ_2 and γ_3 respectively represent the fixed impact of covariates on baseline level and slope. Finally, μ_{0i} and μ_{1i} represent the random intercepts and random slopes for the individual i, which capture the individual deviations from the central values of intercept (i.e., $\gamma_0 + \gamma_2 X_i$) and slope (i.e., $\gamma_1 + \gamma_3 X_i$).

Based on these coefficient estimates, we calculate the baseline level of cognitive deficit and rate of cognitive decline for each individual i as a combination of group fixed effect, $\gamma_0 + \gamma_2 X_i$ and $\gamma_1 + \gamma_3 X_i$, and individual random effect, μ_{0i} and μ_{1i}. (Belsky et al., 2015; Burton-Jeangros et al., 2015),

$$L_i = \gamma_0 + \gamma_2 X_i + \mu_{0i} \quad (2)$$

$$R_i = \gamma_1 + \gamma_3 X_i + \mu_{1i} \quad (3)$$

After obtaining individual level of cognitive deficit, L_i, and rate of decline, R_i, we use linear regressions to study the association of childhood characteristics with the level of cognitive deficit and the rate of decline. We do not directly include our comprehensive set of childhood characteristics and their time interaction terms in the linear mixed-effect model to avoid overparameterizing or mis-specifying the model (Bolker et al., 2009; Harrison et al., 2018). The regression equation is illustrated as follows,

$$Y_i = \alpha + \beta \cdot EarlyLife_i + \delta \cdot X_i + \epsilon_i$$

where Y_i is the outcome of interest, representing either the level of cognitive deficit, L_i, or the rate of decline, R_i, of individual i. $EarlyLife_i$ include four domains of childhood circumstances, including childhood SES, neighborhood social environment, social relationships, and health conditions. X_i contains a set of covariates, including baseline age, gender, education level, rural/urban hukou status, marital status, log income and number of chronic diseases. Each domain of childhood circumstances is added subsequently into linear regression, from Model 1 with only childhood SES to Model 4 with all four domains of childhood circumstances, to check robustness of our findings. Among them, Model 4 is our preferred model specification with complete sets of childhood factors. Because the long-term health impacts could vary across gender (Lei et al., 2012), baseline rural/urban status (Zhang et al., 2017), and education level (Foverskov et al., 2018), we also explore the heterogeneity of the effects across these subgroups and test the

statistical significance of the differences between two groups following the Chow test (Chow, 1960).

In addition to our main regression analyses, we conduct a set of mediation analyses to provide suggestive evidence on the mechanisms of the effects following the Difference Method (VanderWeele, 2016). In particular, we examine whether including potential mediators (e.g., education, social engagements) in the regression model would attenuate the exposure estimates. If the coefficient estimates of particular childhood circumstances reduce markedly after accounting for potential mediators, this would be a signal of mediation that can explain some of the effects of the childhood circumstances on cognitive aging and may corroborate certain pathways (VanderWeele, 2016).

All regression models are weighted using individual sample weights, with household and individual non-response adjustment. Standard errors are clustered at urban/rural communities to account for correlation within clusters. Detailed analytical procedure is illustrated in Appendix Figure A2. All the data are analyzed using Stata 16.1.

3. Results

Decomposing cognitive aging into the level of cognitive deficit and the rate of cognitive decline, the summary statistics of our model estimates are shown in Table 2. Using the sample with complete cognition data (N=9,109), we obtain the average baseline level of 15.77, with the level estimates L_i ranging from 6.43 to 25.64. The average rate of cognitive decline R_i is 0.23, with maximum value of 1.00. For the sample with complete cognition and life history data (N=6,700),

the summary statistics of these two measures are similar to the estimates using the full sample, reducing the potential concern over selection bias. A scatterplot of the level and rate estimates is shown in Appendix Figure A3. We next present the results on childhood circumstances and two components of cognitive aging, respectively.

3.1 Association between Childhood Circumstances and the Level of Cognitive Deficit

Table 3 reports the linear regression estimates with different model specifications. In the model with only childhood SES and covariates (i.e., Column 1), father's education, parental work status, and the first residence architecture type are significantly associated with baseline level of deficit. Although the estimates slightly declined as we add more domains of variables into the regressions (i.e., Column 3, 5, and 7), they remain statistically significant.

In our preferred model with complete sets of childhood circumstances (i.e., Column 7), we find a negative association between father's education and the level of cognitive deficit. In addition, compared to those whose mothers had no full-time job, people whose mothers worked in full-time farming, often indicating disadvantaged family SES or limited time with children, show higher level of cognitive deficit (Browning et al., 2014). Furthermore, people living in more inferior residence during childhood show a significantly greater level of cognitive deficit.

Neighborhood cohesion and safety are found to be strongly associated with later life cognitive deficit. People who lived in a less close-knit and unsafe community show a significantly higher level of cognitive deficit. We also find a strong protective effect of a good childhood friendship

on both dimensions of cognitive aging. However, no significant association between childhood relationships with parents and level of cognitive deficit is observed.

Moreover, poor childhood health status is significantly associated with a higher level of cognitive deficit; people with insufficient vaccination and nutrition in early childhood (0-5 years old) also show significantly greater cognitive deficits in later life.

To examine robustness of the results, we also conduct linear regressions based on each of the three waves of cognitive deficit scores. As shown in Table A2, these results (i.e., Column 1-3) as well as those obtained based on the pooled three waves of data (i.e., Column 4) are consistent with the results on level of cognitive deficit obtained from LMM (i.e., Column 5, which repeats Column 7 of Table 3 for ease of comparisons).

Lastly, we explore heterogeneous effects. In particular, we apply our full model (i.e., Model 4) to the subsamples of low versus high levels of education, males versus females, and rural versus urban hukou status at baseline. The coefficient estimates are respectively plotted in Figure 2, Appendix Figure A4 and Figure A5. As shown in Figure 2, significantly larger effects are found for the subsample with less education (i.e., primary school or below) than that with more education in the effects of father's education, mother's work status, and child health status on the level of cognitive deficit. By contrast, the size of the effects are largely similar between male and female subsamples (Figure A4). Father's work status and child health status show smaller effects for urban than rural samples (Figure A5), suggesting the potential role of social welfare benefits.

3.2 Association between Childhood Circumstances and the Rate of Cognitive Decline

The estimates of childhood circumstances on rate of cognitive decline are shown in Columns 2, 4, 6, and 8 in Table 3. In our full model (Column 8, Table 3), people who report greater father's education and work status, higher mother's education, better family residence, greater neighborhood cohesion, more friendship, better relationship with mother, better health status, more vaccination, and better nutrition are found to have a significantly lower rate of cognitive decline.

Some salient differences are identified comparing the relationships between childhood circumstances and the two components of cognitive aging. Specifically, unlike the results for level of cognitive deficit (Column 7, Table 3), no significant association is observed between childhood neighborhood safety and rate of cognitive decline. Moreover, having a good relationship with mother are significantly associated with a lower rate of cognitive decline but not the level of cognitive deficit. Nonetheless, childhood neighborhood cohesion, friendship, health status, vaccination, and nutrition show significant association with both components of cognitive aging. In particular, the gradient of association between childhood friendship and cognitive aging indicates a strong protective effect of friendship.

To enable more meaningful comparisons between the level of cognitive deficit and the rate of cognitive decline, we standardize the coefficient estimates of our full model (i.e., Model 4, Table 3) in standard deviations (SDs) and presented the effect size in Table A2, Columns 7 and 8. Our results indicate that, one SD change in childhood circumstances mostly have larger effects on the level of cognitive deficit than those on the rate of cognitive decline, in terms of changes in SD.

Nevertheless, the effect size of relationship with parents is larger on the rate of decline than on baseline level.

Finally, similar to our findings on cognitive level, the impacts of father's education, childhood health status and malnutrition, neighborhood safety, childhood friendship are larger on the rate of cognitive decline for the less educated subsample; and the impact of father's work status is more salient for rural than urban samples. No significant difference is found between male and female samples.

3.3 The Mediation Effects of Adult- and Later-life Factors

The chains of risk model suggests that childhood circumstances may affect cognitive aging through adulthood exposures, which enable a set of important pathways. To offer suggestive evidence, we examine the roles of educational attainment, later-life family wealth, health and health behaviors, and social engagements in the relationships between childhood circumstances and cognitive aging. We cumulatively include these factors into the model to test if they attenuate the effects of some or all aspects of childhood circumstances on cognitive aging. In addition, because childhood neighborhood social environment and social relationships are fundamental in shaping patterns of socialization, which may influence the onset of dementia or cognitive decline (Borenstein and Mortimer, 2016d), we explore the extent to which their effects on cognitive aging can be mediated by later-life social engagements.

In Appendix Table A3, we first compare the exposure estimates of the regressions with versus those without controlling for education. Adding education into the model substantially attenuate

the coefficient estimates of all childhood circumstances. The reductions in the size of the coefficients are 23-53% for childhood SES, 19-31% for neighborhood social environment, 9-60% for social relationships, and 29-58% for health conditions. These findings thus imply that the effects of childhood circumstances on cognitive aging can be mediated by education. Moreover, in Appendix Table A4, we cumulatively control for later-life family wealth, health and health behaviors, and social engagements. Results show that including family wealth, health and health behaviors has little impact on the estimates of childhood exposure, while controlling for social engagements shrinks the coefficients of neighborhood cohesion and friendship, though the size of mediation effect is smaller than that led by education. Therefore, adulthood social engagement is likely an underlying pathway through which neighborhood cohesion and friendship in childhood influence cognitive aging. Overall, education seems the most important mediator.

4. Conclusions and Discussion

Childhood family economic conditions, health, community environment, and relationships can lead to increased vulnerability to the cognitive aging process later in life. This study offer novel evidence on the long-term relationship between a comprehensive set of these childhood circumstances and cognitive aging (Luo and Waite, 2005; Zhang et al., 2008). We also advance the literature by offering novel evidence with longitudinal data and a mixed effect model to distinguish key components of cognitive aging (Fors et al., 2009; Kaplan et al., 2001). Our finding suggests varying effects of childhood circumstances on components of cognitive aging, including the level of cognitive deficit and the rate of cognitive decline. In particular, one SD change in childhood circumstances often have larger effects on the level of cognitive deficit than on the rate of cognitive decline, except for the relationship with parents. Finally, we also offer novel evidence

on own educational attainment mediating the effect of a wide spectrum of adverse childhood circumstances.

First, we show that exposure to adverse childhood SES or health conditions may worsen both components of cognitive aging. Though the size and significance of the effects vary by factors, this pattern may reflect two important pathways. On the one hand, father's education, family housing status, and child health conditions may have profound effects on children's cognitive development, reserve and cognitive aging (Borenstein and Mortimer, 2016a). Father's education largely affects labor supply and determines the resources that a family can invest in children (Browning et al., 2014); and family housing and child health conditions (especially vaccination and nutritional status) to large extent reflect the family resources and society support available. Disadvantaged SES in early life hence may greatly limit the level of resources provided to children, impede individuals' healthy brain development, and in turn expose them to adverse brain pathologies and functioning loss in later life (Noble et al., 2015; Staff, 2012). On the other hand, disadvantaged early-life SES and health conditions may also affect later-life cognitive deficit and decline through a chain of adult-life exposures, such as education, employment, health conditions, and health behaviors (Borenstein and Mortimer, 2016a), where education seems a more important channel as indicated in this study. For example, this study show that mother's education had significant effects on *both* components of cognitive aging without adjusting for own education, but *only* affecting rate of cognitive decline after adjusting for own education.

Second, we find that the relationship with mother can buffer against cognitive decline in later life; whereas the relationship with father cannot. This pattern can be explained by the different roles

that father and mother play at home, which contribute differently to children's cognitive development. Literature suggests that parents collectively allocate their time to labor market and investments in children given their resources and preferences (Blundell et al., 2005). With more human capital, fathers tend to spend more time on the labor market, while mothers invest more time in children. Hence, as the major caregiver at home, mothers tend to spend more time in educating and interacting with children than fathers do (Browning et al., 2014). Mothers are also more likely to be the main decision maker for children's health inputs and education (Attanasio et al., 2012). Children with better relationships with mothers in early life thus are more likely to receive adequate care, education, and intellectual stimulation at home, and are more resilient to brain pathologies in later life (Murray et al., 2012; Noble et al., 2015).

Finally, we reveal how childhood friendship and neighborhood social environment can be associated with later life cognitive aging. In particular, we find that childhood friendship and neighborhood cohesion have strong protective impacts on both dimensions of cognitive aging. Three potential pathways may account for the relationships. First, childhood friendship and neighborhood cohesion represent the social support and connections individuals have that may benefit cognitive health in terms of initial level of reserve or vulnerability to brain pathologies (Borenstein and Mortimer, 2016d). Second, these childhood factors, especially friendship, may influence educational attainment and health behaviors (Fletcher et al., 2020; Fletcher and Ross, 2018), which in turn impose effects on cognitive aging. Our mediation analysis shows that education account for a considerable part of the associations. Third, better childhood friendship and neighborhood cohesion may influence cognitive aging through more active social engagements in adulthood (Crosnoe, 2000), which helps build cognitive reserve or prevent

functional loss in the life course (Bassuk et al., 1999). In comparison, neighborhood safety, i.e., another aspect of neighborhood social environment, is mainly linked to stress and other psychosocial factors with influence on initial cognitive function and reserve, while the pathway through which it affects later-life cognitive change is relatively limited (Wu et al., 2015). Consistently, this study finds a significant effect of neighborhood safety on the level of cognitive deficit but not on the cognitive decline, and the effect size for neighborhood safety is small.

Overall, our findings lend support to studies on life course cognitive health. First, growing evidence shows independent associations between childhood SES and later-life cognitive function (Fors et al., 2009; Kaplan et al., 2001; Luo and Waite, 2005; Marden et al., 2017; Nguyen et al., 2008) and cognitive decline (Brown, 2010; Marden et al., 2017; Melrose et al., 2015; Steptoe and Zaninotto, 2020). Second, existing literature have also demonstrated the important role of child health and nutrition in determining both components of cognitive aging (Kobayashi et al., 2017; Nguyen et al., 2008; Zhang et al., 2010). Third, though prior research mainly focuses on the impact of social environment on cognitive function but not on cognitive trajectories (see a systematic review Wu et al., 2015), cross-sectional studies show evident link between neighborhood safety and cognitive deficit (Wu et al., 2015; Yen et al., 2009). Fourth, while there is no direct evidence on the relationship between childhood friendship, social cohesion and cognitive aging, partly due to challenges in collecting life history data, our findings are supported by a strand of literature on later-life social cohesion, social networks and cognitive aging (Bassuk et al., 1999; Borenstein and Mortimer, 2016d; James et al., 2012). Emerging research on childhood social activities also corroborate our results (Chan et al., 2019).

Some limitations could impede the generalizability of this study. First, although cognitive deficit is longitudinally examined, only three waves of cognitive assessments are collected. Cognitive aging trajectories may be better modeled with longer follow-up waves. Second, as most of our childhood factors are self-reported, results may suffer from recall bias (Borenstein and Mortimer, 2016a), despite our intention to select more objective measures. Third, although the CHARLS survey respondents are randomly sampled and their information is collected following a well-administered process (Zhao et al., 2020, 2014), the sample with missing values in certain childhood circumstances or cognitive outcomes can be nonrandomly missing, which implies the existence of selection bias. For example, people with more disadvantaged childhood circumstances may have more difficulty understanding the questions to comply with the surveying process. Survival bias may select healthier older adults or those who experienced more favorable circumstances in early life. Hence, our findings should be interpreted with caution. Fourth, we offer initial evidence on associations between childhood circumstances and key components of cognitive aging. No causal relationship can be drawn at this stage. The underlying mechanisms require further examinations with causal study designs. Finally, future work will understand the mediating effects of life course factors other than education.

Despite these limitations, our study may have valuable policy implications. First, we have shown that a wide range of childhood circumstances could contribute to the early onset and progression of cognitive aging, even after controlling for education and other adult-life characteristics. This finding highlights the critical and persisting impacts childhood adversity may have across the life course. Hence, to delay pathologic evolution and promote healthy aging, it is important to intervene early in life by providing adequate social support and resources. Timely interventions

during childhood would generate significant health benefits in the long term and relieve the burden of population aging. Second, though childhood circumstances may affect different dimensions of cognitive aging (deficits vs. trajectories) through different pathways, they share some common grounds that require targeted interventions. On the one hand, the adversity of childhood circumstances, such as low parental SES, food deprivation, and lack of vaccination, reflect the inadequacy of social and economic policies, emphasizing the significance of public investments in education, public health programs, and targeted transfer programs. On the other hand, the establishment of advantaged childhood circumstances require joint efforts from families and society. In particular, families and society should not only work together to provide sufficient resources for children, but also build a supporting environment that is beneficial for individuals' health and social wellbeing, especially given the important roles of social cohesion and relationships revealed in this study. Finally, the large differences in childhood circumstances imply the needs for training and educational programs to narrow the gap in cognitive skills across contexts of different educational background to enhance comparability and accuracy of cognitive assessments. Improved cognitive assessments make the surveillance and early targeting of cognitive impairment and dementia more efficient.

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Table 1. Descriptive statistics of childhood characteristics

Childhood Characteristics	Level (%)
1. Childhood socioeconomic status	
Education of father	1. Illiterate (57.85); 2. Elementary school and below (34.49); 3. Middle school and above (7.66)
Education of mother	1. Illiterate (88.99); 2. Elementary school and below (9.57); 3. Middle school and above (1.45)
Work status of father	1. None or limited working (3.25); 2. Full-time farming work (78.39); 3. Full-time non-agricultural work (18.36)
Work status of mother	1. None or limited working (15.85); 2. Full-time farming work (79.81); 3. Full-time non-agricultural work (4.34)
Architecture type of first residence house	1. Concrete structure (11.55); 2. Adobe house (61.64); 3. Wood house/thatched houses (18.49); 4. Cave/Mongolian yurt/boat house/others (8.31)
2. Childhood neighborhood social environment	
Neighborhood safety	1. Very safe (50.22); 2. Somewhat safe (42.21); 3. Not very safe (5.54); 4. Not safe at all (2.03)
Neighborhood cohesion	1. Very close-knit (44.18); 2. Somewhat close-knit (51.91); 3. Not very close-knit (3.24) 4. Not close-knit at all (0.67)
3. Childhood social relationship	
Friendship	1. Often have a group of friends playing (65.54); 2. Sometimes (13.52); 3. Not very often (8.54); 4. Never (12.40)
Relationship with father	1. Fair/poor (19.72); 2. Good (80.28)
Relationship with mother	1. Fair/poor (17.25); 2. Good (82.75)
4. Childhood health conditions (before 15 years old)	
Relative health status compared to peers	1. Healthier (36.40); 2. about average (52.15); 3. Less Healthy (11.45)
Ever confined to bed more than one month	1. No (94.82) 2. Yes (5.18)
Ever hospitalized	1. No (98.13) 2. Yes (1.87)
Ever receive any vaccinations (before 15 years old)	1. No (13.76) 2. Yes (86.24)
Not enough food during 0-5 years old	1. No (65.01); 2. Yes (34.99)

Notes: N= 6,700 individuals. First column shows the variable names and categories; and the second column shows the descriptive statistics of the childhood characteristics. The definition, construction and conceptualization of these variables are further presented in Appendix Table C1.

Table 2. Descriptive statistics of baseline level of cognitive deficit and rate of cognitive decline estimates

Cognitive measures	N	Mean	SD	Min	Max
Level L_i	9,109	15.77	3.41	6.43	25.64
Rate of Decline R_i	9,109	0.23	0.20	-0.34	1.00
Level L_i (with complete life history data)	6,700	15.60	3.35	6.43	25.33
Rate of Decline R_i (with complete life history data)	6,700	0.22	0.19	-0.34	1.00

Notes: Individual level L_i and rate R_i are estimated using linear mixed-effect model. Row 1 and row 2 are the summary statistics of sample with three waves of cognitive tests (N=9,109). Row 3 and row 4 are the summary statistics of subsample with three waves of cognitive tests and complete life history data (N=6,700)

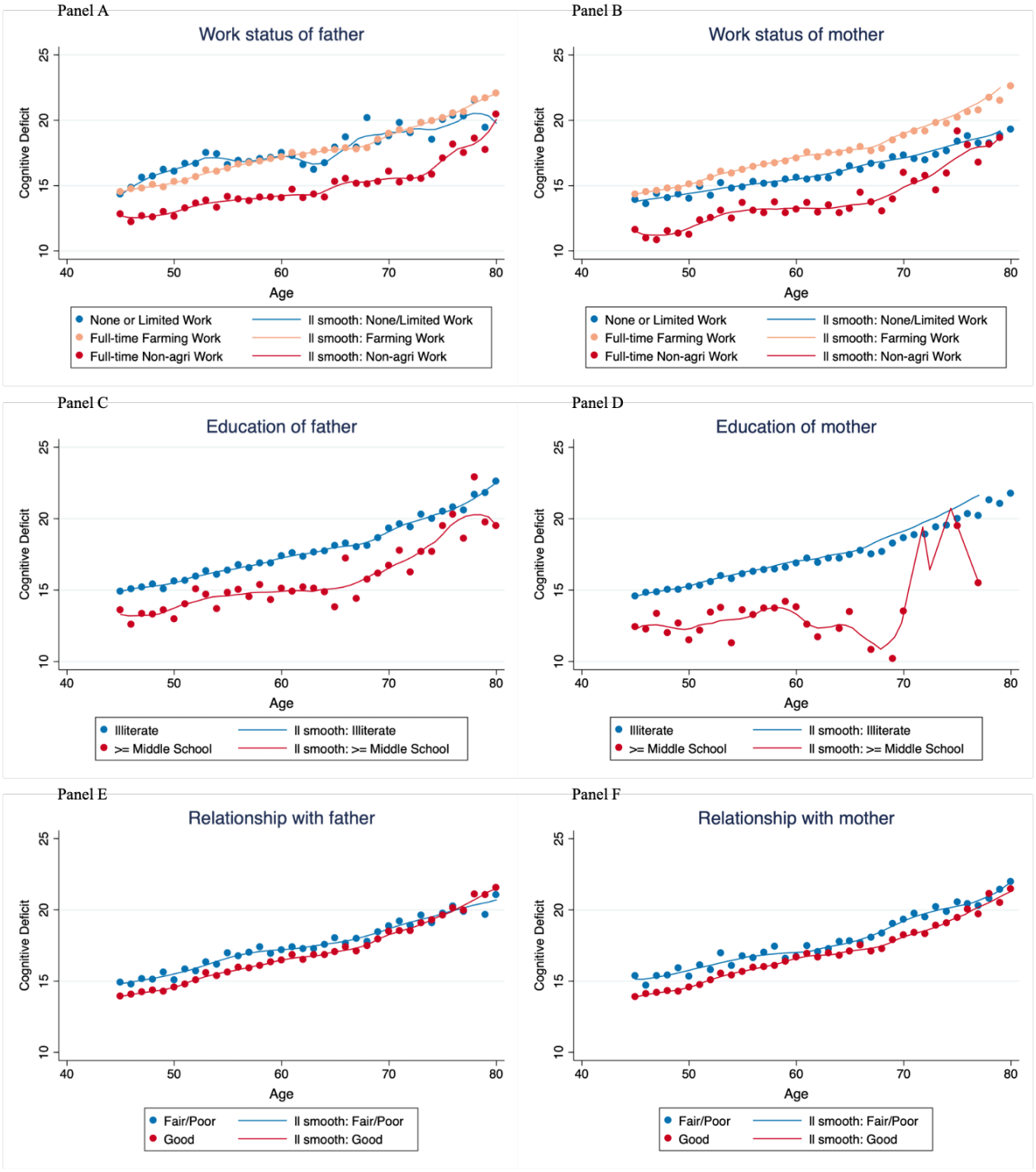
Table 3. Regression results of the association of childhood circumstances with the level of cognitive deficit (intercept) and the rate of cognitive decline (slope)

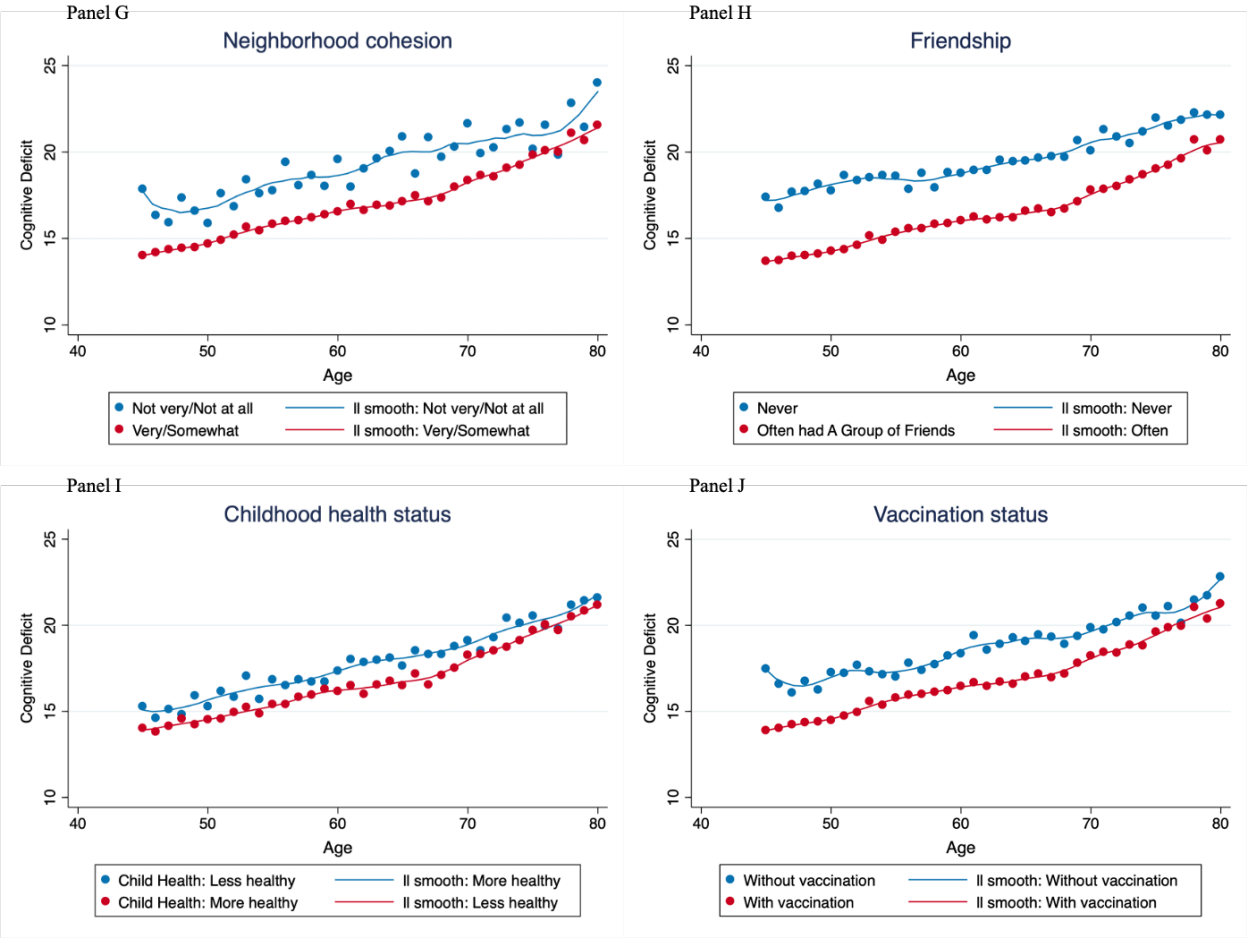
	Model 1		Model 2		Model 3		Model 4	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Level	Rate	Level	Rate	Level	Rate	Level	Rate
Education of father (Ref. Illiterate)								
Elementary school and below	-0.474***	-0.018***	-0.475***	-0.018***	-0.454***	-0.017***	-0.452***	-0.017***
	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)
Middle school and above	-0.388**	-0.011*	-0.377**	-0.011*	-0.366**	-0.011	-0.356**	-0.010
	(0.006)	(0.044)	(0.006)	(0.045)	(0.007)	(0.056)	(0.007)	(0.056)
Education of mother (Ref. Illiterate)								
Elementary school and below	-0.217	-0.008	-0.222	-0.008	-0.209	-0.008	-0.197	-0.007
	(0.059)	(0.075)	(0.054)	(0.066)	(0.065)	(0.071)	(0.081)	(0.090)
Middle school and above	-0.959	-0.039*	-0.929	-0.039*	-0.898	-0.037*	-0.923	-0.038*
	(0.062)	(0.018)	(0.064)	(0.019)	(0.077)	(0.025)	(0.060)	(0.016)
Work status of father (Ref. None/limited)								
Full-time farming work (Farther)	-0.373	-0.018*	-0.341	-0.017*	-0.343	-0.017*	-0.326	-0.016*
	(0.062)	(0.026)	(0.088)	(0.038)	(0.084)	(0.034)	(0.094)	(0.037)
Full-time non-agricultural work	-0.450*	-0.020*	-0.426*	-0.019*	-0.422*	-0.019*	-0.380	-0.017*
	(0.034)	(0.023)	(0.043)	(0.029)	(0.043)	(0.029)	(0.062)	(0.044)
Work status of mother (Ref. None/limited)								
Full-time farming work (Mother)	0.208*	0.005	0.201*	0.005	0.195*	0.004	0.191*	0.004
	(0.024)	(0.248)	(0.029)	(0.270)	(0.032)	(0.290)	(0.034)	(0.293)
Full-time non-agricultural work	-0.301	-0.012	-0.311	-0.012	-0.303	-0.012	-0.300	-0.011
	(0.132)	(0.125)	(0.126)	(0.122)	(0.127)	(0.121)	(0.131)	(0.128)
Architecture type (Ref. concrete structure)								
Adobe house	0.395**	0.016**	0.391**	0.016**	0.388**	0.015**	0.375**	0.015**
	(0.001)	(0.005)	(0.001)	(0.006)	(0.001)	(0.005)	(0.002)	(0.007)
Wood/thatched house	0.538***	0.022***	0.523***	0.021***	0.515***	0.021***	0.501***	0.020***
	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)
Cave/Mongolian yurt/boat house/others	0.248	0.007	0.239	0.007	0.226	0.006	0.218	0.006
	(0.163)	(0.370)	(0.179)	(0.384)	(0.183)	(0.412)	(0.193)	(0.433)
Neighborhood safety (Ref. very safe)								
Somewhat safe			-0.061	-0.002	-0.061	-0.002	-0.068	-0.002
			(0.349)	(0.622)	(0.344)	(0.610)	(0.290)	(0.532)
Not very safe			-0.000	0.003	-0.071	0.000	-0.096	-0.001
			(0.999)	(0.589)	(0.655)	(0.941)	(0.550)	(0.867)
Not safe at all			0.657**	0.020*	0.665**	0.020*	0.626**	0.018
			(0.003)	(0.047)	(0.003)	(0.043)	(0.005)	(0.065)
Neighborhood cohesion (Ref. very close)								
Somewhat close-knit			0.210**	0.003	0.139	0.001	0.123	-0.000
			(0.005)	(0.298)	(0.064)	(0.836)	(0.100)	(0.992)
Not very close-knit			0.462*	0.017	0.292	0.010	0.261	0.008
			(0.020)	(0.061)	(0.140)	(0.272)	(0.186)	(0.351)
Not close-knit at all			1.612***	0.054***	1.381***	0.046**	1.354***	0.044**
			(<0.001)	(<0.001)	(<0.001)	(0.003)	(<0.001)	(0.004)
Friendship (Ref. often)								
Sometimes					0.248*	0.010*	0.226*	0.009*
					(0.010)	(0.014)	(0.019)	(0.025)
Not very often					0.352**	0.016**	0.333**	0.014**
					(0.003)	(0.001)	(0.005)	(0.003)
Never					0.772***	0.030***	0.747***	0.029***
					(<0.001)	(<0.001)	(<0.001)	(<0.001)
Relationship with mother (Ref. Fair/Poor)								
Good (Mother)					-0.154	-0.012**	-0.139	-0.011*
					(0.177)	(0.010)	(0.221)	(0.015)
Relationship with father (Ref. Fair/Poor)								

Good (Father)					0.002	0.007	0.010	0.008
					(0.988)	(0.095)	(0.928)	(0.085)
Relative Health Status (Ref. Healthier)								
About average							0.209**	0.009**
							(0.003)	(0.001)
Less healthy							0.141	0.004
							(0.284)	(0.473)
Confined to bed (Ref. No)								
Yes							-0.082	0.001
							(0.647)	(0.860)
Hospitalized (Ref. No)								
Yes							0.269	0.011
							(0.328)	(0.312)
Ever receive vaccinations (Ref. No)								
Yes							-0.248*	-0.014***
							(0.011)	(<0.001)
Not enough food during 0-5 (Ref. No)								
Yes							0.172*	0.009**
							(0.022)	(0.009)
Observations	6,700	6,700	6,700	6,700	6,700	6,700	6,700	6,700
R-squared	0.547	0.767	0.550	0.768	0.556	0.771	0.558	0.773
Covariates	YES	YES	YES	YES	YES	YES	YES	YES

Notes: N=6,700 observations. Standard errors are clustered at community level. Covariates are controlled in all four models, including age, gender, education, hukou status (rural/urban), marital status, log income and number of chronic diseases. Regressions are weighted at individual level with household and individual non-response adjustment. P-values are shown in parentheses. Statistical significance: *** $p<0.001$, ** $p<0.01$, * $p<0.05$

Figure 1. Course of cognitive aging with diverse childhood circumstances

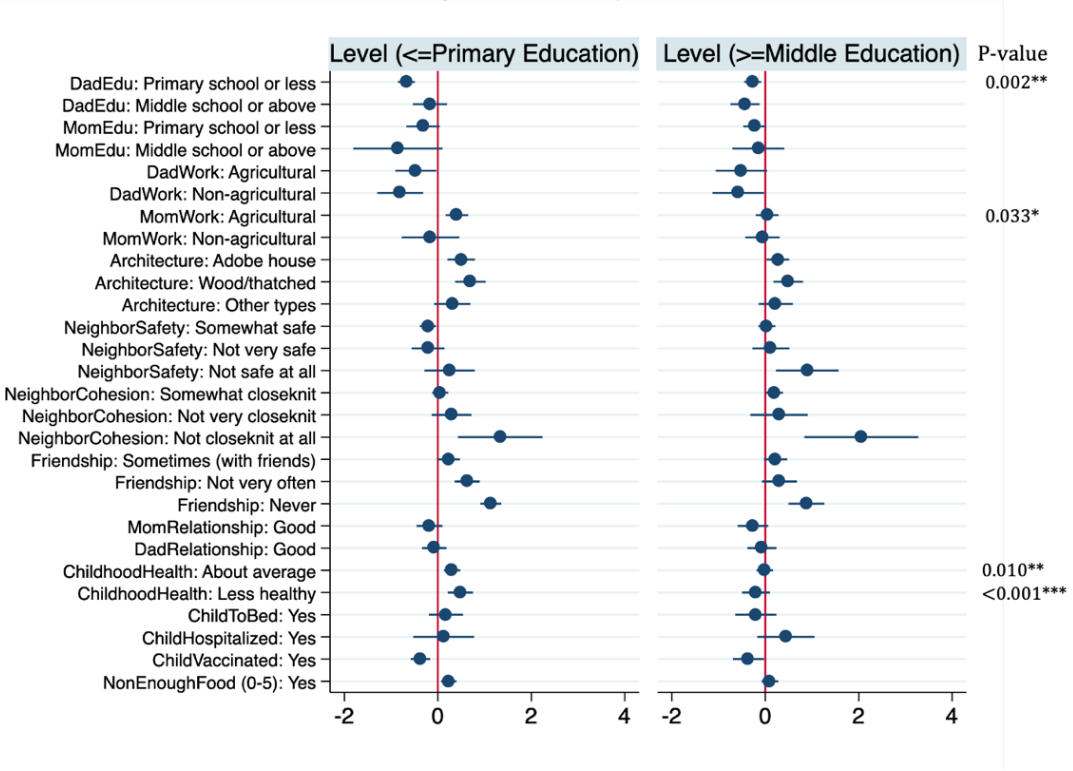




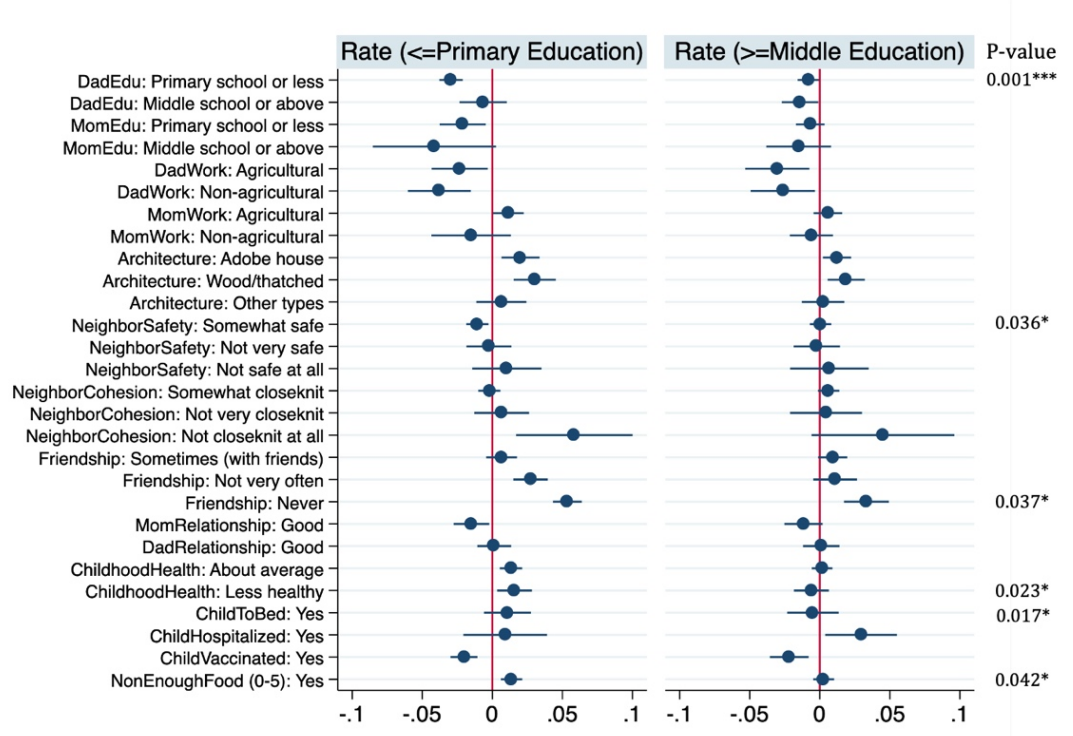
Notes: Panel A-J illustrate the diverse course of cognitive aging from age 45 to age 80 with different childhood circumstances, including parental education, parental work status, childhood relationships, childhood neighborhood social environment, and childhood health conditions. The X axis denotes the respondents' age when their cognitions were assessed. As cognition function is measured longitudinally in CHARLS, each individual may contribute more than one observation to the trend, and his/her cognitive function may reflect in more than one age group depending on the exact time of cognitive assessment. The plotted points in each panel, thus, represent the average level of cognitive deficit, for the ones with particular ages when the cognitive test was conducted, and with particular childhood circumstances. Cognitive deficit is defined as the reversed summary score of five cognitive tests, with higher value indicating greater cognitive deficit; age is specified as the age when the cognitive tests were conducted. All the regression lines were fitted using local linear smoothing.

Figure 2. The effects of childhood circumstances on cognitive aging among people with lower and higher education

Panel A. Childhood circumstances and level of cognitive deficit by education



Panel B. Childhood circumstances and rate of cognitive decline by education



Notes: Coefficient plots of the childhood circumstances on level of cognitive deficit (Panel A) and rate of decline (Panel B) among people with lower (primary school or below) and higher education level (middle school or above). The cross-equation test is conducted respectively to examine the statistical difference between the coefficients in two linear regressions. P-value is calculated based on Chow/Wald test, showing at the rightmost side of each panel (Only significant results are illustrated, whereas other estimates are available upon request. Statistical significance: *** $p<0.001$, ** $p<0.01$, * $p<0.05$).

Appendix A. Supplementary Results

Table A1. Comparisons between our study sample and the sample with missing data

Childhood Characteristics	Study Sample (N=6,700)	Sample with Incomplete Life History Data (N=2,409)	P-value
	(1)	(2)	(3)
1. Childhood socioeconomic status			
Education of father			
Illiterate	57.85	61.60	0.039
Elementary school and below	34.49	31.39	
Middle school and above	7.66	7.02	
Education of mother			
Illiterate	89.23	91.79	0.001
Elementary school and below	9.24	6.65	
Middle school and above	1.53	1.56	
Work status of father			
None or limited working	3.25	4.35	0.075
Full-time farming work	78.39	78.31	
Full-time non-agricultural work	18.36	17.34	
Work status of mother			
None or limited working	15.85	14.93	0.160
Full-time farming work	79.81	79.75	
Full-time non-agricultural work	4.34	5.32	
Architecture type of first residence house			
Concrete structure	11.55	13.10	0.087
Adobe house	61.64	62.43	
Wood house/thatched houses	18.49	17.04	
Cave/Mongolian yurt/boat house/others	8.31	7.42	
2. Childhood neighborhood social environment			
Neighborhood safety			
Very safe	50.22	46.97	<0.001
Somewhat safe	42.21	42.14	
Not very safe	5.54	7.77	
Not safe at all	2.03	1.69	
Neighborhood cohesion			
Very close-knit	44.18	39.97	<0.001
Somewhat close-knit	51.91	53.87	
Not very close-knit	3.24	4.46	
Not close-knit at all	0.67	1.69	
3. Childhood social relationship			
Friendship			
Often have a group of friends playing	65.54	58.60	<0.001
Sometimes	13.52	13.85	

Not very often	8.54	10.91	
Never	12.40	16.64	
Relationship with father			
Fair/Poor	19.72	21.24	0.184
Good	80.28	78.76	
Relationship with mother			
Fair/Poor	17.25	18.41	0.260
Good	82.75	81.59	
4. Childhood health conditions (before 15 yrs old)			
Relative health status compared to peers			
Healthier	36.40	33.67	<0.001
About average	52.15	50.98	
Less Healthy	11.45	15.35	
Ever confined to bed more than one month			
No	94.82	94.82	0.467
Yes	5.18	5.59	
Ever hospitalized			
No	98.13	98.14	0.998
Yes	1.87	1.86	
Ever receive any vaccinations (before 15 yrs old)			
No	13.76	17.51	<0.001
Yes	86.24	82.49	
Not enough food during 0-5 years old			
No	65.01	61.08	0.002
Yes	34.99	38.92	

Notes: Column 1 shows the distribution (in proportion) of life history variables among the sample included in our regression analysis (N=6,700), while Column 2 shows the distribution of the sample with complete cognitive tests, but incomplete life history data (N=2,409). Column 3 shows the p-value of Pearson chi2 test.

Table A2. Comparison of the regression results using the reversed cognitive test scores of three measured waves and the regression results using the level and rate estimated from linear mixed effect model

	Cross-sectional				LMM Decomposition		Effect Size	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Wave 2011	Wave 2013	Wave 2015	Pooled Avg	Level	Rate	Level	Rate
Education of father (Ref. Illiterate)								
Elementary school and below	-0.596*** (<0.001)	-0.671*** (<0.001)	-0.750*** (<0.001)	-0.672*** (<0.001)	-0.452*** (<0.001)	-0.017*** (<0.001)	-0.064	-0.041
Middle school and above	-0.495* (0.040)	-0.713** (0.003)	-0.374 (0.145)	-0.527** (0.007)	-0.356** (0.007)	-0.010 (0.056)	-0.029	-0.015
Education of mother (Ref. Illiterate)								
Elementary school and below	-0.335 (0.118)	-0.127 (0.584)	-0.418* (0.036)	-0.293 (0.079)	-0.197 (0.081)	-0.007 (0.090)	-0.018	-0.012
Middle school and above	-1.296 (0.165)	-0.866 (0.146)	-1.967* (0.016)	-1.377 (0.058)	-0.923 (0.060)	-0.038* (0.016)	-0.039	-0.028
Work status of father (Ref. None/limited)								
Full-time farming work (Farther)	-0.155 (0.662)	-0.658* (0.042)	-0.655 (0.102)	-0.489 (0.091)	-0.326 (0.094)	-0.016* (0.037)	-0.041	-0.036
Full-time non-agricultural work	-0.351 (0.338)	-0.619 (0.076)	-0.734 (0.084)	-0.568 (0.061)	-0.380 (0.062)	-0.017* (0.044)	-0.046	-0.035
Work status of mother (Ref. None/limited)								
Full-time farming work (Mother)	0.350* (0.033)	0.327 (0.056)	0.166 (0.383)	0.281* (0.036)	0.191* (0.034)	0.004 (0.293)	0.023	0.009
Full-time non-agricultural work	-0.479 (0.226)	-0.244 (0.458)	-0.616 (0.102)	-0.446 (0.129)	-0.300 (0.131)	-0.011 (0.128)	-0.022	-0.014
Architecture type (Ref. concrete structure)								
Adobe house	0.377 (0.066)	0.705** (0.003)	0.595* (0.015)	0.559** (0.002)	0.375** (0.002)	0.015** (0.007)	0.054	0.037
Wood/thatched house	0.428 (0.134)	1.042*** (<0.001)	0.769** (0.005)	0.746*** (<0.001)	0.501*** (<0.001)	0.020*** (<0.001)	0.056	0.039
Cave/Mongolian yurt/boat house/others	0.356 (0.209)	0.387 (0.282)	0.223 (0.475)	0.322 (0.196)	0.218 (0.193)	0.006 (0.433)	0.018	0.008
Neighborhood safety (Ref. very safe)								
Somewhat safe	-0.064 (0.613)	-0.197 (0.108)	-0.038 (0.794)	-0.100 (0.294)	-0.068 (0.290)	-0.002 (0.532)	-0.010	-0.005
Not very safe	-0.223 (0.459)	-0.162 (0.595)	-0.035 (0.898)	-0.140 (0.555)	-0.096 (0.550)	-0.001 (0.867)	-0.006	-0.001
Not safe at all	1.278** (0.002)	0.439 (0.312)	1.062* (0.020)	0.926** (0.005)	0.626** (0.005)	0.018 (0.065)	0.026	0.013
Neighborhood cohesion (Ref. very close)								
Somewhat close-knit	0.409** (0.003)	0.077 (0.576)	0.049 (0.747)	0.179 (0.109)	0.123 (0.100)	-0.000 (0.992)	0.018	-0.000
Not very close-knit	0.487 (0.205)	0.195 (0.600)	0.479 (0.246)	0.387 (0.188)	0.261 (0.186)	0.008 (0.351)	0.014	0.008
Not close-knit at all	2.095** (0.005)	1.834* (0.017)	2.095** (0.003)	2.008*** (<0.001)	1.354*** (<0.001)	0.044** (0.004)	0.032	0.018
Friendship (Ref. often)								
Sometimes	0.205 (0.258)	0.443* (0.013)	0.361 (0.059)	0.337* (0.018)	0.226* (0.019)	0.009* (0.025)	0.023	0.016
Not very often	0.185 (0.435)	0.810*** (<0.001)	0.498* (0.035)	0.498** (0.005)	0.333** (0.005)	0.014** (0.003)	0.028	0.021
Never	0.823*** (<0.001)	1.282*** (<0.001)	1.231*** (<0.001)	1.112*** (<0.001)	0.747*** (<0.001)	0.029*** (<0.001)	0.072	0.049
Relationship with mother (Ref. Fair/Poor)								
Good (Mother)	0.058 (0.795)	-0.201 (0.341)	-0.495* (0.022)	-0.213 (0.207)	-0.139 (0.221)	-0.011* (0.015)	-0.016	-0.021

Relationship with father (Ref. Fair/Poor)								
Good (Father)	-0.220	-0.132	0.417*	0.022	0.010	0.008	0.001	0.015
	(0.301)	(0.548)	(0.040)	(0.894)	(0.928)	(0.085)		
Relative Health Status (Ref. Healthier)								
About average	0.321*	0.094	0.522***	0.313**	0.209**	0.009**	0.031	0.023
	(0.040)	(0.442)	(<0.001)	(0.003)	(0.003)	(0.001)		
Less healthy	0.195	0.331	0.098	0.208	0.141	0.004	0.013	0.006
	(0.430)	(0.112)	(0.687)	(0.287)	(0.284)	(0.473)		
Confined to bed (Ref. No)								
Yes	-0.335	-0.017	-0.000	-0.117	-0.082	0.001	-0.005	0.001
	(0.341)	(0.958)	(1.000)	(0.656)	(0.647)	(0.860)		
Hospitalized (Ref. No)								
Yes	0.310	0.377	0.516	0.401	0.269	0.011	0.011	0.008
	(0.527)	(0.418)	(0.322)	(0.326)	(0.328)	(0.312)		
Ever receive vaccinations (Ref. No)								
Yes	-0.118	-0.335*	-0.670***	-0.374*	-0.248*	-0.014***	-0.025	-0.025
	(0.535)	(0.050)	(<0.001)	(0.010)	(0.011)	(<0.001)		
Not enough food during 0-5 (Ref. No)								
Yes	0.161	0.151	0.463**	0.258*	0.172*	0.009**	0.024	0.022
	(0.191)	(0.257)	(0.006)	(0.021)	(0.022)	(0.009)		
Observations	6,700	6,700	6,700	6,700	6,700	6,700	6,700	6,700
R-squared	0.275	0.331	0.342	0.428	0.558	0.773		
Covariates	YES	YES	YES	YES	YES	YES	YES	YES

Notes: Standard errors were clustered at community level. Covariates were controlled in all six models, including age, gender, education, hukou status (rural/urban), marital status, log income and number of chronic diseases. LMM = linear mixed-effect model. Columns 1-3 show the estimates of the model using reversed cognitive test scores from each of the three waves, respectively. Column 4 shows the regression results of the model using the average reversed test scores (i.e., Pooled Avg). Columns 5, 6 replicate the regression results of the model using the level and rate estimated from LMM (i.e., Columns 7, 8 in Table 3). The standardized effect size estimates in Column 7 and Column 8 respectively represent the effect of a one SD change in childhood circumstances on the level and rate of cognitive aging (SDs of level and rate). P-values are shown in parentheses. Statistical significance: *** $p<0.001$, ** $p<0.01$, * $p<0.05$

Table A3. Comparing the exposure estimates of regressions with and without adjusting for education.

	(1) Level	(2) Rate	(3) Level	(4) Rate
Education of father (Ref. Illiterate)				
Elementary school and below	-0.724***	-0.028***	-0.394***	-0.014***
	(0.000)	(0.000)	(0.000)	(0.000)
Middle school and above	-0.514**	-0.017*	-0.340*	-0.011*
	(0.004)	(0.022)	(0.015)	(0.048)
Education of mother (Ref. Illiterate)				
Elementary school and below	-0.511***	-0.018**	-0.241*	-0.009
	(0.000)	(0.001)	(0.042)	(0.065)
Middle school and above	-1.471*	-0.057**	-1.080*	-0.044**
	(0.019)	(0.010)	(0.028)	(0.006)
Work status of father (Ref. None/limited)				
Full-time farming work (Farther)	-0.596*	-0.031**	-0.358	-0.021*
	(0.024)	(0.005)	(0.093)	(0.013)
Full-time non-agricultural work	-0.919***	-0.040***	-0.356	-0.018*
	(0.001)	(0.000)	(0.107)	(0.041)
Work status of mother (Ref. None/limited)				
Full-time farming work (Mother)	0.331**	0.009	0.217*	0.004
	(0.004)	(0.066)	(0.025)	(0.317)
Full-time non-agricultural work	-0.251	-0.011	-0.344	-0.014
	(0.421)	(0.334)	(0.120)	(0.089)
Architecture type (Ref. concrete structure)				
Adobe house	0.440*	0.021**	0.309*	0.015**
	(0.013)	(0.006)	(0.022)	(0.008)
Wood/thatched house	0.939***	0.041***	0.495**	0.021***
	(0.000)	(0.000)	(0.001)	(0.001)
Cave/Mongolian yurt/boat house/others	0.267	0.008	0.125	0.004
	(0.203)	(0.378)	(0.489)	(0.574)
Neighborhood safety (Ref. very safe)				
Somewhat safe	-0.142	-0.007	-0.039	-0.002
	(0.126)	(0.095)	(0.597)	(0.555)
Not very safe	-0.040	0.000	-0.089	-0.001
	(0.824)	(0.971)	(0.590)	(0.821)
Not safe at all	0.828**	0.023	0.674**	0.017
	(0.004)	(0.070)	(0.007)	(0.136)
Neighborhood cohesion (Ref. very close)				
Somewhat close-knit	0.035	-0.003	0.034	-0.002
	(0.705)	(0.449)	(0.662)	(0.500)
Not very close-knit	0.350	0.009	0.289	0.007
	(0.163)	(0.437)	(0.181)	(0.398)
Not close-knit at all	1.617**	0.061**	1.308**	0.042*
	(0.001)	(0.007)	(0.002)	(0.012)
Friendship (Ref. often)				

Sometimes	0.277*	0.010	0.252**	0.010*
	(0.026)	(0.074)	(0.010)	(0.018)
Not very often	0.681***	0.029***	0.270*	0.013**
	(0.000)	(0.000)	(0.040)	(0.010)
Never	1.366***	0.059***	0.795***	0.031***
	(0.000)	(0.000)	(0.000)	(0.000)
Relationship with mother (Ref. Fair/Poor)				
Good (Mother)	-0.276	-0.019**	-0.131	-0.013**
	(0.059)	(0.002)	(0.289)	(0.006)
Relationship with father (Ref. Fair/Poor)				
Good (Father)	-0.234	0.000	-0.048	0.007
	(0.072)	(0.994)	(0.679)	(0.105)
Relative Health Status (Ref. Healthier)				
About average	0.321***	0.014***	0.203**	0.010**
	(0.000)	(0.000)	(0.004)	(0.001)
Less healthy	0.168	0.006	0.155	0.005
	(0.463)	(0.487)	(0.268)	(0.356)
Confined to bed (Ref. No)				
Yes	0.231	0.011	-0.034	0.003
	(0.338)	(0.237)	(0.859)	(0.681)
Hospitalized (Ref. No)				
Yes	0.386	0.027	0.258	0.015
	(0.267)	(0.057)	(0.409)	(0.235)
Ever receive vaccinations (Ref. No)				
Yes	-0.725***	-0.035***	-0.303**	-0.016***
	(0.000)	(0.000)	(0.004)	(0.000)
Not enough food during 0-5 (Ref. No)				
Yes	0.264**	0.013***	0.155*	0.008*
	(0.003)	(0.001)	(0.036)	(0.011)
Observations	6,042	6,042	6,042	6,042
R-squared	0.367	0.655	0.551	0.769
Other covariates in the full model except education	YES	YES	YES	YES
Education	NO	NO	YES	YES

Notes: Standard errors were clustered at community level. Column 1 and 3 show the regression results using the level of cognitive deficit as outcomes, whereas column 2 and 4 show the result using the rate of cognitive decline as outcomes. The models for column 1-2 only adjusted for baseline covariates except education, including age, gender, hukou status (rural/urban), marital status, log income and number of chronic diseases, while the models for column 3-4 additionally controlled for education. Regressions were weighted at individual level with household and individual non-response adjustment. P-values are shown in parentheses. Statistical significance: *** $p<0.001$, ** $p<0.01$, * $p<0.05$

Table A4. Comparing the exposure estimates of regressions cumulatively adjusted for later-life family wealth, health and health behaviors, and social engagements.

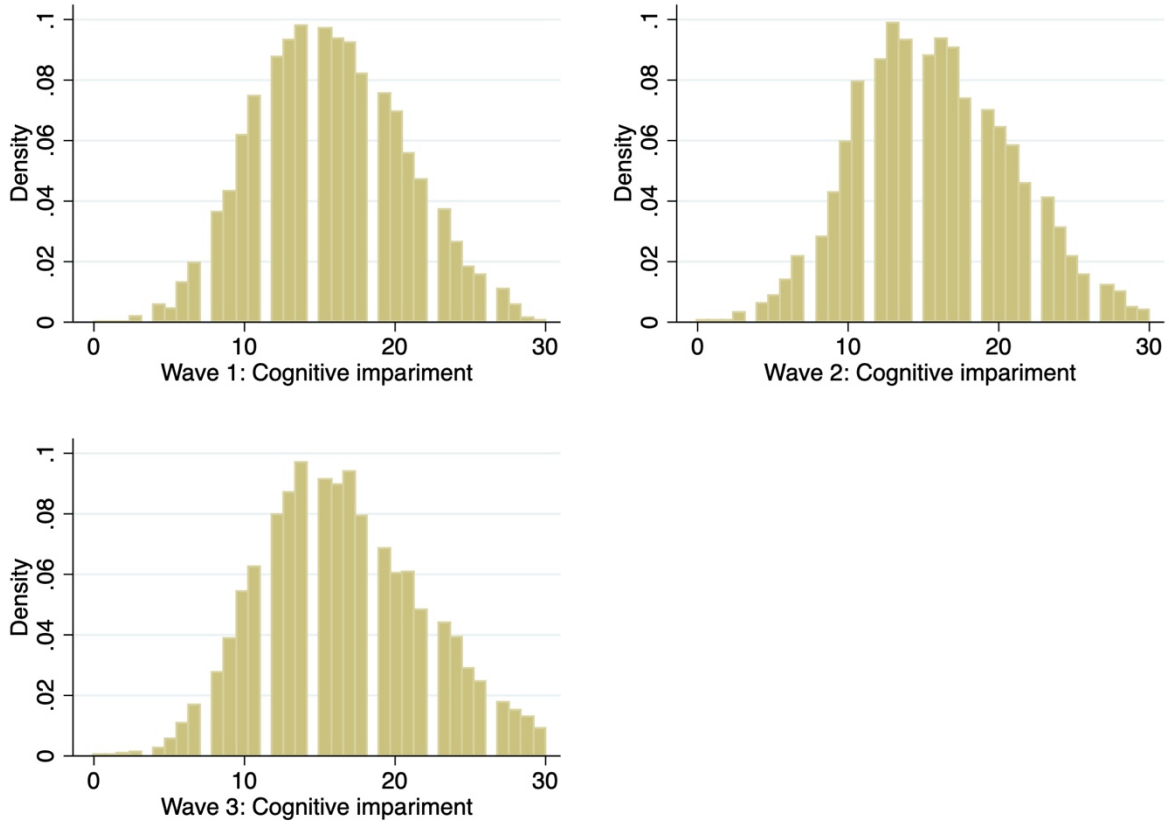
	(1) Level	(2) Rate	(3) Level	(4) Rate	(5) Level	(6) Rate
Education of father (Ref. Illiterate)						
Elementary school and below	-0.388***	-0.014***	-0.387***	-0.014***	-0.369***	-0.013***
	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)
Middle school and above	-0.335*	-0.011	-0.324*	-0.010	-0.358**	-0.011*
	(0.016)	(0.051)	(0.020)	(0.063)	(0.009)	(0.045)
Education of mother (Ref. Illiterate)						
Elementary school and below	-0.235	-0.008	-0.235*	-0.009	-0.195	-0.008
	(0.053)	(0.074)	(0.049)	(0.068)	(0.100)	(0.106)
Middle school and above	-0.936*	-0.041**	-0.948*	-0.042**	-0.824*	-0.039**
	(0.029)	(0.006)	(0.024)	(0.004)	(0.047)	(0.007)
Work status of father (Ref. None/limited)						
Full-time farming work (Farther)	-0.345	-0.021*	-0.345	-0.021*	-0.338	-0.020*
	(0.108)	(0.015)	(0.102)	(0.014)	(0.103)	(0.014)
Full-time non-agricultural work	-0.337	-0.018*	-0.325	-0.017	-0.296	-0.016
	(0.128)	(0.046)	(0.136)	(0.051)	(0.166)	(0.064)
Work status of mother (Ref. None/limited)						
Full-time farming work (Mother)	0.214*	0.004	0.215*	0.004	0.206*	0.004
	(0.027)	(0.326)	(0.024)	(0.325)	(0.027)	(0.325)
Full-time non-agricultural work	-0.211	-0.011	-0.230	-0.012	-0.215	-0.011
	(0.262)	(0.169)	(0.229)	(0.145)	(0.253)	(0.177)
Architecture type (Ref. concrete structure)						
Adobe house	0.314*	0.015**	0.313*	0.016**	0.293*	0.015**
	(0.015)	(0.007)	(0.015)	(0.006)	(0.024)	(0.008)
Wood/thatched house	0.497***	0.021***	0.487**	0.021***	0.458**	0.020**
	(<0.001)	(<0.001)	(0.001)	(<0.001)	(0.002)	(0.001)
Cave/Mongolian yurt/boat house/others	0.106	0.004	0.106	0.004	0.083	0.004
	(0.558)	(0.617)	(0.558)	(0.577)	(0.644)	(0.629)
Neighborhood safety (Ref. very safe)						
Somewhat safe	-0.057	-0.002	-0.054	-0.002	-0.045	-0.002
	(0.424)	(0.467)	(0.453)	(0.502)	(0.527)	(0.587)
Not very safe	-0.113	-0.002	-0.109	-0.002	-0.070	-0.000
	(0.493)	(0.749)	(0.509)	(0.769)	(0.665)	(0.944)
Not safe at all	0.648**	0.016	0.643**	0.016	0.601*	0.015
	(0.009)	(0.151)	(0.010)	(0.161)	(0.014)	(0.185)
Neighborhood cohesion (Ref. very close)						
Somewhat close-knit	0.036	-0.002	0.023	-0.003	0.004	-0.004
	(0.634)	(0.514)	(0.760)	(0.413)	(0.954)	(0.291)
Not very close-knit	0.283	0.007	0.277	0.007	0.223	0.006
	(0.189)	(0.407)	(0.196)	(0.425)	(0.290)	(0.502)
Not close-knit at all	1.317**	0.042*	1.285**	0.041*	1.215**	0.039*
	(0.002)	(0.012)	(0.002)	(0.014)	(0.002)	(0.017)
Friendship (Ref. often)						

Sometimes	0.254**	0.010*	0.259**	0.011*	0.235*	0.010*
	(0.010)	(0.018)	(0.008)	(0.016)	(0.016)	(0.024)
Not very often	0.278*	0.013**	0.276*	0.013**	0.181	0.010*
	(0.034)	(0.009)	(0.034)	(0.009)	(0.166)	(0.047)
Never	0.791***	0.030***	0.784***	0.030***	0.667***	0.027***
	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)
Relationship with mother (Ref. Fair/Poor)						
Good (Mother)	-0.127	-0.013**	-0.117	-0.013**	-0.085	-0.012*
	(0.297)	(0.006)	(0.338)	(0.008)	(0.475)	(0.014)
Relationship with father (Ref. Fair/Poor)						
Good (Father)	-0.055	0.007	-0.054	0.007	-0.091	0.006
	(0.634)	(0.112)	(0.641)	(0.104)	(0.428)	(0.177)
Relative Health Status (Ref. Healthier)						
About average	0.192**	0.009**	0.193**	0.010**	0.170*	0.009**
	(0.007)	(0.002)	(0.008)	(0.002)	(0.017)	(0.004)
Less healthy	0.151	0.005	0.144	0.005	0.123	0.004
	(0.259)	(0.355)	(0.282)	(0.370)	(0.374)	(0.435)
Confined to bed (Ref. No)						
Yes	-0.058	0.002	-0.074	0.002	-0.075	0.001
	(0.763)	(0.741)	(0.699)	(0.826)	(0.685)	(0.867)
Hospitalized (Ref. No)						
Yes	0.237	0.014	0.246	0.015	0.214	0.014
	(0.448)	(0.252)	(0.432)	(0.227)	(0.491)	(0.251)
Ever receive vaccinations (Ref. No)						
Yes	-0.292**	-0.016***	-0.280**	-0.015***	-0.238*	-0.014***
	(0.005)	(<0.001)	(0.007)	(<0.001)	(0.016)	(<0.001)
Not enough food during 0-5 (Ref. No)						
Yes	0.157*	0.008*	0.153*	0.008*	0.148*	0.008*
	(0.036)	(0.012)	(0.041)	(0.013)	(0.042)	(0.012)
Observations	6,042	6,042	6,042	6,042	6,016	6,016
R-squared	0.553	0.769	0.554	0.770	0.563	0.773
Covariates in the full model (including education)	YES	YES	YES	YES	YES	YES
Later-life family wealth	YES	YES	YES	YES	YES	YES
Later-life health and health behaviors	NO	NO	YES	YES	YES	YES
Later-life social engagements	NO	NO	NO	NO	YES	YES

Notes: Standard errors were clustered at community level. Other than the covariates controlled in the full model, including age, gender, education, hukou status (rural/urban), marital status, log income and number of chronic diseases, the models for columns 1-6 also cumulatively controlled for three other sets of covariates, including later-life family wealth, health and health behaviors, and social engagements. Later-life family wealth represents the total non-housing financial wealth of the respondent and spouse at the baseline. Later-life health captures the health risks related to dementia, including hypertension, heart diseases, diabetes, and dyslipidemia at the baseline; and health behaviors measure whether the respondents were still smoking or drinking at the baseline. Later-life social engagements measure whether the respondents participated in any of the following social activities in the last month: "Interacted with friend", "Played Ma-jong, chess, cards, or went to a community club", "Went to a sporting event, participated in a social group, or participated in some other sort of club", "Took part in a community-related organization", "Took part in voluntary or charity work", "Attended an educational or training course", where we included the measures collected from Wave 1 to Wave 3 to capture the respondents' long-term patterns of social activities. Regressions were weighted at individual

level with household and individual non-response adjustment. P-values are shown in parentheses. Statistical significance: *** $p<0.001$, ** $p<0.01$, * $p<0.05$

Figure A1. The distributions of cognitive deficit of sample collected in three waves.



Note: Each histogram shows the distribution of cognitive deficit for each measured wave among the sample used in linear regression (N=6,700)

Figure A2. A flow chart of consecutive sample selection and data analysis

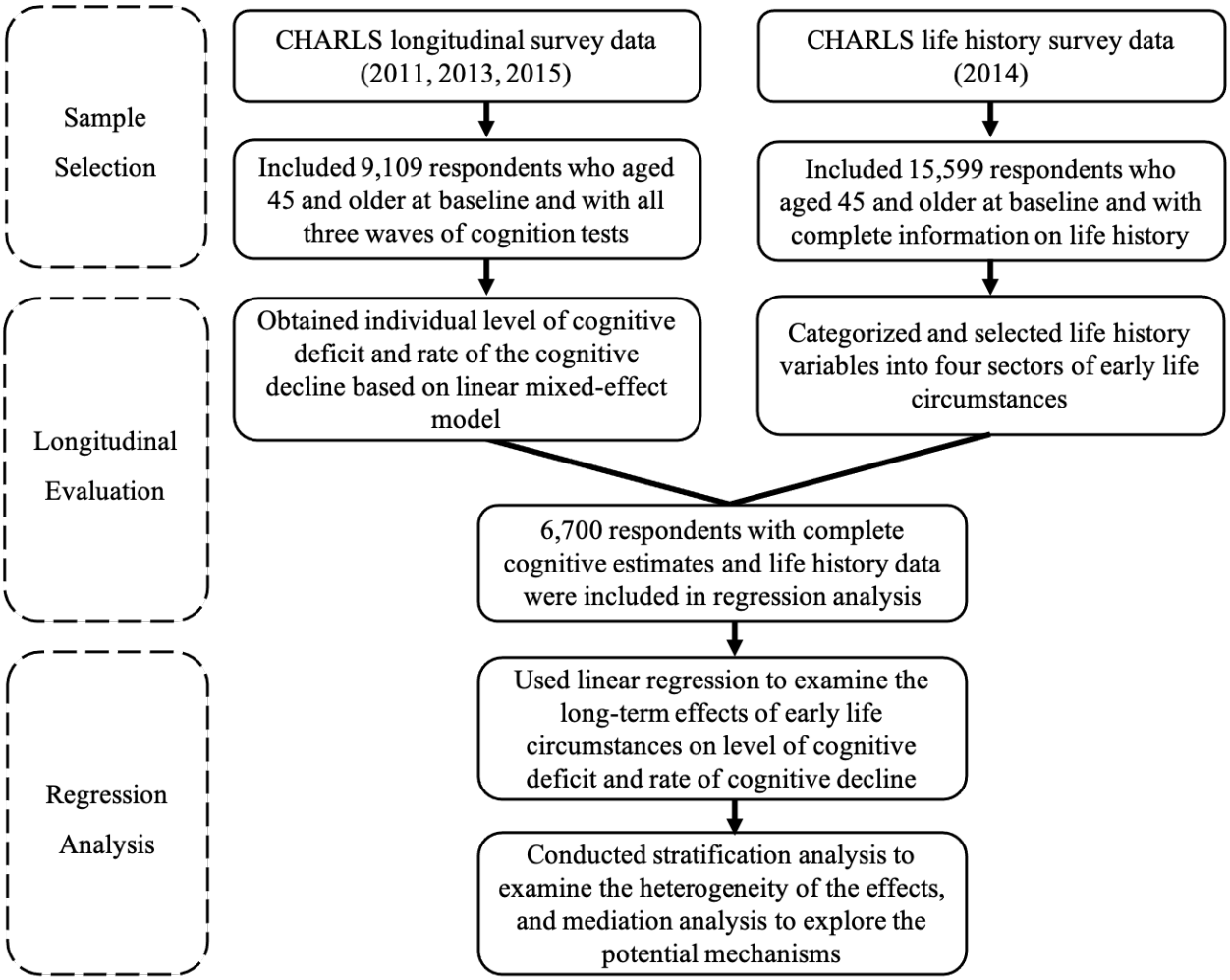
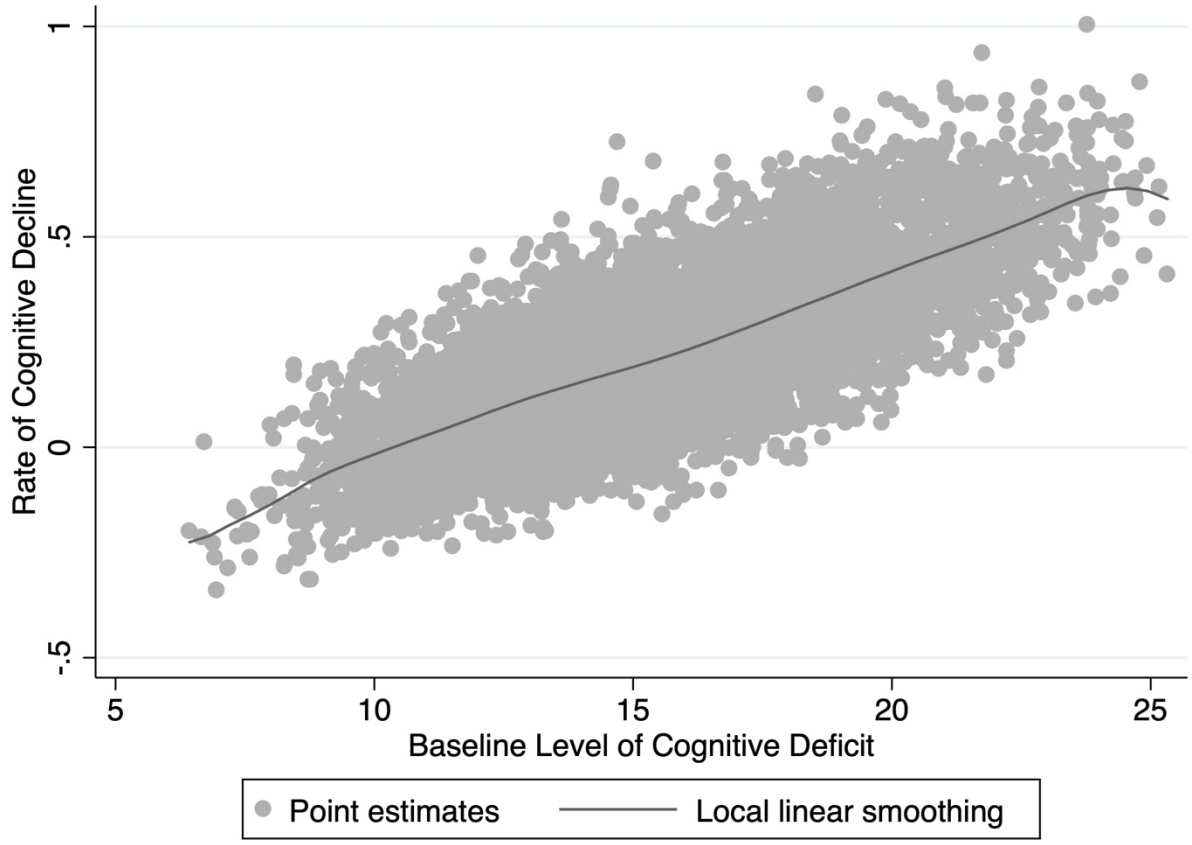


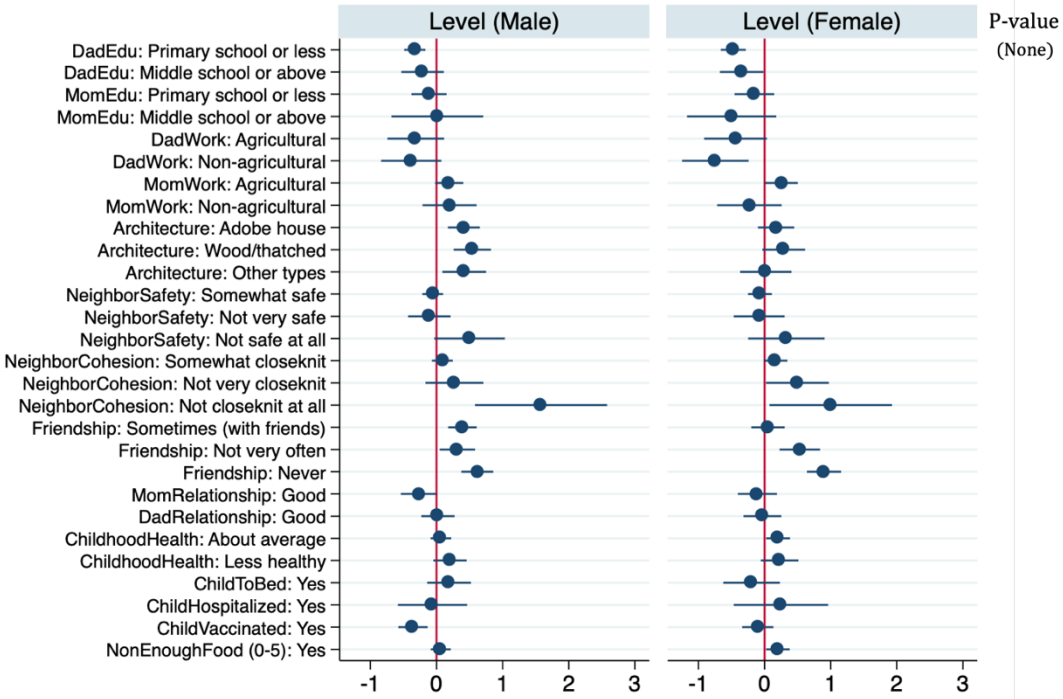
Figure A3. Estimated rate of cognitive decline and baseline level of cognitive deficit



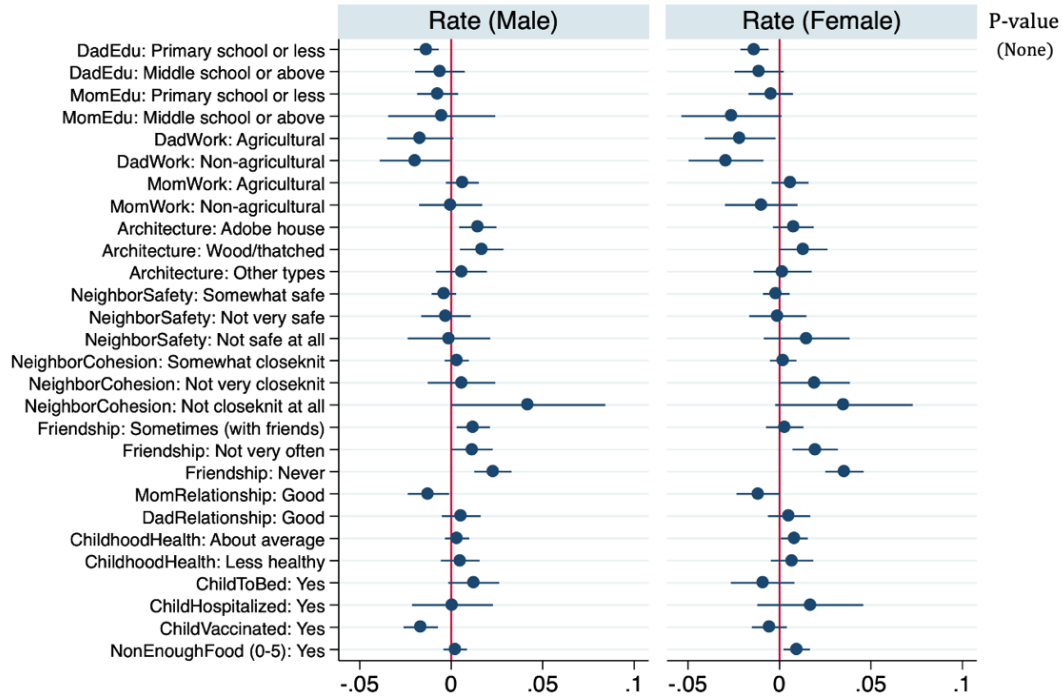
Notes: The relationship between rate of cognitive decline and baseline level of cognitive deficit is illustrated above. Plotted points represent the individual estimates of level and rate. The regression line was fitted by local linear smoothing (N=6,700). Pearson's correlation coefficient=0.751, $p<0.001$.

Figure A4. The effects of childhood circumstances on cognitive aging among male and female

Panel A. Childhood circumstances and level of cognitive deficit by gender



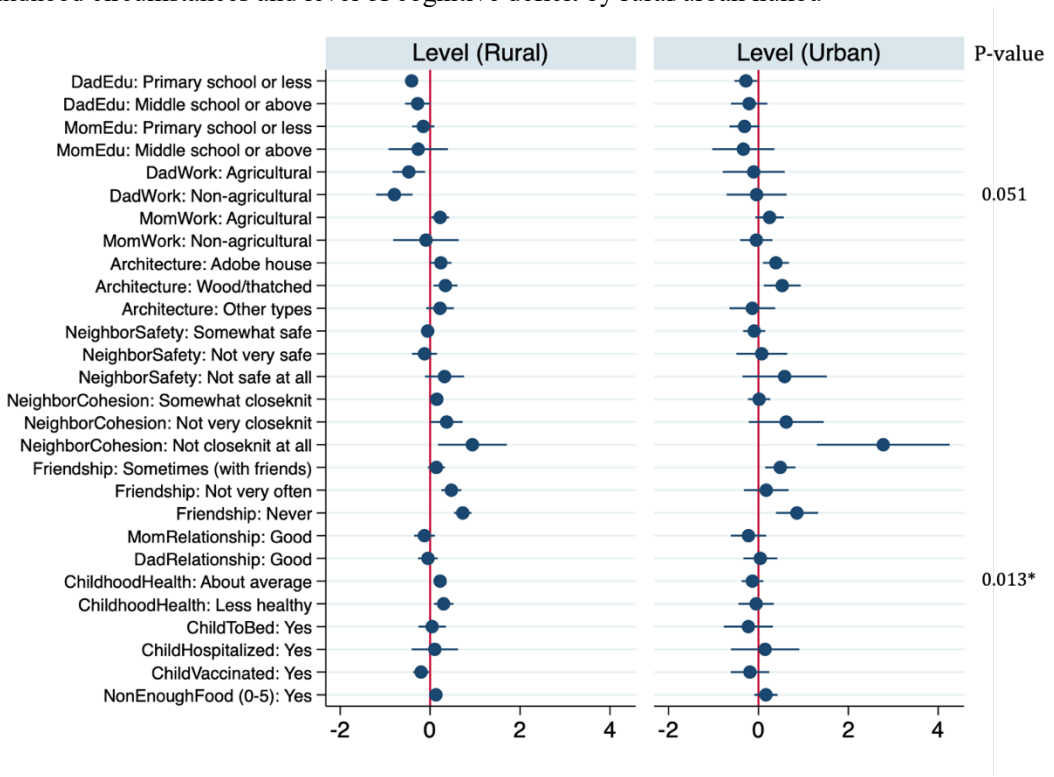
Panel B. Childhood circumstances and rate of cognitive decline by gender



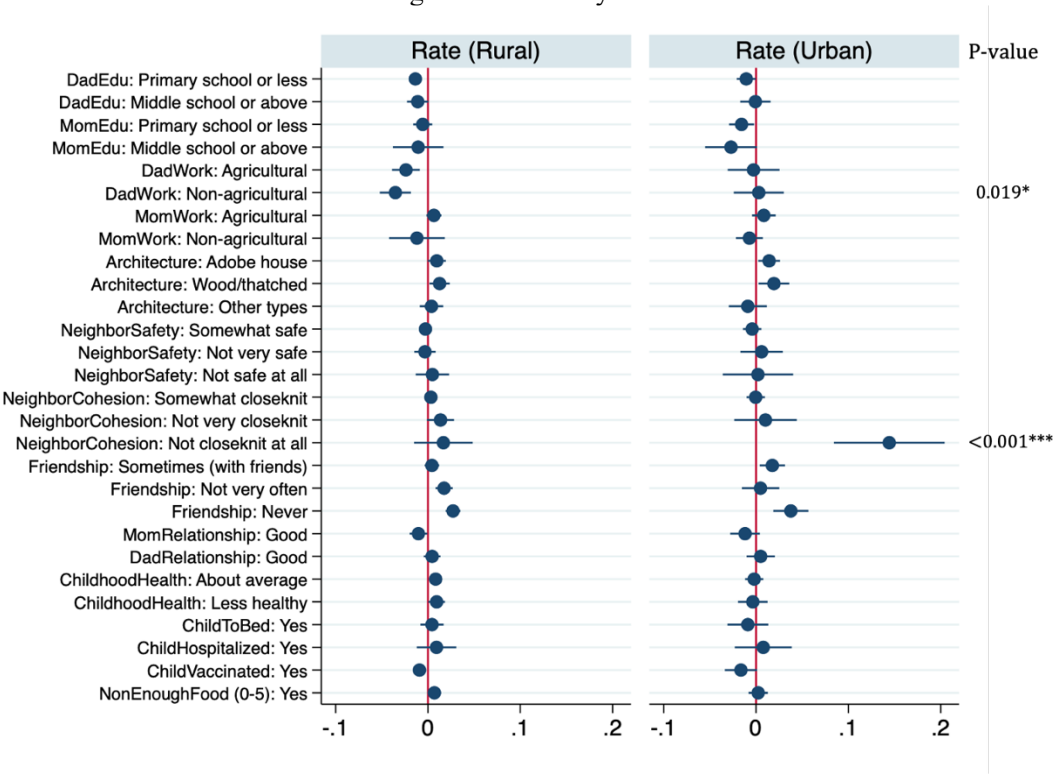
Notes: Coefficient plots of the childhood circumstances on level of cognitive deficit (Panel A) and rate of decline (Panel B) among male and female. The cross-equation test was conducted respectively to examine the statistical difference between the coefficients in two linear regressions. P-value was calculated based on Chow/Wald test, showing at the rightmost side of each panel (Only significant results are illustrated, whereas other estimates are available upon request. Statistical significance: *** $p<0.001$, ** $p<0.01$, * $p<0.05$).

Figure A5. The effects of childhood circumstances on cognitive aging among people with rural and urban hukou

Panel A. Childhood circumstances and level of cognitive deficit by rural/urban hukou



Panel B. Childhood circumstances and rate of cognitive decline by rural/urban hukou



Notes: Coefficient plots of the childhood circumstances on level of cognitive deficit (Panel A) and rate of decline (Panel B) among individuals with rural hukou status at the baseline compared to those with urban hukou status. Hukou status (rural/urban) is a special identifier for the population in China as every Chinese citizen should legally register as either agricultural or non-agricultural residency status (normally referred to as rural vs. urban). Detailed definition and implications of rural/urban hukou status can be found in Appendix Table C2. The cross-equation test was conducted respectively to examine the statistical difference between the coefficients in two linear regressions. P-value was calculated based on Chow/Wald test, showing at the rightmost side of each panel. (Only significant/marginally significant results are illustrated, whereas other estimates are available upon request. Statistical significance: *** $p<0.001$, ** $p<0.01$, * $p<0.05$).

Appendix B. Data

Data Sampling

The CHARLS national baseline survey (i.e., wave 1, 2011-2012) adopted a stratified, multi-stage (county/district - village/community - household), probability proportional to population (PPS) random sampling strategy. In specific, 150 counties or urban districts were randomly chosen with probability proportional to population (PPS) out of all county-level units from all provinces except Tibet, where the county units were stratified by region, urban-rural, and by GDP per capita (Zhao et al., 2016, 2014). Then for each county, three administrative villages/urban neighborhoods (i.e., the primary sampling units, PSUs) were randomly selected with PPS sampling, which resulted in a total of 450 villages/neighborhoods. The sampling process, hence, makes CHARLS national representative and representative of both rural and urban areas in China, with the selected counties and districts representing 28 provinces out of 30 (Zhao et al., 2014). To obtain the most dated household listings, CHARLS developed a mapping/listing software (CHARLS-GIS) to list all dwellings units within a building based on Google-earth map images, to create sampling frames. From the frames, approximately 20 age eligible households were sampled per PSU; and in each sampled household, one person aged 45 or above was randomly selected as the main respondent, and his/her spouse was also interviewed (Zhao et al., 2020, 2016). Finally, a total of 17,708 individuals in 10,257 households were included in the national baseline survey. The respondents were followed up every two years since wave 1 (2011-2012), and a refreshment sample of 45-46-years-olds and his/her spouse were randomly drawn from each sampled household in wave 2 (2013), and in wave 3 (2015) to fully ensure the sample representativeness of the 45+ population (as the baseline respondents got older in later waves) (Zhao et al., 2020). In addition to the biennial

core survey waves (2011, 2013. 2015), a life history survey was conducted in 2014 to collect detailed information on respondents' life course circumstances.

Data Collection and Administration

As for data collection, the cognitive assessments were longitudinally taken in 2011 and 2013 and 2015, and the childhood circumstances of respondents was systematically collected in the 2014 survey. The surveys were mainly administered by Peking University. All survey workers were trained by CHARLS staff members with a standard protocol, and two interviewers were sent to each county-level unit to interview about 72 households and required to conduct the face-to-face interviews in respondents' homes. Data were collected using a computer-assisted personal interview (CAPI) system, and a quality assurance program was also carried out to ensure the reliability of the survey (Zhao et al., 2020, 2016).

Ethical Approval and Informed Consent

The study protocols for all the CHARLS waves obtained ethical approval from the Institutional Review Board (IRB) at Peking University. Each respondent who agreed to participate in the survey was asked to sign two copies of the informed consent, and the written informed consent was obtained from all study participants, and was electronically scanned and archived (Zhao et al., 2020).

Appendix C. Variables

Table C1. The Construction and the Conceptualization of the Measures of Childhood Circumstances.

Variables	Questions in the Survey	Construction of Variables	Conceptualization of Variables
Education of father	What is the highest level of education your biological father completed? (Categorical) 1. No formal education (illiterate); 2. Did not finish primary school but capable of reading or writing; 3. Sishu/Home School; 4. Graduate from elementary school; 5. Graduate from middle school; 6. Graduate from high school; 7. Graduate from vocational school; 8. Graduate from two/three Year College/Associate degree; 9. Graduate from Four Year College/Bachelor's degree; 10. Graduate from Post-graduate, Master degree; 11. Graduate from Post-graduate, PhD degree.	We re-categorized father's education level into three groups: 1. Illiterate; (=1) 2. Elementary school and below; (=2-4) 3. Middle school and above. (=5-11)	Parental education, as a measure of childhood socioeconomic status (SES).
Education of mother	What is the highest level of education your biological mother completed? (Categorical) 1. No formal education (illiterate); 2. Did not finish primary school but capable of reading or writing; 3. Sishu/Home School; 4. Graduate from elementary school; 5. Graduate from middle school; 6. Graduate from high school; 7. Graduate from vocational school; 8. Graduate from two/three Year College/Associate degree; 9. Graduate from Four Year College/Bachelor's degree; 10. Graduate from Post-graduate, Master degree; 11. Graduate from Post-graduate, PhD degree.	We re-categorized mother's education level into three groups: 1. Illiterate; 2. Elementary school and below; 3. Middle school and above.	Parental education, as a measure of childhood socioeconomic status (SES).
Work status of father	How much of your childhood before you were age 17 did your male guardian either work for pay or work in a family business? 1. All of my childhood; 2. Part of my childhood; 3. None of my childhood.	Based on the two questions, we specified whether respondents' father had full-time job or not during their childhood; and if so, what type of jobs their	Parental occupation/work status, as a measure of childhood SES.

	What was your male guardian's usual occupation when you were growing up before you were 17? Please specify occupation in detail, including the department, key responsibility and the position. 1. Farming; 2. Non-agricultural.	father did. This leaded to three categories: 1. None or limited work; 2. Full-time farming work; 3. Full-time non-agricultural work.	
Work status of mother	How much of your childhood before you were age 17 did your male guardian either work for pay or work in a family business? 1. All of my childhood; 2. Part of my childhood; 3. None of my childhood. What was your male guardian's usual occupation when you were growing up before you were 17? Please specify occupation in detail, including the department, key responsibility and the position. 1. Farming; 2. Non-agricultural.	Based on the two questions, we specified whether respondents' mother had full-time job or not during their childhood; and if so, what type of jobs their father did. This leaded to three categories: 1. None or limited work; 2. Full-time farming work; 3. Full-time non-agricultural work.	Parental occupation/work status, as a measure of childhood SES.
Architecture type of first residence house	From your birth/Year, what is the architectural type of your first residence? 1. Concrete structure, Built with bricks and wood; 2. Adobe house; 3. Wood house/Thatched houses; 4. Cave; 5. Mongolian yurt; 6. Boat house; 7. Others;	We re-categorized mother's education level into four groups: 1. Concrete structure; 2. Adobe house; 3. Wood house/thatched houses; 4. Cave/Mongolian yurt/boat house/others. The categorization was based on the economic value that the housing structure might reflect, where we classified "Cave", "Mongolian yurt", "Boat house" and "Others" into one group.	Housing characteristics, as a proxy to childhood family economic and financial status (i.e., SES)
Neighborhood safety	Was it safe being out alone at night in the neighborhood where you lived as a child? Is it very safe, somewhat safe, not very safe or not safe at all? 1. Very safe; 2. Somewhat safe; 3. Not very safe; 4. Note safe at all.	The categories were identical to the survey question.	Neighborhood safety, as a measure of childhood neighborhood social environment.

Neighborhood cohesion	Were the neighbors of the place where you lived as a child very close-knit? Is it very close-knit, somewhat close-knit, not very close-knit or not close-knit at all? 1. Very close-knit; 2. Somewhat close-knit; 3. Not very close-knit; 4. Not close-knit at all.	The categories were identical to the survey question.	Neighborhood safety, as a measure of childhood neighborhood social environment.
Friendship	When you were a child, did you often have a group of friends that you felt comfortable spending time with? Is it often, sometimes, not very often or never? 1. Often; 2. Sometimes; 3. Not very often; 4. Never.	The categories were identical to the survey question.	Friendship, as a measure of childhood social relationships.
Relationship with father	How would you rate your relationship with your female guardian when you were growing up? 1. Excellent 2. Very good 3. Good 4. Fair 5. Poor	We re-categorized the relationship with father into two groups: 1. Fair/Poor (=4 or 5) 2. Good (=1 or 2 or 3)	Relationships with parents, as a measure of childhood social relationships.
Relationship with mother	How would you rate your relationship with your female guardian when you were growing up? 1. Excellent 2. Very good 3. Good 4. Fair 5. Poor	We re-categorized the relationship with father into two groups: 1. Fair/Poor (=4 or 5) 2. Good (=1 or 2 or 3)	Relationships with parents, as a measure of childhood social relationships.
Relative health status compared to peers	Before you were 15 years old (including 15 years old), would you say that compared to other children of the same age, you were 1. Much healthier 2. Somewhat healthier 3. About average 4. Somewhat less healthy 5. Much less healthy	We re-categorized the childhood health into three groups: 1. Healthier (=1 or 2) 2. About average (=3) 3. Less healthy (=4 or 5)	Childhood self-reported health status, as a measure of general childhood health conditions.
Ever confined to bed more than one month	Before you were 15 years old (including 15 years old), because of a health condition, were you ever confined to bed or home for a month or more? 1. Yes 2. No	The categories were identical to the survey question. We used "No" as the reference group.	Disadvantaged health situation, as an objective measure of childhood health conditions.
Ever hospitalized	Before you were 15 years old (including 15 years old), because of a health condition, were you ever hospitalized for a month or more?	The categories were identical to the survey question. We used "No" as the reference group.	Disadvantaged health situation, as an objective measure of

	1. Yes 2. No		childhood health conditions.
Ever receive any vaccinations (before 15 years old)	Before you were 15 years old (including 15 years old), have you received any vaccinations? 1. Yes 2. No	The categories were identical to the survey question. We used "No" as the reference group.	Preventive care, as a measure of childhood health resources.
Not enough food during 0-5 years old	When you were a child before age 17 was there ever a time when your family did not have enough food to eat? 1. Yes 2. No At what age ranges did this (your family had no enough food to eat) happen? (Multiple answers are allowed) 1. Age 0-5 2. Age 6-12 3. Age 13-17	Based on these two questions, we specified whether the respondent had enough food or not during age 0-5: 1. Yes 2. No We used "No" as the reference group.	Childhood nutritional status; chose age 0-5 as it is a critical stage of brain development.

Notes: The covariates were constructed based on the CHARLS life history survey, which was collected in 2014.

Table C2. The Construction and Definition of Covariates and Mediators

Variables	Construction of Variables	Definition of Variables
Age	Age denoted the respondent's age in years at the baseline (i.e., wave 1), which was calculated by the respondent's birth year and month minus the interview year and month.	Age in years at the baseline.
Gender	Gender was reported in each wave of CHARLS surveys. There were two categories: 1. Male; 2. Female.	Biological gender/sex, male and female.
Education level	The highest level of education that the respondent attained was self-reported in CHARLS in categories (e.g., primary school, middle school, college). Considering the high prevalence of lower education among the study sample, we categorized it into four groups: 1. Illiterate or informal education; 2. Primary school; 3. Middle school; High school and above.	Educational attainment (categorical).
Hukou status	Respondents were asked to report their hukou status, which is a population registration system used in China that indicate individual's rural or urban residency status. Specifically, agricultural hukou was classified as rural hukou, while non-agricultural hukou and unified residence hukou were classified as urban hukou. 1. Urban 2. Rural	Hukou is a population registration system that has long been used in China. Every Chinese citizen is required to legally register in the system, as either agricultural or non-agricultural residency (normally referred to as rural vs. urban). Hukou status (rural/urban) often determines the social programs (and benefits) that individuals are eligible for, and affects many aspects of life such as school enrollment, real estate transaction, public insurance coverage and health services. It thus encompasses rich information on individuals' social status and welfare benefits. Therefore, we used hukou as the measure of respondents' rural or urban status.
Marital Status	In CHARLS, respondents were asked to indicate their marital status (e.g., married, divorced, widowed). We categorized it into two categories: 1. Married with spouse present; 2. Not.	Baseline marital status (i.e., married with spouse present or not).
Log annual per capita income	It represented log annual per capita income in the household, which was calculated using all the sources of incomes reported in the past year.	Baseline annual income (in the past year)
The number of chronic diseases	We added up the chronic diseases that individuals self-reported at the baseline, including hypertension, diabetes or high blood sugar, cancer or a malignant tumor, chronic lung disease such as chronic	Total number of self-reported chronic diseases that had been diagnosed at the baseline.

	bronchitis or emphysema, heart diseases, stroke, emotional, nervous, or psychiatric problems, arthritis, dyslipidemia, liver disease, kidney disease, stomach or other digestive disease, asthma.	
Family wealth	It represented the total value of non-housing financial wealth that was reported by respondent and his/her spouse at the baseline. It was calculated by summing cash and saving deposits, stocks and mutual funds, government bonds and all other savings, minus the value of debt.	Total value of non-housing financial wealth at the baseline
Later-life Health	It measured whether the respondents have particular diseases and health risks that are closely related to dementia at the baseline, including hypertension, heart diseases, diabetes, and dyslipidemia at the baseline. A set of dummy variables was constructed to denote the diseases.	Health risks for dementia and cognitive impairment.
Health behaviors (i.e., Smoking, Drinking)	The respondent was asked to report their current smoking habit (i.e., still smoking) and drinking (i.e., has had an alcoholic beverage in the last 12 months). We used dummy variables to denote whether the respondent was still smoking at the baseline (0/1), and has had drinking behavior.	Smoking, and drinking habits, as measures of the respondent's health risk behaviors.
Social Engagement	In each of the three CHARLS core surveys, the respondent was asked to report whether they participated in the following social activities in the past month: "Interacted with friend", "Played Ma-jong, chess, cards, or went to a community club", "Went to a sporting event, participated in a social group, or participated in some other sort of club", "Took part in a community-related organization", "Took part in voluntary or charity work", "Attended an educational or training course". A set of dummy variables was constructed to denote whether the respondent participated in any of these social activities in the three waves (0/1).	Social activities, as a measure of social engagement.

Notes: The social engagement were constructed based on the measures collected from wave 1 to wave 3 to capture the respondents' long-term patterns of social activities. Other mediators or covariates were constructed based on the baseline CHARLS survey (i.e., wave 1), which was fielded in 2011/2012.

Appendix D. Cognitive Tests in CHARLS

There were five cognitive tests measured in the CHARLS baseline and two follow-up surveys: immediate word recall, delayed word recall, serial 7s, date naming, and picture drawing. Among them, immediate and delayed word recall tests, were used to assess individuals' short-term and long-term memory.

- **Immediate word recall.** The respondent was first asked to recall as many as words as he/she could, immediately after the interviewer read out a list of 10 words (i.e., immediate word recall, range 0-10). The interviewer recorded the number of words that the respondent remembered correctly, and the words did not have to be in the same order as the ones he/she heard
- **Delayed word recall.** Approximately 5 minutes after the respondent recall the words, he/she was asked to repeat the list of words again (i.e., delayed word recall, range: 0-10) without any hints from the interviewer. Similarly, the interviewer recorded the number of words that the respondent remembered correctly this time (and the words did not have to be in the same order as the ones)

The other three tests, serial 7's test, date naming, and picture drawing were designed to assess the respondents' ability to perform mathematical tasks, orientation, and mental intactness.

- **Serial 7's.** The test asked the respondent to subtract 7 from 100 for 5 trials; and the interviewer recorded the number of correct answers (range 0-5).
- **Date naming.** The test tested whether the respondent was able to correctly report today's date, including the day of month, month, year, as well as the day of the week (range 0-4).

- **Picture drawing.** The test assessed whether the respondent was able to redraw a picture (i.e., a picture of two pentagons overlapped) shown by the interviewer (0/1) (Ofstedal et al., 2005; Zhao et al., 2020).

These cognitive tests were conducted by interviewers who were trained with a standard and stringent protocol. Though the interviewers were mostly college or graduate students, the cognitive tests were well-designed, straightforward, and easy to conduct. In addition, the tests were largely objective evaluations, while requiring limited expertise in medical or cognitive science. Therefore, interviewers with standard training would be able to conduct the tests through face-to-face interviews (Zhao et al., 2020, 2014).

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