# Effects of Education and Income on Cognitive Decline: A Multilevel Longitudinal Analysis

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PSYC 575

Fall 2020

## Abstract

Previous research on the relationship between higher education attainment and the rate of cognitive decline in older adults remains contradicting. In the present study, we investigated the effects of education, income, and sex on older adults' performance on five cognitive tasks over time using a multilevel model. The cognitive task scores were as follows: WAIS similarities, letter fluency, categorical fluency, digit ordering, and immediate recall. The cognitive tasks were assessed at ages between 52 and 74. Data came from 4249 participants in the Wisconsin Longitudinal Study (WLS). Results indicated that attainment of higher education was associated with a slower decline in categorical fluency. Women experienced greater decline across all measures but were shown to benefit more than men from higher education, specifically in immediate recall. Lastly, we observed that higher adult income slowed the decline of verbal IQ. No combined effects of education and income were observed. Our results demonstrate that, using a longitudinal design and multilevel analysis, sex, education, and income play a significant role in different facets of cognitive decline due to aging.

## Introduction

Past research consistently revealed that increased age is associated with lower levels of cognitive performance (Colsher and Wallace 1991). Although gradual decline is common in later life, the rate of cognitive decline varies substantially (Schaie, 1996; Zelinski & Stewart, 1998; Alley et al., 2007). Education is an important factor in such varying rates of cognitive decline. Longitudinal studies suggested that higher educational attainment is related to higher levels of cognitive performance in late life (Albert et al. 1995; Lyketsos, Chen, & Anthony, 1999). However, some research reports the opposite, suggesting that higher education does not protect against cognitive decline (Christensen et al. 2001; Hultsch et al. 1998). To our knowledge, whether attaining higher levels of education leads to a delay in cognitive decline for older adults remains unclear.

Despite the inconclusive results in previous research on the role of higher education attainment and cognitive decline, much research has found the relationship between different life factors - such as socioeconomic status (SES) and education - and general health and cognition in adults. Higher SES predicts better health for both men and women across different societies (Feinstein, 1993). Individuals' general health affects the rate of cognitive decline. For instance, older adults with cardiovascular disease or diabetes are more likely to have a measurable decline in neurocognitive function (Maggi et al., 2009; Okonkwo et al., 2010). In addition to adult SES, childhood SES is also an important determinant of health and cognitive outcomes in later life (Bradley & Corwyn, 2002; Greenfield & Moorman, 2019). This could be due to different factors such as less access to learning materials and experiences at a young, which may discourage the development of important learning skills that are necessary throughout life (Bradley et al., 2001; Buckingham, Wheldall, & Beaman-Wheldall, 2013).

Attainment of higher education also matters for better general health. Research has found that college-education adults are also generally more likely to fare better in mental and physical health (Ross, Masters, & Hummer, 2012). However, Luo and Waite (2005) found differences in sex; while college education was a stronger factor for women's later health, adult income seemed to be a stronger factor for men's later health.

Knowing the role of SES and education attainment on general health and cognition, it is worth noting the relationship between SES and higher education attainment. SES plays a critical role in determining whether the individual attends higher education later or not. Even from high school, children from low SES backgrounds are on average five years behind in literary skills in comparison to children from higher SES backgrounds (Reardon, et al., 2013). Low SES is a barrier for higher education attainment at all stages. Prospective college students from low SES backgrounds are less likely to have accessible resources about college and, even after being accepted into college, students of low SES backgrounds are less likely to be successful in obtaining a bachelor's degree (Brown, Wohn, & Ellison, 2016; McLaughlin & Sheridan, 2016).

In the current investigation, we assess the role of education and socioeconomic status as it interacts with sex on the rate of cognitive decline with a longitudinal design. Our present study addresses the following questions: 1. Does educational attainment protect against cognitive decline later in life? 2. Does childhood or adulthood income, or sex, interact with the relationship between education and cognitive decline? We hypothesize that education and SES will moderate cognitive decline in which individuals with higher education will show less decline in cognitive measurements over time. We exploratorily investigate the interaction between education, SES, and sex with the aim of clarifying whether older men or women may benefit more than the opposite sex from higher education or higher SES in terms of their cognitive decline.

## Methods

### *Respondents*

We used the Wisconsin Longitudinal Study (WLS) Data which is from a long-term study of a random sample of men and women born between 1937 and 1940 who graduated from Wisconsin high schools in 1957 ($N$ = 10,317). The WLS collected data during 6 time points: 1957 (in-person questionnaire), 1964 (mail surveys), 1975/77 (telephone and mail surveys), 1992/94 (telephone and mail surveys), 2003–2007 (telephone and mail surveys), and 2010–2011 (in-person and mail surveys). Demographically, the WLS sample consists of mainly white, non-Hispanic American men and women, and only a handful of African American, Hispanic, and Asian people. The white sample consists of participants of German, English, Irish, Scandinavian, Polish, or Czech descent.

### *Measures*

We used the highest level of post-high-school education (none, Associate's, Bachelor's, Master's, Doctorate), childhood and adult income, and gender to predict cognitive abilities at two time points from 1992, 2004, or 2011, when participants were approximately 53, 65, and 72, respectively. Childhood income was a subjective rating of how parents' income compared to other families, and adult income was the participant's total household income in 12 months. Cognitive abilities were assessed as performance on five tasks: WAIS Similarities (total cognition score), Letter and Category Fluency (total number of scored words named), Digit ordering (total score), Immediate recall (correct words). In 2004, the cognitive tasks were administered to random subsamples of participants to reduce participants' response burden. Only

participants who completed all time points were included (N = *4,249*). Demographic variables of participants used in the present study are presented in Table 1.

*WAIS Similarities Task.* WAIS Similarities scores were collected in 1992 and 2004. Participants were read two words and asked to describe what made them similar. Scores were totaled.

*Category Fluency Task.* The Category Fluency task was conducted in 2004 and 2011. In this task, participants were read a category (e.g., "fruits") and asked to list as many words that they could think of that belonged to that category within the time limit. The number of words that correctly fit the category was included in the total score.

*Letter Fluency Task.* The Letter Fluency task was conducted in 2004 and 2011. Participants were given a single letter (e.g., "F") and asked to list as many words that they could think of that began with that word. The number of words that were correct and non-repeated were included in the total score.

*Immediate Recall Task.* The Immediate Recall task was conducted in 2004 and 2011. Participants were read a list of ten words and asked to repeat as many words as they could immediately after. Correctly recalled words were included in the total score.

*Digit Ordering Task.* The Digit Ordering task was conducted in 2004 and 2011. Participants were read a list of numbers and then asked to recite the words in order from smallest to largest. Word lists got longer as the participant progressed through the task. The number of correct levels was included in the total score.

| | | Mean (SD) | % |
|---|---|---|---|
| *N= 4,249* | | | |
| *Gender* | | | |
| | *Females* | | 47 |
| | *Males* | | 53 |
| *Year of Birth* | | | |
| | *1937* | | 1 |
| | *1938* | | 15 |
| | *1939* | | 79 |
| | *1940* | | 5 |
| *Education* | | | |
| | *No Higher Education* | | 66 |
| | *Associates* | | 3 |
| | *Bachelors* | | 17 |
| | *Masters* | | 10 |

| | | |
|---|---|---|
| | *Doctorate* | 4 |
| *Adult Income* | | $74,426<br>($57,375) |

**Table 1.** Demographic characteristics of sample.

Participants' highest education attainments were collected every data collection year. For income, we used both adult and childhood income as predictors. We used the total household income in the last 12 months collected in 1992, 2004, and 2011 for our adult income predictor. We used the parental income comparison collected in 1957 for our childhood income predictor.

### *Analyses*

All analyses were conducted using R statistics (R Core Team, 2020). Our multilevel design was as follows (see Figure 1): Level 1 was the time point and Level 2 was the subject. Level 1 variables include measures of cognition. Level 2 variables included id, sex (female or male), and SES (childhood and adulthood).

Three models were fitted for each measure of cognition. Cognition at the first time point was allowed to vary across participants as a random intercept. Models 1, 2, and 3 assessed the association between cognitive change across time and educational attainment, childhood income, or adult income, respectively. We also assessed the interactions between these three predictors, as well as sex, on each outcome measure (model 4).

First, we fitted a multilevel model using the *glmmTMB* package (Mollie et al., 2017) to predict one cognitive measure at a time using time and education or income, separately. The model equations were:

**Level 1 (within person)**

$$\text{CognitiveDecline}_{ij} = B_{0j} + B_{1j}(\text{time}) + e_{ij}$$

**Level 2 (between person)**

$$B_{0j} = \gamma_{00} + \gamma_{01}(\text{education or SES})_j * \gamma_{02}(\text{sex})_j + u_{0j}$$

$$B_{1j} = \gamma_{10} + \gamma_{11}(\text{education or SES})_j * \gamma_{02}(\text{sex})_j + u_{0j}$$

$$B_{2j} = \gamma_{20} + \gamma_{21}(\text{education})_j * \gamma_{02}(\text{sex})_j * \gamma_{03}(\text{SES})_j + u_{0j}$$

Then, we evaluated the interaction between sex, time, and education or income. To assess whether the addition of sex improved the model fit, we compared $R^2$ values, preferring models with a higher $R^2$. Adult income was divided by $10,000 for better interpretability.

## Results

### *Intraclass Correlation*

We calculated the ICC for all cognitive measures to determine whether each cognitive measure varies across individuals (see Table 2). Variability at the individual level accounts for 41%, 95% CI [.38, .43], of the total variability of similarities score, 58%, 95% CI [.55, .61], of the total variability of categorical fluency score, 59%, 95% CI [.57, .61], of the total variability

of letter fluency score, 24%, 95% CI [.21, .27], of the total variability of the immediate recall score, and 31%, 95% CI [.28, .35], of the total variability of the digit ordering score. Our ICC results reveal that the inclusion of a multilevel model is appropriate for all the cognitive tasks in our study.

| | **ICC** | **95% CI** |
|---|---|---|
| *WAIS Similarities* | 0.41 | [0.38, 0.43] |
| *Categorical Fluency* | 0.58 | [0.55, 0.61] |
| *Letter Fluency* | 0.59 | [0.57, 0.61] |
| *Immediate Recall* | 0.24 | [0.21, 0.27] |
| *Digit Ordering* | 0.31 | [0.28, 0.35] |

**Table 2.** Intraclass correlations.

### *Descriptive Statistics*

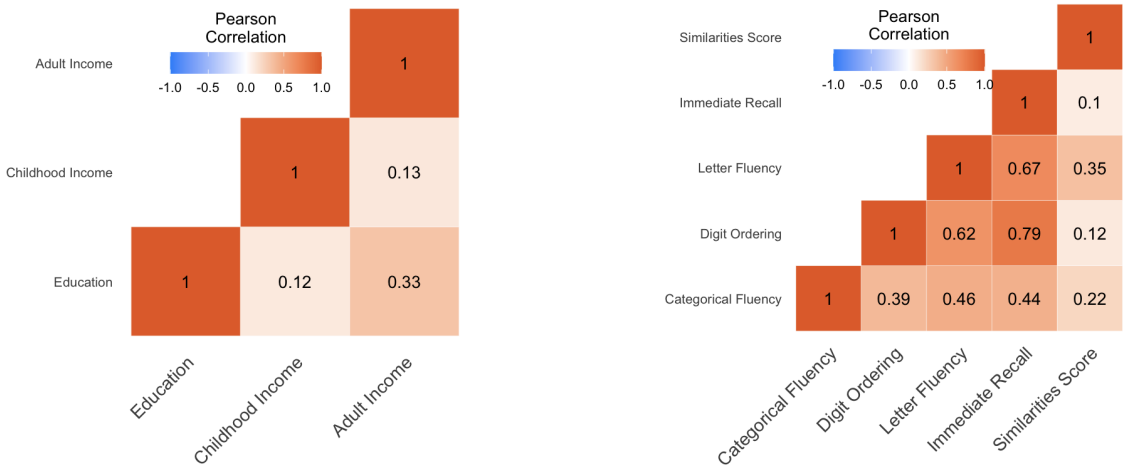


**Figure 1.** Correlations between predictors, and measures of cognition (in 2004 only).

To investigate similarity between predictors and similarity between outcome variables, we computed Pearson correlations (see Figure 1). As expected, adult income was somewhat correlated with education ($r = 0.33$). Digit ordering, letter fluency, immediate recall, and categorical fluency were moderately to highly correlated with each other ($r$s: 0.39-0.79). Similarities scores from the WAIS were relatively independent of other measures of cognition. Means and standard deviations for each task at each year are presented in Table 3.

| | **1992** Mean (SD) | **2004** Mean (SD) | **2011** Mean (SD) |
|---|---|---|---|
| *WAIS Similarities* | 8.11 (2.68) | 6.81 (2.33) | |
| *Categorical Fluency* | | 21.39 (6.11) | 19.95 (5.94) |
| *Letter Fluency* | | 11.68 (4.27) | 11.36 (4.16) |
| *Immediate Recall* | | 6.25 (1.70) | 5.55 (1.40) |
| *Digit Ordering* | | 7.82 (2.46) | 7.23 (2.19) |

**Table 3.** Summary of cognitive tasks at each year of measurement.

### *Model Selection*

$R^2$ comparisons are shown in Supplementary Table 1. Across tasks, models including the interaction with sex showed an improvement of fit as compared to models that did not include this interaction. Thus, for all analyses described below, sex was included as an interaction in all models.

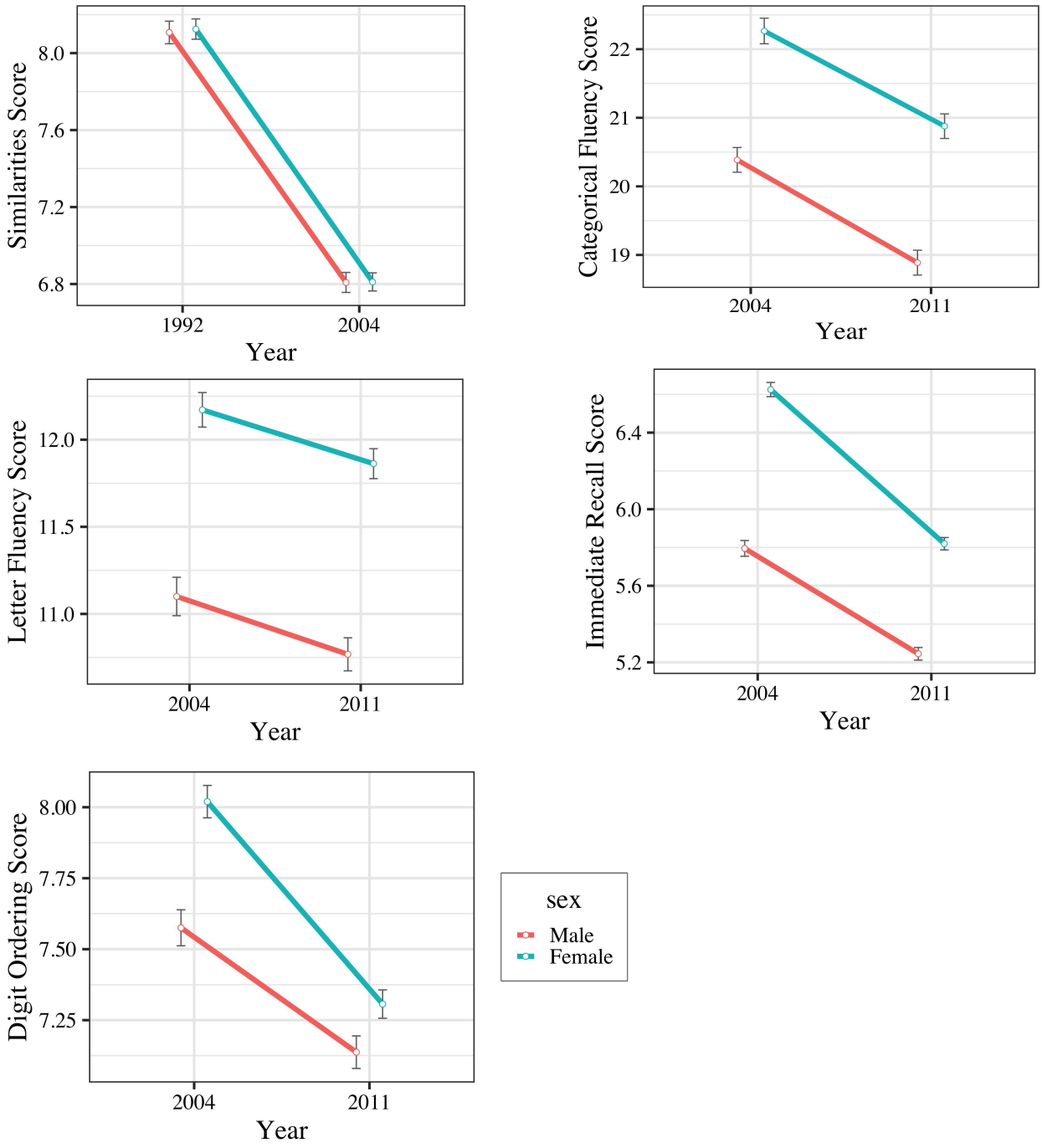


**Figure 2.** Change in cognitive measures over time by sex.

***WAIS Similarities Score***

Table 4 shows the parameter estimates of the model. The within-person coefficient of year was significant, with the coefficient estimated at -1.23 (SE: 0.07), indicating that participants' score on the similarities task declined from 1992 to 2004, as shown in Figure 2.

| | **by Time** | **Edu * Sex * Year** | **Income * Sex * Year** | **Income * Sex * Edu * Year** | **Child Income * Sex * Year** | **Child Income * Sex * Edu * Year** |
|---|---|---|---|---|---|---|
| (Intercept) | 8.12 *** | 7.35 *** | 7.37 *** | 6.91 *** | 7.83 *** | 7.58 *** |
| | (0.04) | (0.07) | (0.10) | (0.12) | (0.32) | (0.40) |
| year2004 | -1.31 *** | -1.23 *** | -1.15 *** | -1.08 *** | -1.13 *** | -0.81 * |
| | (0.04) | (0.07) | (0.09) | (0.12) | (0.30) | (0.40) |
| sexFemale | | 0.27 ** | 0.25 | 0.41 ** | -0.23 | -0.07 |
| | | (0.09) | (0.13) | (0.15) | (0.44) | (0.53) |
| edu | | 0.74 *** | | 0.87 *** | | 0.84 *** |
| | | (0.04) | | (0.07) | | (0.21) |
| sexFemale:edu | | 0.06 | | 0.00 | | 0.22 |
| | | (0.06) | | (0.11) | | (0.32) |

| | | | | | |
|---|---|---|---|---|---|
| sexFemale:year2004 | -0.07 | -0.13 | -0.19 | -0.27 | -0.56 |
| | (0.09) | (0.12) | (0.15) | (0.42) | (0.54) |
| edu:year2004 | -0.08 | | -0.10 | | -0.31 |
| | (0.04) | | (0.07) | | (0.21) |
| sexFemale:edu:year2004 | 0.04 | | 0.05 | | 0.19 |
| | (0.06) | | (0.11) | | (0.33) |
| adultincome | | 0.09 *** | 0.06 *** | | |
| | | (0.01) | (0.01) | | |
| sexFemale:adultincome | | -0.01 | -0.01 | | |
| | | (0.01) | (0.02) | | |
| adultincome:year2004 | | -0.02 * | -0.02 | | |
| | | (0.01) | (0.01) | | |
| sexFemale:adultincome:year2004 | | 0.01 | 0.02 | | |
| | | (0.01) | (0.02) | | |
| adultincome:edu | | | -0.02 ** | | |
| | | | (0.01) | | |
| sexFemale:adultincome:edu | | | 0.00 | | |

| | | | |
|---|---|---|---|
| | (0.01) | | |
| adultincome:edu:year2004 | 0.00 | | |
| | (0.01) | | |
| sexFemale:adultincome:edu:year2004 | -0.00 | | |
| | (0.01) | | |
| childincomecompare | | 0.09 | -0.07 |
| | | (0.10) | (0.12) |
| sexFemale:childincomecompare | | 0.08 | 0.11 |
| | | (0.14) | (0.17) |
| childincomecompare:year2004 | | -0.05 | -0.13 |
| | | (0.09) | (0.13) |
| sexFemale:childincomecompare:year2004 | | 0.08 | 0.16 |
| | | (0.13) | (0.17) |
| childincomecompare:edu | | | -0.03 |
| | | | (0.06) |
| sexFemale:childincomecompare:edu | | | -0.05 |
| | | | (0.10) |

| | | | | | | |
|---|---|---|---|---|---|---|
| childincomecompare:edu:year2004 | | | | | | 0.07 |
| | | | | | | (0.06) |
| sexFemale:childincomecompare:edu:year2004 | | | | | | -0.05 |
| | | | | | | (0.10) |
| AIC | 41343.6 | 40504.0 | 41174.2 | 40470.8 | 41349.0 | 40513.6 |
| Log Likelihood | -20666.8 | -20241.0 | -20576.1 | -20216.4 | -20663.5 | -20237.8 |
| Num. obs. | 9130 | 9130 | 9130 | 9130 | 9130 | 9130 |
| Num. groups: personid | 4674 | 4674 | 4674 | 4674 | 4674 | 4674 |
| Var: personid (Intercept) | 7.19 | 6.33 | 6.97 | 6.28 | 7.18 | 6.32 |
| Var: personid year2004 | 6.26 | 6.26 | 6.25 | 6.26 | 6.26 | 6.26 |

**Table 4.** Parameter estimates for model predicting WAIS Similarities score.

*Education.* The main effect of education was significant. The coefficient for education was 0.74 (SE: 0.04), indicating that, in general, higher educational attainment was associated with overall higher scores on the similarities task (see Supplementary Figure 1). The main effect of sex indicated that females overall had significantly higher scores than males across time, with a coefficient of 0.27 (SE: 0.09) (see Figure 2). Next, assessed the interactions between year, sex, and education. The interaction between education and year was not significant (-0.08, SE: 0.04),

and the interaction between sex and year was not significant (-0.07, SE: 0.09). The interaction between year, sex, and education was also not significant, with a coefficient of 0.04 (SE: 0.06).

*Income.* The main effect of adult income was significant, with a coefficient of 0.09 (SE: 0.01) indicating that higher income (in units of $10,000) was associated with higher scores on the similarities task across time. The interaction between income and year was significant (-0.02, SE: 0.01 (see Figure 3), indicating that the effect of year on similarities scores was dependent on adult income. The interaction between sex and income was not significant (-0.01, SE: 0.01), and the interaction of sex, income, and year was also not significant (0.01, SE: 0.01).

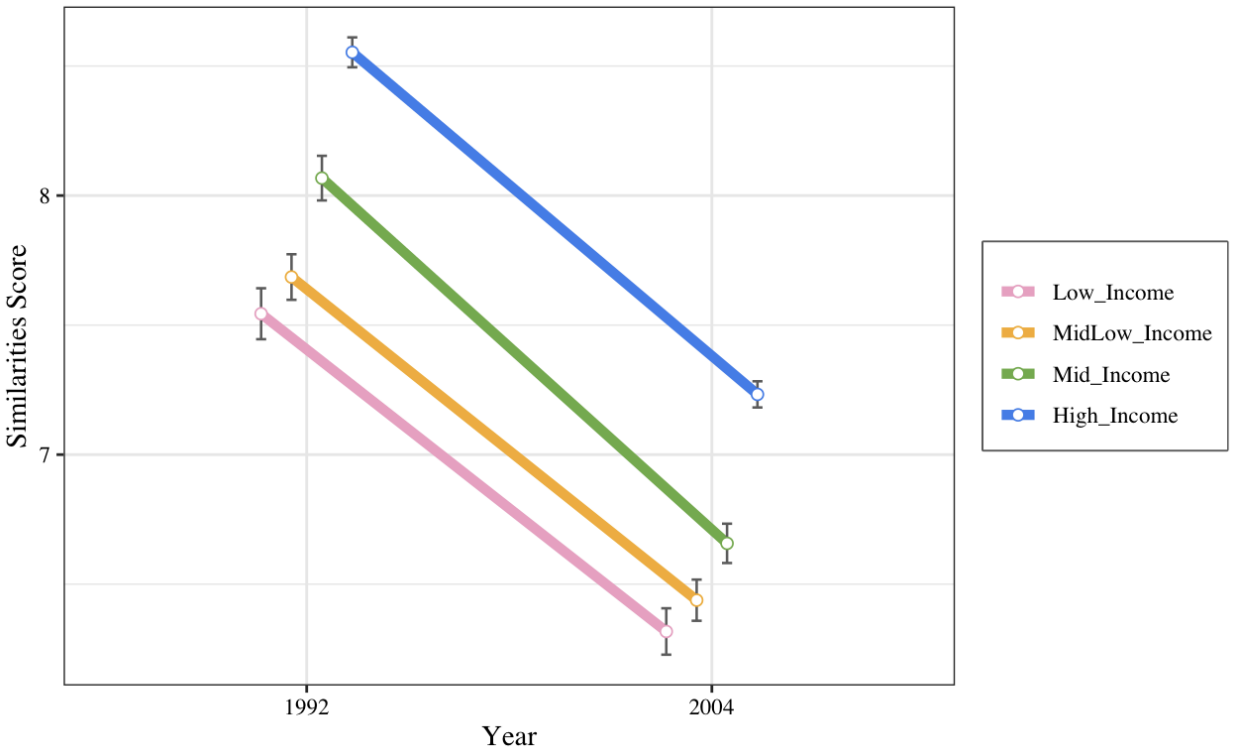


**Figure 3.** Similarity scores by adult income and year. Low income grouping is < $32k, MidLow income grouping is $32k - $48.5k, Mid income grouping is $48.5k -$ 65k, and High income grouping is > $65k.

The main effect of childhood income comparison was not significant (0.09, SE: 0.10). Both the interactions of childhood income and time (-0.05, SE: 0.09), and childhood income, time, and sex (0.08, SE:0.13) were not significant.

*Income and Education.* Lastly, we assessed the interaction between education, adult income, sex, and time. This interaction was not significant with a coefficient of -<0.001 (SE: 0.01) (see Supplementary Figure 2). The interaction between education, childhood income, sex, and time was additionally not significant (-0.05, SE: 0.10).

### *Categorical Fluency*

Table 5 shows the parameter estimates of the model. The within-person coefficient of year was significant, with the coefficient estimated at -1.49 (SE: 0.12), indicating that participants' score on the categorical fluency task declined from 2004 to 2011, as shown in Figure 2.

| | **by Time** | **Edu * Sex * Year** | **Income * Sex * Year** | **Income * Sex * Edu * Year** | **Child Income * Sex * Year** | **Child Income * Sex * Edu * Year** |
|---|---|---|---|---|---|---|
| (Intercept) | 21.39 *** | 19.08 *** | 7.47 *** | 15.66 *** | 7.94 *** | 20.48 *** |
| | (0.13) | (0.23) | (0.08) | (0.33) | (0.26) | (1.36) |
| year2011 | -1.49 *** | -1.29 *** | | -0.68 | | -1.27 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | (0.12) | (0.22) | | (0.37) | | (1.28) |
| sexFemale | | 2.15 *** | 0.16 | 8.18 *** | -0.39 | 0.09 |
| | | (0.30) | (0.10) | (0.44) | (0.36) | (1.80) |
| edu | | 1.27 *** | | 2.58 *** | | 0.58 |
| | | (0.13) | | (0.20) | | (0.71) |
| sexFemale:edu | | 0.28 | | -0.48 | | 1.35 |
| | | (0.20) | | (0.29) | | (1.09) |
| sexFemale:year2011 | | 0.23 | | -0.27 | | 0.16 |
| | | (0.29) | | (0.50) | | (1.70) |
| edu:year2011 | | -0.26 * | | 0.22 | | 0.22 |
| | | (0.12) | | (0.23) | | (0.67) |
| sexFemale:edu:year2011 | | -0.28 | | -0.04 | | -1.06 |
| | | (0.19) | | (0.33) | | (1.04) |
| adultincome | | | 0.00 *** | 0.00 *** | | |
| | | | (0.00) | (0.00) | | |
| year2004 | | | -1.31 *** | | -1.31 *** | |
| | | | (0.04) | | (0.04) | |

| | | | | |
|---|---|---|---|---|
| sexFemale:adultincome | -0.00 | -0.00 *** | | |
| | (0.00) | (0.00) | | |
| adultincome:edu | | -0.00 *** | | |
| | | (0.00) | | |
| adultincome:year2011 | | -0.00 *** | | |
| | | (0.00) | | |
| sexFemale:adultincome:edu | | 0.00 *** | | |
| | | (0.00) | | |
| sexFemale:adultincome:year2011 | | 0.00 *** | | |
| | | (0.00) | | |
| adultincome:edu:year2011 | | 0.00 *** | | |
| | | (0.00) | | |
| sexFemale:adultincome:edu:year2011 | | -0.00 *** | | |
| | | (0.00) | | |
| childincomecompare | | | 0.05 | -0.45 |
| | | | (0.08) | (0.43) |
| sexFemale:childincomecompare | | | 0.13 | 0.66 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | (0.11) | (0.57) |
| childincomecompare:edu | | | | | | 0.21 |
| | | | | | | (0.22) |
| childincomecompare:year2011 | | | | | | -0.01 |
| | | | | | | (0.40) |
| sexFemale:childincomecompare:edu | | | | | | -0.34 |
| | | | | | | (0.33) |
| sexFemale:childincomecompare:year2011 | | | | | | 0.02 |
| | | | | | | (0.54) |
| childincomecompare:edu:year2011 | | | | | | -0.14 |
| | | | | | | (0.20) |
| sexFemale:childincomecompare:edu:year2011 | | | | | | 0.24 |
| | | | | | | (0.32) |
| AIC | 26431.86 | 26176.22 | 41196.06 | 27951.39 | 41369.02 | 26189.07 |
| Log Likelihood | -13210.93 | -13077.11 | -20590.03 | -13956.70 | -20676.51 | -13075.53 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Num. obs. | 4249 | 4249 | 9135 | 4249 | 9135 | 4249 |
| Num. groups: personid | 2280 | 2280 | 4677 | 2280 | 4677 | 2280 |
| Var: personid (Intercept) | 37.42 | 33.58 | 6.98 | 21.90 | 7.19 | 33.55 |
| Var: personid year2011 | 28.58 | 28.33 | | 27.08 | | 28.32 |
| Var: personid year2004 | | | 6.26 | | 6.26 | |

**Table 5.** Parameter estimates for model predicting Categorical Fluency score.

*Education.* The main effect of education was significant, with a coefficient of 1.27 (SE: 0.13) This indicated that higher educational attainment was associated with overall higher scores on the categorical fluency task. The main effect of sex was also significant, (2.15, SE: 0.30), indicating that females overall had higher scores than males across time. Next, we assessed the interactions between year, sex, and education. The interaction between education and year was significant with a coefficient of -0.26 (SE: 0.12), indicating the effect of year on categorical fluency scores was moderated by higher education attainment (see Figure 4). The interactions between sex and year (0.23, SE: 0.29) and sex and edu (0.28, SE: 0.20) were not significant. The year by sex by education interaction was also not significant (-0.28, SE: 0.19).

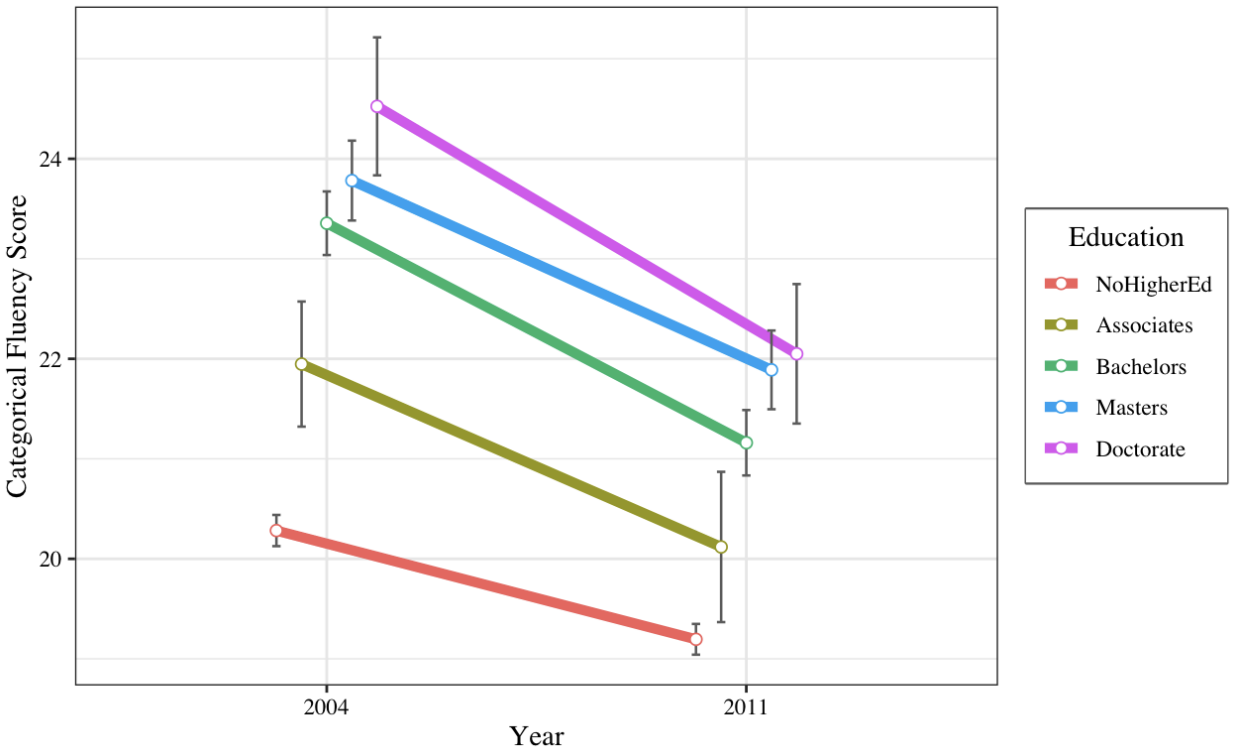


**Figure 4.** Effect of education on decline of categorical fluency scores.

*Income.* The main effect of adult income was significant, with a coefficient of 0.09 (SE: 0.01), indicating that higher income was associated with better categorical fluency scores across time. The interaction between sex and adult income was not significant (-0.01, SE: 0.01). The year by adult income interaction was significant (-0.02, SE: 0.01), indicating that the effect of time on categorical fluency scores was dependent on adult income (see Figure 5). The year by sex by adult income interaction was not significant (0.01, SE: 0.01).

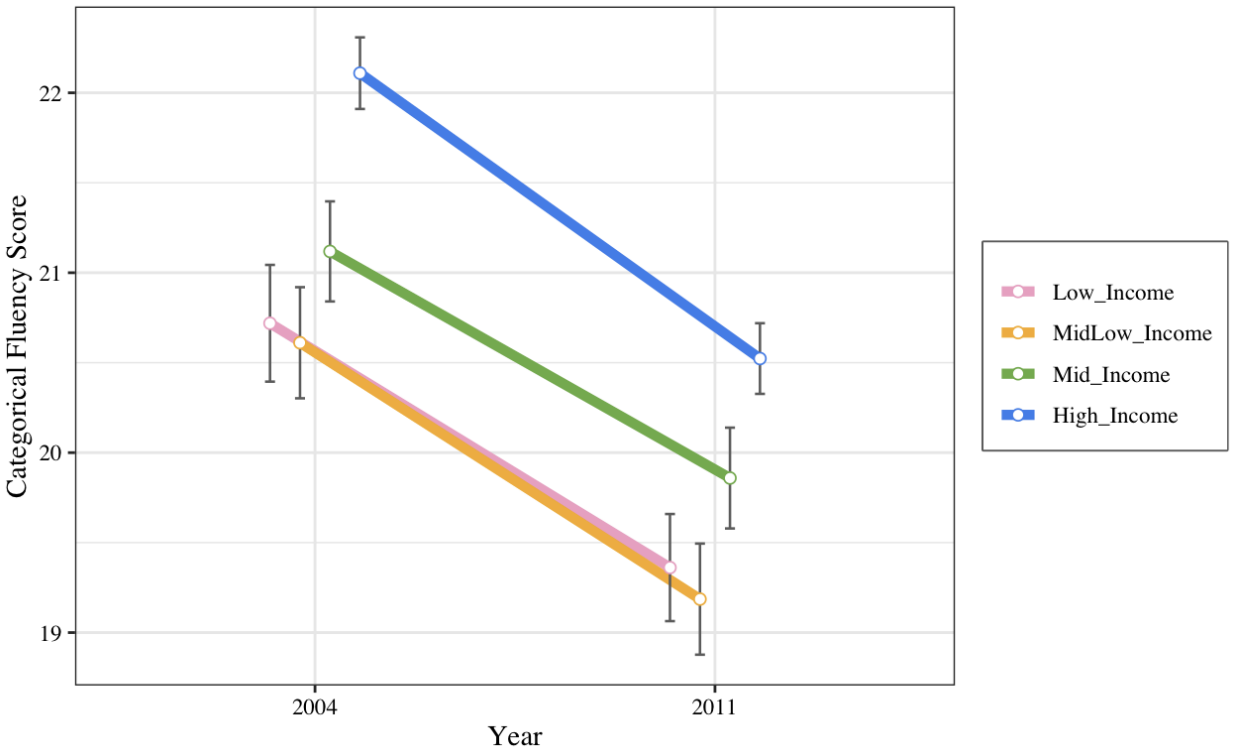


**Figure 5.** Effect of income on decline of categorical fluency scores. Low income grouping is < $32k, MidLow income grouping is $32k - $48.5k, Mid income grouping is $48.5k -$ 65k, and High income grouping is > $65k.

The childhood income comparison main effect was not significant (0.09, SE: 0.10). The sex by childhood income (0.08, SE: 0.14) and year by childhood income (-0.05, SE: 0.09) interactions were not significant. Additionally, the interaction of sex, childhood income, and year was not significant (0.08, SE: 0.13).

*Education and Income.* Lastly, we investigated the interaction between education, adult income, sex, and year. This interaction was not significant (< 0.001, SE: 0.03) (see Supplementary Figure 3). The interaction between education, childhood income, sex, and year was also not significant (0.24, SE: 0.32).

***Letter Fluency***

Table 6 the parameter estimates of the model. The within-person coefficient of year was significant, with the coefficient estimated at -0.39 (SE: 0.12), indicating that participants' score on the letter fluency declined from 2004 to 2011, as shown in Figure 2.

| | **by Time** | **Edu * Sex * Year** | **Income * Sex * Year** | **Income * Sex * Edu * Year** | **Child Income * Sex * Year** | **Child Income * Sex * Edu * Year** |
|---|---|---|---|---|---|---|
| (Intercept) | 11.63 *** | 10.23 *** | 10.14 *** | 9.31 *** | 11.64 *** | 11.97 *** |
| | (0.07) | (0.13) | (0.18) | (0.22) | (0.57) | (0.77) |
| year2011 | -0.31 *** | -0.39 ** | -0.20 | 0.08 | -0.55 | -0.47 |
| | (0.07) | (0.12) | (0.17) | (0.21) | (0.54) | (0.74) |
| sexFemale | | 1.41 *** | 1.24 *** | 1.96 *** | 0.05 | 0.67 |
| | | (0.17) | (0.23) | (0.29) | (0.79) | (1.01) |
| edu | | 0.78 *** | | 0.99 *** | | 0.46 |
| | | (0.07) | | (0.13) | | (0.40) |
| sexFemale:edu | | -0.04 | | -0.46 * | | -0.74 |

| | | | | | |
|---|---|---|---|---|---|
| | (0.11) | | (0.20) | | (0.60) |
| sexFemale:year2011 | 0.03 | -0.06 | -0.15 | -0.23 | -0.04 |
| | (0.16) | (0.22) | (0.27) | (0.75) | (0.98) |
| edu:year2011 | 0.07 | | 0.14 | | -0.01 |
| | (0.07) | | (0.13) | | (0.38) |
| sexFemale:edu:year2011 | 0.04 | | -0.02 | | -0.11 |
| | (0.11) | | (0.19) | | (0.58) |
| adultincome | | 0.00 *** | 0.00 *** | | |
| | | (0.00) | (0.00) | | |
| sexFemale:adultincome | | 0.00 | -0.00 | | |
| | | (0.00) | (0.00) | | |
| adultincome:year2011 | | -0.00 | -0.00 | | |
| | | (0.00) | (0.00) | | |
| sexFemale:adultincome:year2011 | | 0.00 | -0.00 | | |
| | | (0.00) | (0.00) | | |
| adultincome:edu | | | -0.00 * | | |
| | | | (0.00) | | |

| | | | |
|---|---|---|---|
| sexFemale:adultincome:edu | 0.00 | | |
| | (0.00) | | |
| adultincome:edu:year2011 | -0.00 | | |
| | (0.00) | | |
| sexFemale:adultincome:edu:year2011 | 0.00 | | |
| | (0.00) | | |
| childincomecompare | | -0.19 | -0.56 * |
| | | (0.18) | (0.24) |
| sexFemale:childincomecompare | | 0.32 | 0.23 |
| | | (0.25) | (0.32) |
| childincomecompare:year2011 | | 0.07 | 0.03 |
| | | (0.17) | (0.23) |
| sexFemale:childincomecompare:year2011 | | 0.08 | 0.02 |
| | | (0.23) | (0.31) |
| childincomecompare:edu | | | 0.11 |
| | | | (0.12) |
| sexFemale:childincomecompare:edu | | | 0.21 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | | (0.18) |
| childincomecompare:edu:year2011 | | | | | | 0.02 |
| | | | | | | (0.12) |
| sexFemale:childincomecompare:edu:year2011 | | | | | | 0.04 |
| | | | | | | (0.18) |
| AIC | 41619.77 | 41231.05 | 41439.25 | 41243.67 | 41538.52 | 41227.38 |
| Log Likelihood | -20804.88 | -20604.53 | -20708.62 | -20602.84 | -20758.26 | -20594.69 |
| Num. obs. | 7509 | 7509 | 7509 | 7509 | 7509 | 7509 |
| Num. groups: personid | 4504 | 4504 | 4504 | 4504 | 4504 | 4504 |
| Var: personid (Intercept) | 18.32 | 17.16 | 17.62 | 17.37 | 18.03 | 17.11 |
| Var: personid year2011 | 14.54 | 14.52 | 14.57 | 13.97 | 14.53 | 14.52 |

**Table 6.** Parameter estimates for model predicting Letter Fluency score.

*Education.* The main effect of education was significant. The coefficient for education was 0.78 (SE: 0.07), indicating that, in general, higher educational attainment was associated with overall higher scores on the letter fluency score (see Supplementary Figure 4). The main

effect of sex indicated that females overall had significantly higher letter fluency scores than males across time, with a coefficient of 1.41 (SE: 0.17). Next, assessed the interactions between year, sex, and education. The interaction between education and year was not significant (0.07, SE: 0.07), and the interaction between sex and year was not significant (0.03, SE: 0.16). The interaction between year, sex, and education was also not significant, with a coefficient of 0.04 (SE: 0.11).

*Income.* The main effect of adult income was significant, with a coefficient of 0.11 (SE: 0.02) indicating that higher income (in units of $10,000) was associated with higher scores on the letter fluency task across time (see Supplementary Figure 5). The interaction between income and year was not significant (-0.01, SE: 0.01). The interaction between sex and income was not significant (-0.01, SE: 0.01), and the interaction of sex, income, and year was also not significant (0.01, SE: 0.01).

The main effect of childhood income comparison was not significant (-0.19, SE: 0.18). The interactions of childhood income and time (0.07, SE: 0.09), and childhood income, time, and sex (0.08, SE: 0.23) were not significant.

*Education and Income.* Lastly, we assessed the interaction between education, adult income, sex, and time. This interaction was not significant with a coefficient of 0.02 (SE: 0.02) (see Supplementary Figure 6). The interaction between education, childhood income, sex, and time was also not significant (0.04, SE: 0.18).

***Immediate recall***

Table 7 shows the parameter estimates of the model. The within-person coefficient of year was significant, with the coefficient estimated at -0.48 (SE: 0.06), indicating that participants' immediate recall score declined from 2004 to 2011 (see Figure 2).

| | **by Time** | **Edu * Sex * Year** | **Income * Sex * Year** | **Income * Sex * Edu * Year** | **Child Income * Sex * Year** | **Child Income * Sex * Edu * Year** |
|---|---|---|---|---|---|---|
| (Intercept) | 6.24 *** | 5.47 *** | 5.48 *** | 6.82 *** | 5.29 *** | 5.18 *** |
| | (0.03) | (0.05) | (0.07) | (0.11) | (0.22) | (0.30) |
| year2011 | -0.69 *** | -0.48 *** | -0.45 *** | -0.85 *** | -0.18 | 0.09 |
| | (0.03) | (0.06) | (0.08) | (0.09) | (0.25) | (0.34) |
| sexFemale | | 1.08 *** | 0.94 *** | 0.56 *** | 1.20 *** | 1.08 ** |
| | | (0.07) | (0.09) | (0.12) | (0.31) | (0.40) |
| edu | | 0.31 *** | | 0.49 *** | | 0.38 * |
| | | (0.03) | | (0.06) | | (0.16) |
| sexFemale:edu | | -0.20 *** | | -1.33 *** | | 0.00 |

| | | | | | |
|---|---|---|---|---|---|
| | (0.04) | | (0.10) | | (0.24) |
| sexFemale:year2011 | -0.39 *** | -0.39 *** | 0.15 | -0.79 * | -0.83 |
| | (0.08) | (0.10) | (0.11) | (0.35) | (0.46) |
| edu:year2011 | -0.06 | | 0.46 *** | | -0.25 |
| | (0.03) | | (0.05) | | (0.18) |
| sexFemale:edu:year2011 | 0.17 ** | | -0.16 * | | 0.10 |
| | (0.05) | | (0.08) | | (0.27) |
| adultincome | | 0.00 *** | -0.00 *** | | |
| | | (0.00) | (0.00) | | |
| sexFemale:adultincome | | -0.00 | 0.00 ** | | |
| | | (0.00) | (0.00) | | |
| adultincome:year2011 | | -0.00 | 0.00 ** | | |
| | | (0.00) | (0.00) | | |
| sexFemale:adultincome:year2011 | | 0.00 | -0.00 *** | | |
| | | (0.00) | (0.00) | | |
| adultincome:edu | | | -0.00 | | |
| | | | (0.00) | | |

| | | | |
|---|---|---|---|
| sexFemale:adultincome:edu | 0.00 *** | | |
| | (0.00) | | |
| adultincome:edu:year2011 | -0.00 *** | | |
| | (0.00) | | |
| sexFemale:adultincome:edu:year2011 | 0.00 *** | | |
| | (0.00) | | |
| childincomecompare | | 0.16 * | 0.09 |
| | | (0.07) | (0.10) |
| sexFemale:childincomecompare | | -0.11 | 0.00 |
| | | (0.10) | (0.13) |
| childincomecompare:year2011 | | -0.12 | -0.18 |
| | | (0.08) | (0.11) |
| sexFemale:childincomecompare:year2011 | | 0.17 | 0.14 |
| | | (0.11) | (0.14) |
| childincomecompare:edu | | | -0.02 |
| | | | (0.05) |
| sexFemale:childincomecompare:edu | | | -0.06 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | | (0.07) |
| childincomecompare:edu:year2011 | | | | | | 0.06 |
| | | | | | | (0.05) |
| sexFemale:childincomecompare:edu:year2011 | | | | | | 0.02 |
| | | | | | | (0.08) |
| AIC | 25800.63 | 25288.2 | 25441.7 | 27320.6 | 25513.0 | 25298.1 |
| Log Likelihood | -12895.3 | -12633.1 | -12709.8 | -13641.3 | -12745.5 | -12630.0 |
| Num. obs. | 7058 | 7058 | 7058 | 7058 | 7058 | 7058 |
| Num. groups: personid | 3634 | 3634 | 3634 | 3634 | 3634 | 3634 |
| Var: personid (Intercept) | 2.88 | 2.62 | 2.67 | 2.87 | 2.70 | 2.61 |
| Var: personid year2011 | 3.37 | 3.34 | 3.35 | 2.46 | 3.35 | 3.34 |

**Table 7.** Parameter estimates for model predicting Immediate Recall score.

*Education.* The main effect of education was significant. The coefficient for education was 0.31 (SE: 0.03), indicating that, in general, higher educational attainment was associated with overall higher scores on the immediate recall task. The main effect of sex indicated that females overall had significantly higher immediate recall scores than males across time, with a coefficient of 1.08 (SE: 0.07). Next, assessed the interactions between year, sex, and education. The interaction between education and year was not significant (-0.06, SE: 0.03), whereas the

interaction between sex and year was significant (-0.39, SE: 0.08), indicating that the effect of year on immediate recall score was dependent on sex. The interaction between year, sex, and education (0.17, SE: 0.05) was also significant, indicating that sex moderated the relationship between educational attainment and cognitive decline. Specifically, as shown in Figure 6, the effect of education on cognitive decline, in which decline was less steep with higher educational attainment, was stronger in women than in men.

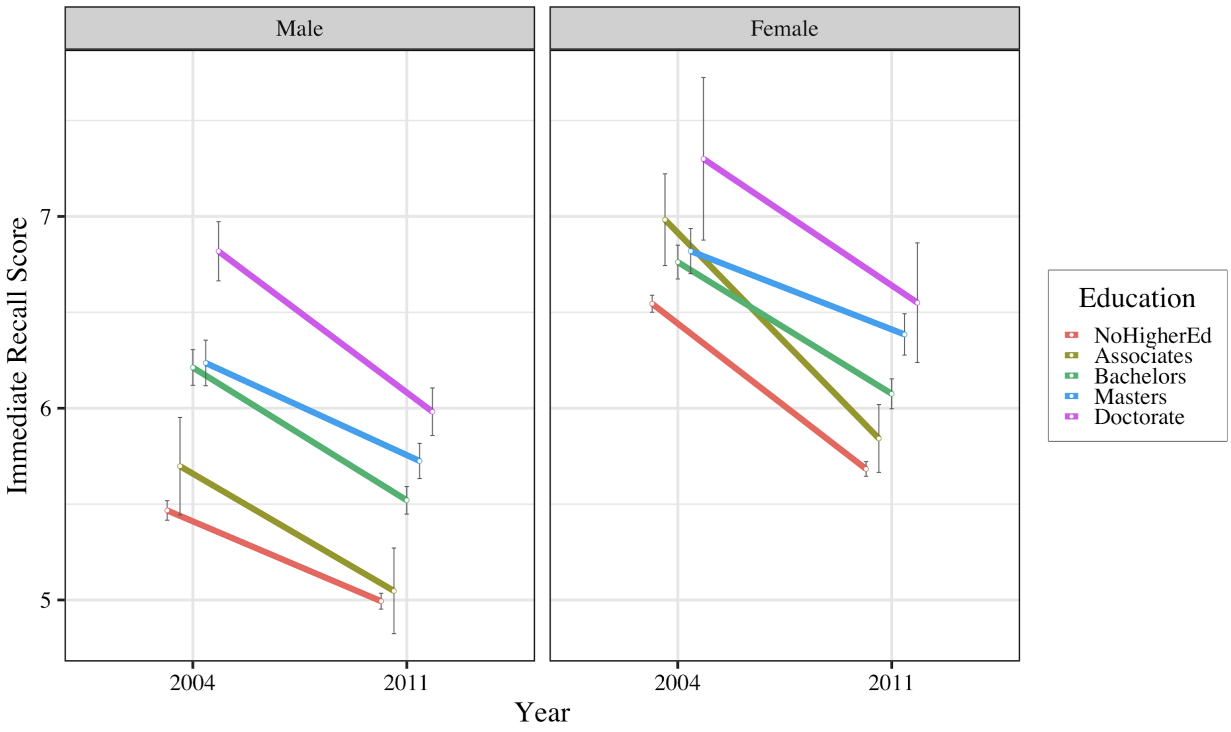


**Figure 6.** Immediate recall scores by year, sex, and education.

*Income.* The main effect of adult income was significant, with a coefficient of 0.04 (SE: 0.01) indicating that higher income (in units of $10,000) was associated with higher scores on the immediate recall task across time (see Supplementary Figure 7). The interaction between income and year was not significant (-0.01, SE: 0.01). The interaction between sex and income

was not significant (-0.01, SE: 0.01), nor was the interaction of sex, income, and year (0.02, SE: 0.01).

The main effect of childhood income comparison was significant (0.16, SE: 0.07), indicating that parents' income as a child was associated with higher scores on the immediate recall task across time (see Supplementary Figure 8). The interaction of childhood income and time was not significant (-0.12, SE: 0.08), and the interaction of childhood income, time, and sex was also not significant (-0.11, SE: 0.10).

*Education x Income.* Lastly, we assessed the interaction between education, adult income, sex, and time (see Supplementary Figure 9). This interaction was not significant with a coefficient of 0.01 (SE: 0.01). The interaction between education, childhood income, sex, and time was also not significant (0.02, SE: 0.08).

### *Digit Ordering*

Table 8 shows the parameter estimates of the model. The within-person coefficient of year was significant, with the coefficient estimated at -0.57 (SE: 0.05), indicating that participants' score on the digit ordering task declined from 2004 to 2011 (see Figure 2).

| | **by Time** | **Edu * Sex * Year** | **Income * Sex * Year** | **Income * Sex * Edu * Year** | **Child Income * Sex * Year** | **Child Income * Sex * Edu * Year** |
|---|---|---|---|---|---|---|
| (Intercept) | 7.79 *** | 7.20 *** | 7.18 *** | 6.79 *** | 7.35 *** | 7.25 *** |

| | | | | | | |
|---|---|---|---|---|---|---|
| | (0.04) | (0.08) | (0.11) | (0.12) | (0.34) | (0.47) |
| year2011 | -0.57 *** | -0.43 *** | -0.46 *** | -0.04 | -0.33 | 0.09 |
| | (0.05) | (0.09) | (0.12) | (0.14) | (0.38) | (0.53) |
| sexFemale | | 0.66 *** | 0.63 *** | 1.38 *** | 1.06 * | 1.15 |
| | | (0.10) | (0.14) | (0.16) | (0.47) | (0.62) |
| edu | | 0.34 *** | | 0.96 *** | | 0.39 |
| | | (0.05) | | (0.07) | | (0.24) |
| sexFemale:edu | | -0.13 | | -1.28 *** | | -0.13 |
| | | (0.07) | | (0.11) | | (0.37) |
| sexFemale:year2011 | | -0.25 * | -0.07 | 0.33 | -0.60 | -0.69 |
| | | (0.12) | (0.16) | (0.18) | (0.53) | (0.70) |
| edu:year2011 | | 0.01 | | -0.26 ** | | -0.29 |
| | | (0.05) | | (0.08) | | (0.27) |
| sexFemale:edu:year2011 | | -0.04 | | -0.35 ** | | -0.12 |
| | | (0.08) | | (0.12) | | (0.41) |
| adultincome | | | 0.00 *** | -0.00 | | |
| | | | (0.00) | (0.00) | | |

| | | | | |
|---|---|---|---|---|
| sexFemale:adultincome | -0.00 | 0.00 | | |
| | (0.00) | (0.00) | | |
| adultincome:year2011 | 0.00 | -0.00 ** | | |
| | (0.00) | (0.00) | | |
| sexFemale:adultincome:year2011 | -0.00 | -0.00 *** | | |
| | (0.00) | (0.00) | | |
| adultincome:edu | | -0.00 *** | | |
| | | (0.00) | | |
| sexFemale:adultincome:edu | | 0.00 *** | | |
| | | (0.00) | | |
| adultincome:edu:year2011 | | 0.00 ** | | |
| | | (0.00) | | |
| sexFemale:adultincome:edu:year2011 | | 0.00 *** | | |
| | | (0.00) | | |
| childincomecompare | | | 0.06 | -0.02 |
| | | | (0.11) | (0.15) |
| sexFemale:childincomecompare | | | -0.20 | -0.16 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | (0.15) | (0.20) |
| childincomecompare:year2011 | | | | | -0.03 | -0.17 |
| | | | | | (0.12) | (0.17) |
| sexFemale:childincomecompare:year2011 | | | | | 0.10 | 0.14 |
| | | | | | (0.16) | (0.22) |
| childincomecompare:edu | | | | | | -0.02 |
| | | | | | | (0.07) |
| sexFemale:childincomecompare:edu | | | | | | 0.00 |
| | | | | | | (0.11) |
| childincomecompare:edu:year2011 | | | | | | 0.09 |
| | | | | | | (0.08) |
| sexFemale:childincomecompare:edu:year2011 | | | | | | 0.02 |
| | | | | | | (0.13) |
| AIC | 30008.62 | 29867.4 | 29950.2 | 30657.8 | 29990.5 | 29875.0 |
| Log Likelihood | -14999.3 | -14922.7 | -14964.1 | -15309.9 | -14984.2 | -14918.5 |
| Num. obs. | 6715 | 6715 | 6715 | 6715 | 6715 | 6715 |
| Num. groups: personid | 3587 | 3587 | 3587 | 3587 | 3587 | 3587 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Var: personid (Intercept) | 6.06 | 5.88 | 5.97 | 4.82 | 6.00 | 5.88 |
| Var: personid year2011 | 7.25 | 7.22 | 7.22 | 5.85 | 7.23 | 7.22 |

**Table 8.** Parameter estimates for model predicting Digit Ordering score.

*Education.* The main effect of education was significant. The coefficient for education was 0.34 (SE: 0.05), indicating that, in general, higher educational attainment was associated with overall higher scores on the digit ordering task (see Supplementary Figure 10). The main effect of sex indicated that females overall had significantly higher scores than males across time, with a coefficient of 0.66 (SE: 0.10). The interaction between education and year was not significant (0.01, SE: 0.05). The interaction between sex and year was significant (-0.25, SE: 0.12), indicating that sex moderated the decline in the digit ordering task (see Figure 2). The interaction between year, sex, and education was not significant, with a coefficient of -0.04 (SE: 0.08).

*Income.* The main effect of adult income was significant, with a coefficient of 0.04 (SE: 0.01), indicating that higher income was associated with higher scores on the digit ordering task (see Supplementary Figure 11). The interactions between adult income and sex (-0.02, SE: 0.02), and between adult income and year (< 0.001, SE: 0.01) were not significant. The interaction between adult income, sex, and year was also not significant (-0.03, SE: 0.02).

The main effect of childhood income comparison was not significant (-0.02, SE: 0.15), nor were the interactions between childhood income and year (-0.17, SE: 0.17), childhood income and sex (-0.16, SE: 0.20) or childhood income, sex, and year (0.14, SE: 0.22).

*Education x Income.* The interaction between education, adult income, sex, and year was not significant (0.01, SE: 0.01) (see Supplementary Figure 12). The interaction between education, childhood income, sex, and year was also not significant (0.02, SE: 0.13).

## Discussion

In the present study, we utilized a large longitudinal dataset to investigate the role of socioeconomic status, education, and gender in age-related cognitive decline. Across measures of cognition, we observed that participants' scores decreased with time, indicating that the majority of participants experienced some level of age-related cognitive decline. Results indicated that women, as compared to men, experienced more decline across memory-related measures, despite having higher overall scores across all tasks at each time point. Our hypotheses that education and socioeconomic status may moderate cognitive decline were supported in measures related to executive functioning and verbal IQ, respectively. Of note, women appeared to benefit more than their male counterparts from higher education. We discuss each finding in detail below.

### *Effect of Sex on Cognitive Decline*

We observed that, overall, women consistently performed better across cognitive tasks than did men. This is in line with previous studies that suggest older women have better cognitive function than men regardless of formal education attainment (Van Exel et al., 2001). Despite greater overall scores, our results indicated that women had a steeper cognitive decline than men, specifically in memory tasks (immediate recall and digit ordering). Our findings coincide with previous findings that women are at higher risk of developing Alzheimer's disease (AD), a form of continuous decline in thinking, than men (Gao et al., 1998; Keith et al., 2018).

This link could be due to several factors. Studies have shown that not only biological factors - such as genetic factors like APOE-4 - explain the sex differences in developing AD, but also social factors - such as occupation - also play an important role. (Altmann et al., 2014; Harada, Love, & Triebel, 2013).

*Effect of Education on Cognitive Decline*

We additionally aimed to assess whether the attainment of higher education may slow the rate of cognitive decline. Our results demonstrated an overall benefit of education on cognitive scores across time, in which individuals with higher levels of post-high school education performed better on all cognitive tasks at each time point. This replicates previous works that suggest a strong relationship between higher education and better cognitive task performances (Lenehan et al., 2015). In relation to the decline of cognitive abilities, we observed a moderating effect of education on the category fluency task, in which participants' rate of decline was less steep with more educational attainment. Category fluency is a measure of executive functioning, language abilities, and semantic memory. Van Hooren and colleagues' (2007) finding that education has a substantial effect on cognitive functioning such as verbal tasks is in line with our current findings.

Contrary to our original hypothesis, we did not observe a similar effect of education on a decline of other cognitive measures. This may indicate that education may lead to benefits selectively for tasks related to executive functioning and language and may not confer advantages to general memory abilities or verbal IQ. Given that our data is from only two time points, it is possible that we missed earlier or later decline of other cognitive abilities and the impact of education on different stages of cognitive decline.

Interestingly, we observed a moderating effect of sex on the relationship between education and cognitive decline, in which women appeared to benefit from higher educational attainment (as evidenced by less steep decline) than did men, in the immediate recall task. Given that women overall had a steeper decline than men on this task, this finding highlights that attainment of higher education may be particularly beneficial in alleviating the exaggerated decline experienced by women in short-term memory tasks. Similar to how the occupation is a strong factor in preventing the development of neurodegenerative diseases like AD, women who received higher education could have higher chances of maintaining occupations over a period of time that aided in slowing down their cognitive decline.

*Effect of Income on Cognitive Decline*

Similar to education, we observed that higher adult income was associated with higher cognitive scores across all tasks at both time points. We additionally observed that the extent to which participants' verbal IQ, as measured by WAIS similarity scores, declined over time was moderated by adult income. Verbal IQ has been shown to differ across the socioeconomic spectrum, which may be due to the availability of parental support (Eilertsen et al., 2016). Here, we additionally show that income may have an effect of slowing the rate of decline on verbal IQ tasks. This replicates previous findings demonstrating that mid to late life-income has a significant role in the rate of cognitive decline (Marden et al., 2017). Income may affect cognitive decline simply due to factors that vary across the social hierarchy such as access to healthcare and health services, or general finance-related daily stressors. We again did not observe any effect of income on the decline of all measures, indicating that income may not produce a universal effect on cognitive decline.

Given past findings suggesting that childhood socioeconomic status may impact later cognitive decline (Liu et al., 2019), we assessed whether a subjective measure of parental income during childhood predicted cognitive scores over time. Our results indicated that higher subjective scores of childhood socioeconomic status were associated with higher scores at both time points in the immediate recall task, but did not predict change in scores over time. This may be due to our measurement of childhood socioeconomic status, which was based on a subjective rating in which participants were asked to compare their economic standing to other families in their area. It is possible that a more direct measure may have been more informative in predicting cognitive decline.

*Joint Effects of Income, Sex, and Education on Cognitive Decline*

Lastly, we exploratorily investigated whether the effects of income or education on cognitive decline were dependent on each other or on participant sex. We did not observe any combined moderation, suggesting that the effect of education and income on decline may operate independently of one another. However, past research has shown that income may mediate the relationship between higher educational attainment and slowed cognitive decline (Zahodne et al., 2014). More research is needed to elucidate these relationships.

*Limitations*

It is worth noting that our findings are limited to White males and females who completed at least high school education. Prior research has shown that word-reading tests more accurately reflect the educational experiences of non-White older adults in comparison to their non-Hispanic, White counterparts (Manly et al., 2002; Sisco et al., 2015). For future studies, it

would be advantageous to investigate the extent to which higher education delays cognitive decline for marginalized groups of people. For instance, children of immigrants are at higher risk of poor health and food insecurity than children of US-born mothers (Chilton et al., 2009). Having a higher risk of poor health and food insecurity as a child could potentially have detrimental effects on cognitive decline in older adults.

Another limitation in our present study is that the WLS started collecting physical and mental health data in 1993 when the participants were at least in their 40's. Acquiring childhood physical and mental health could provide future studies with more nuance to address the question of whether cognitive decline in later adults are due to factors limited to adult contexts or also includes childhood context beyond just parental income.

Additionally, we did not account for the attrition rate in our study. It would be worthwhile to look at the reasons for why participants dropped out of the study or refused to respond, and whether those who dropped out or refused to respond differed in important characteristics from those who responded. According to Herd, Carr, and Roan (2014), financial questions lead to the most item non-responses in the WLS data. Given that financial factors were significant variables of interest in our analysis, this may have impacted our results by not including participants who were uncomfortable discussing their finances.

Lastly, we recognize that our measures of income in both childhood and adulthood are not comprehensive in understanding participants' socioeconomic status. Various factors are important to consider when determining the effect of socioeconomic status on mental and physical health outcomes. While income is important, future studies should include additional measures of subjective socioeconomic status, parental education, and household size in measures of SES.

*Conclusions*

Overall, we observed that education, income, and sex impact the rate of decline of differing cognitive abilities after the fifth decade of life. Specifically, women showed a faster decline despite overall higher cognitive task performance, yet appeared to benefit more from education than men on tasks related to memory. Both sexes showed a slower decline in a verbal executive function task with higher education, and in a verbal IQ task with higher income. Future research should consider a sample of individuals that more proportionally reflects the racial and ethnic makeup of the national population, including participants with less than high school education, and begin cognitive task collection earlier in life.

**Acknowledgements**

We acknowledge Dr. Mark Lai for teaching a wonderful class amidst a global pandemic; we had lots of fun learning and appreciated his care and patience.

The data analytic scripts and supplemental materials for this project are available at https://github.com/sarhen907/MLM-WLS

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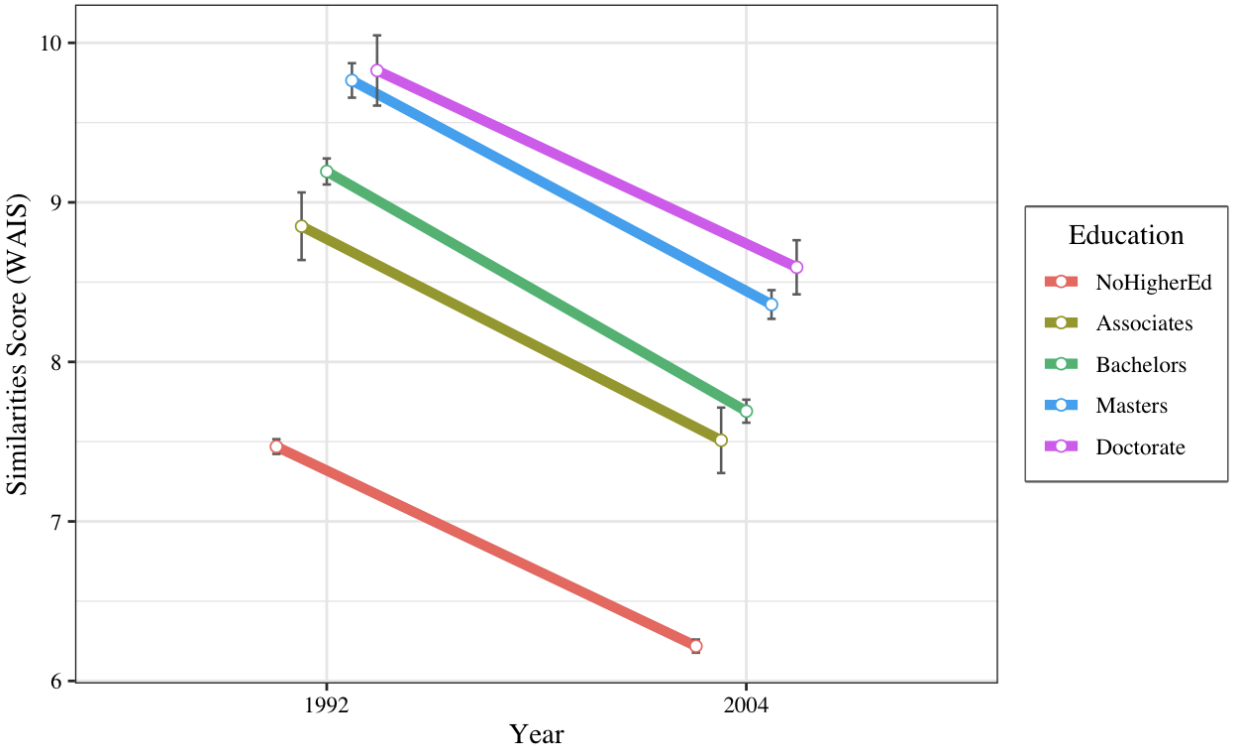
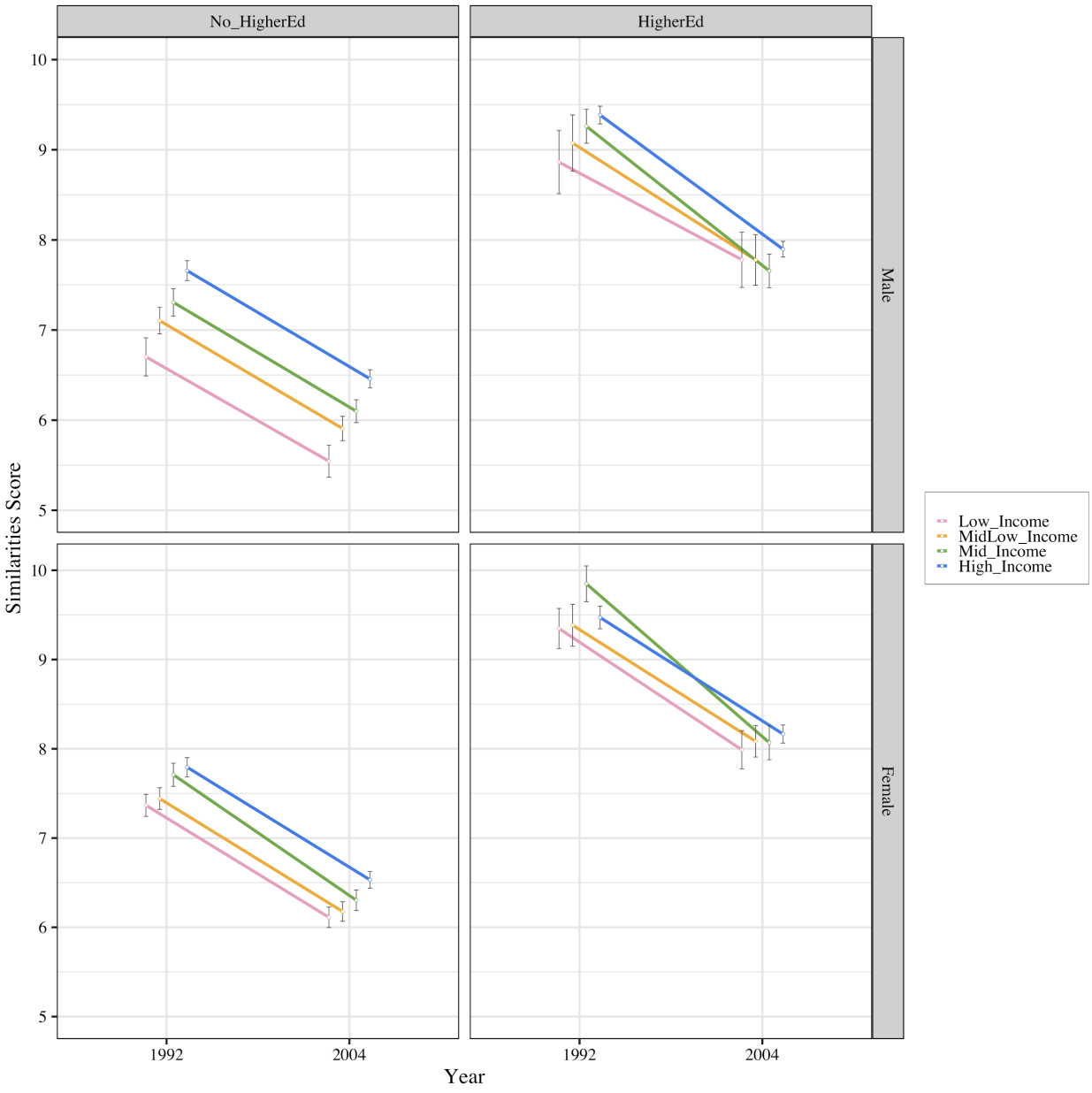
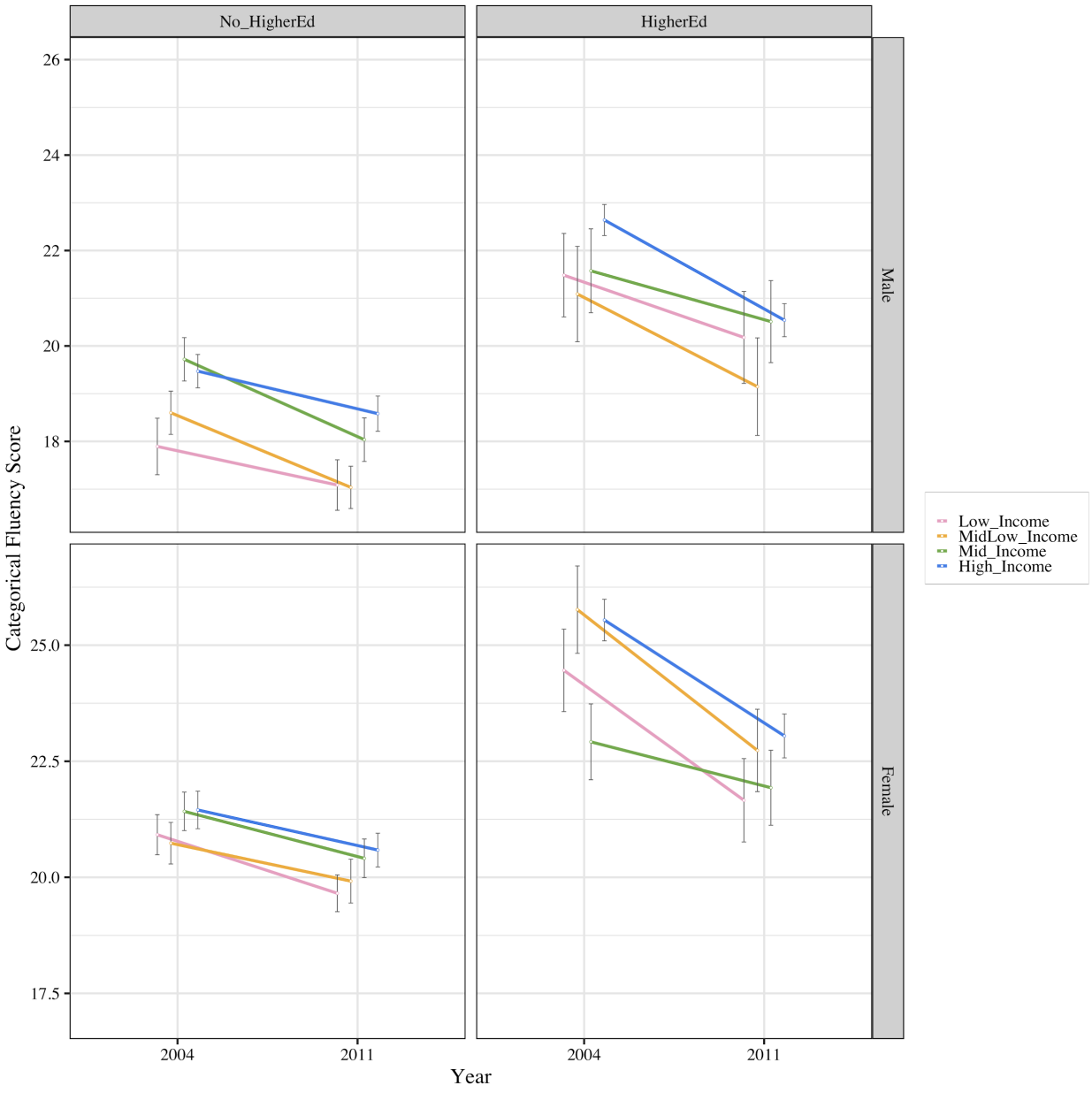
**Supplementary Materials**



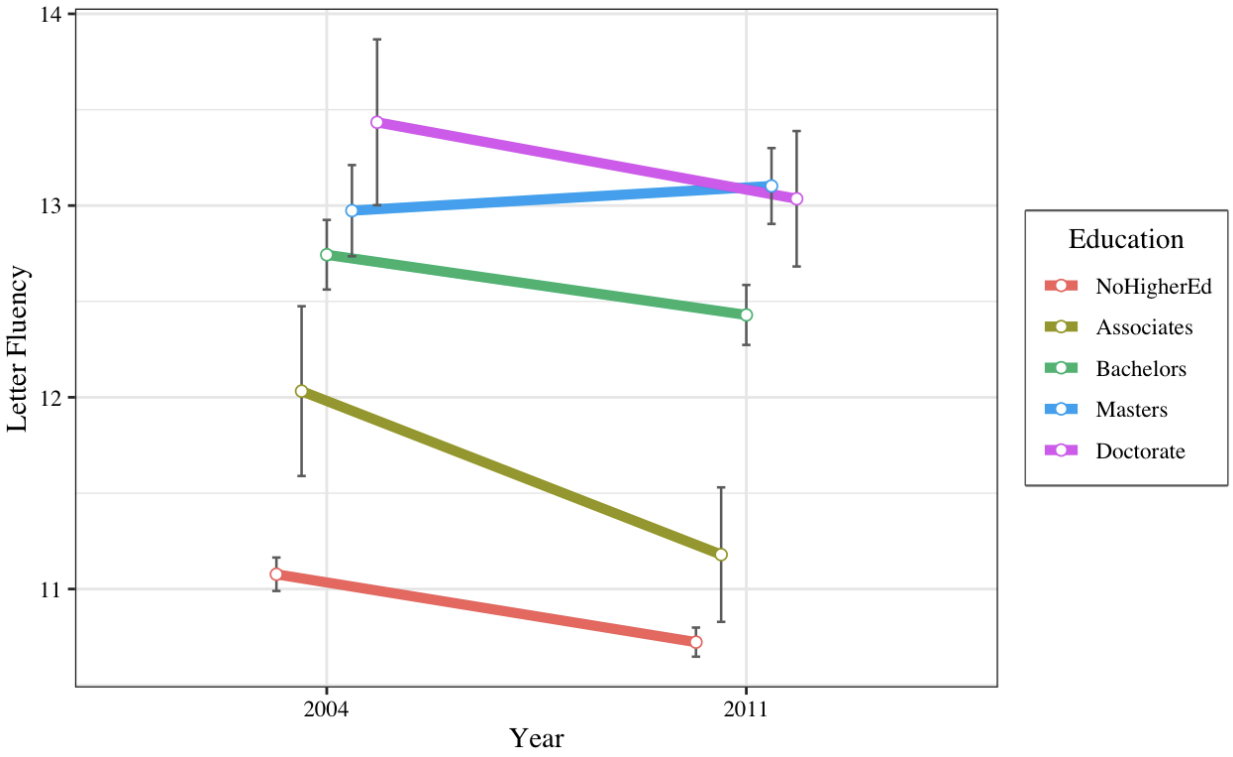

**Supplementary Figure 1.** Education on similarity scores over time.



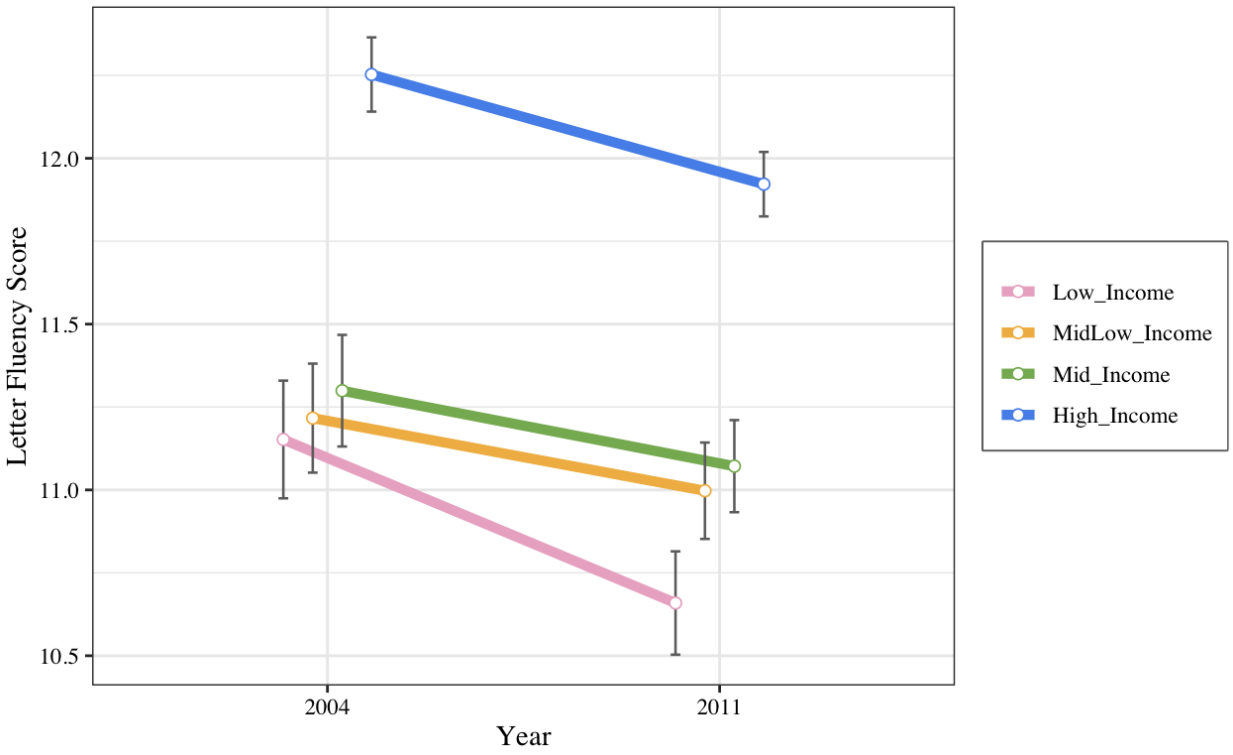

**Supplementary Figure 2.** Effect of age, education, and adult income over time on similarity scores. Low income grouping is < $32k, MidLow income grouping is $32k - $48.5k, Mid income grouping is $48.5k -$ 65k, and High income grouping is > $65k.



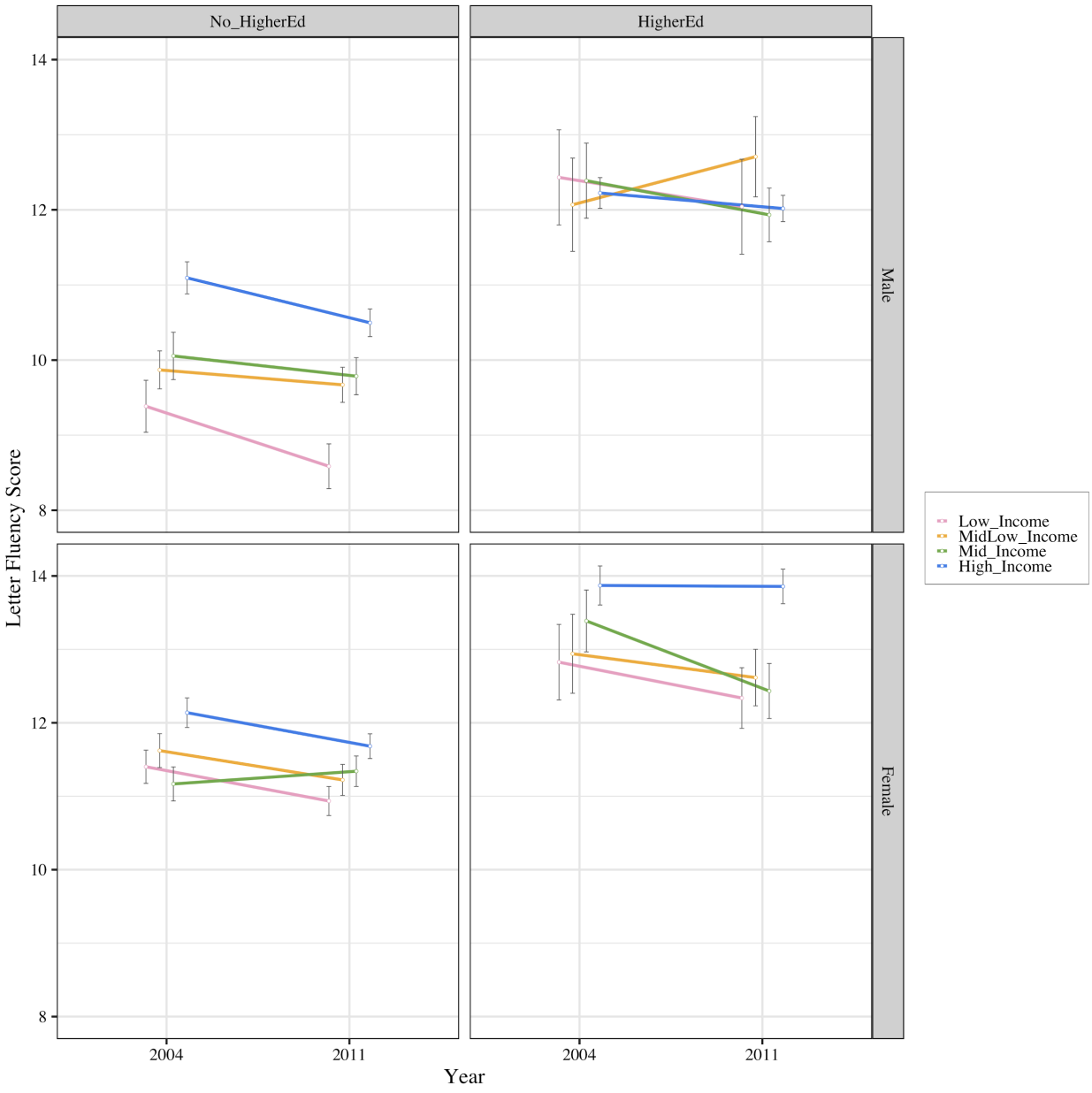

**Supplementary Figure 3.** Effect of age, education, and adult income over time on categorical fluency scores. Low income grouping is < $32k, MidLow income grouping is $32k - $48.5k, Mid income grouping is $48.5k -$ 65k, and High income grouping is > $65k.



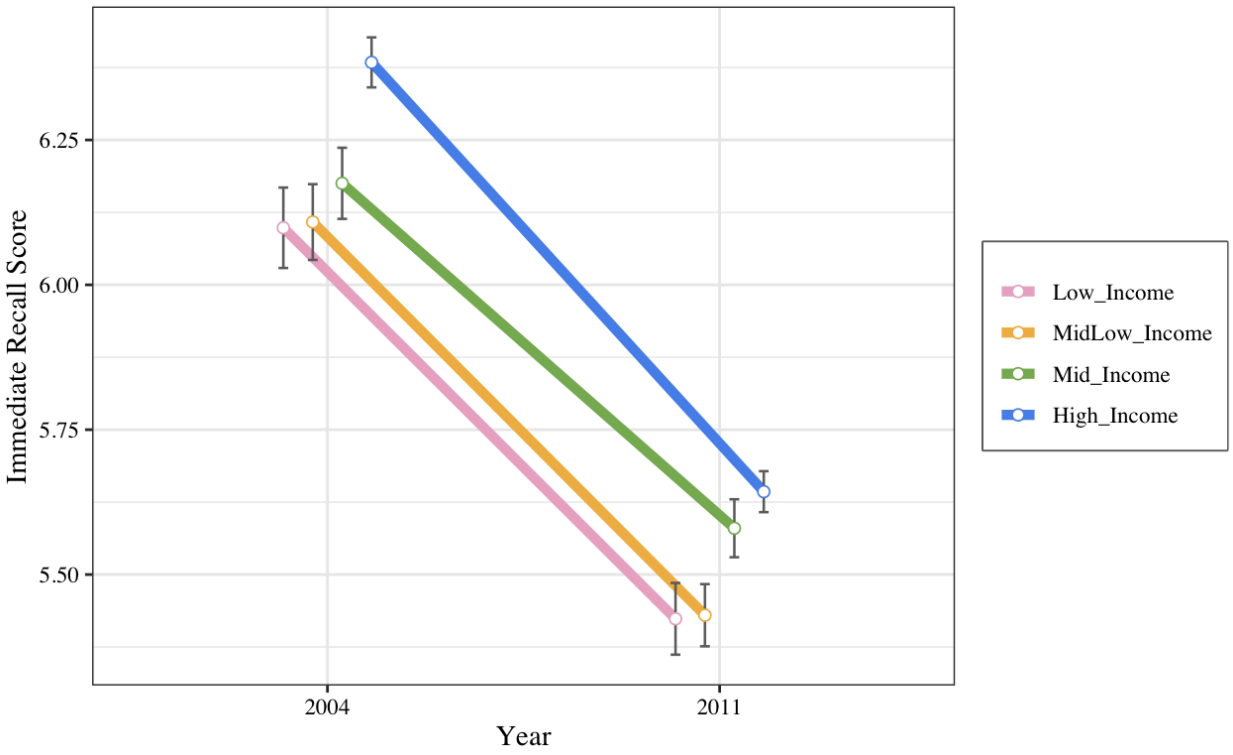

**Supplementary Figure 4.** Education on letter fluency scores over time.



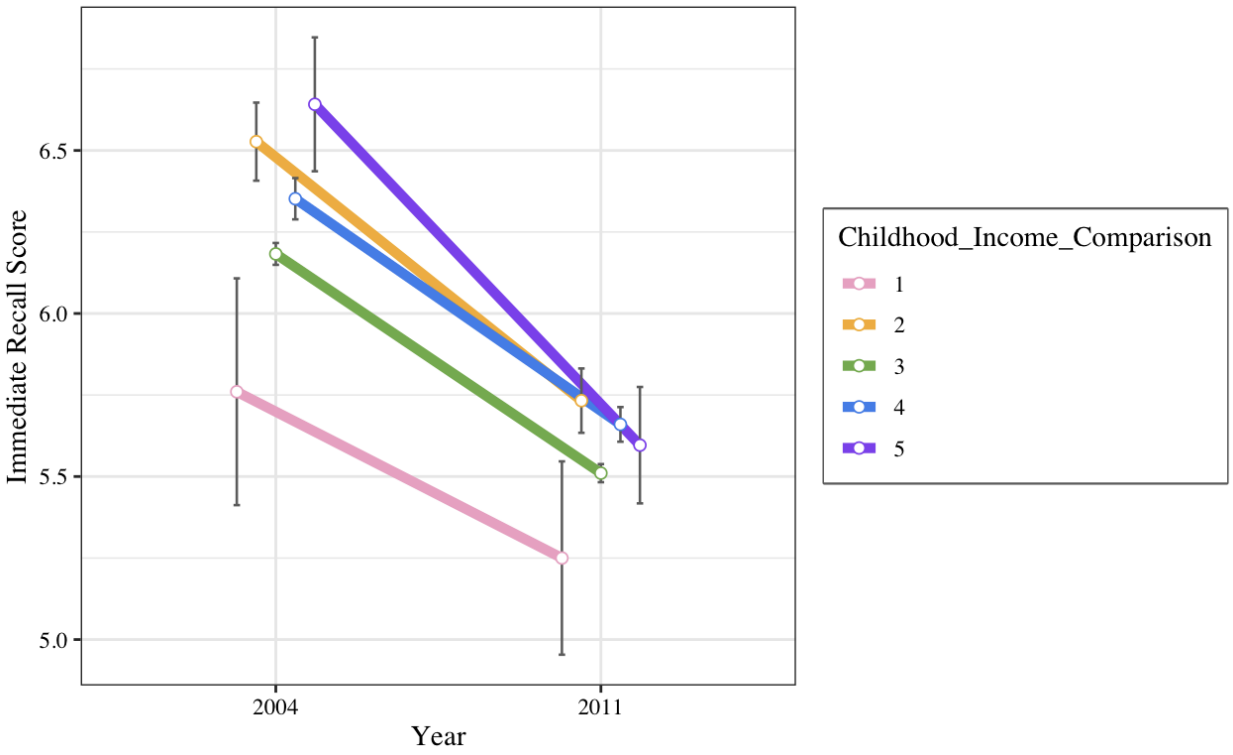

**Supplementary Figure 5.** Income on letter fluency scores over time. Low income grouping is < $32k, MidLow income grouping is $32k - $48.5k, Mid income grouping is $48.5k -$ 65k, and High income grouping is > $65k.



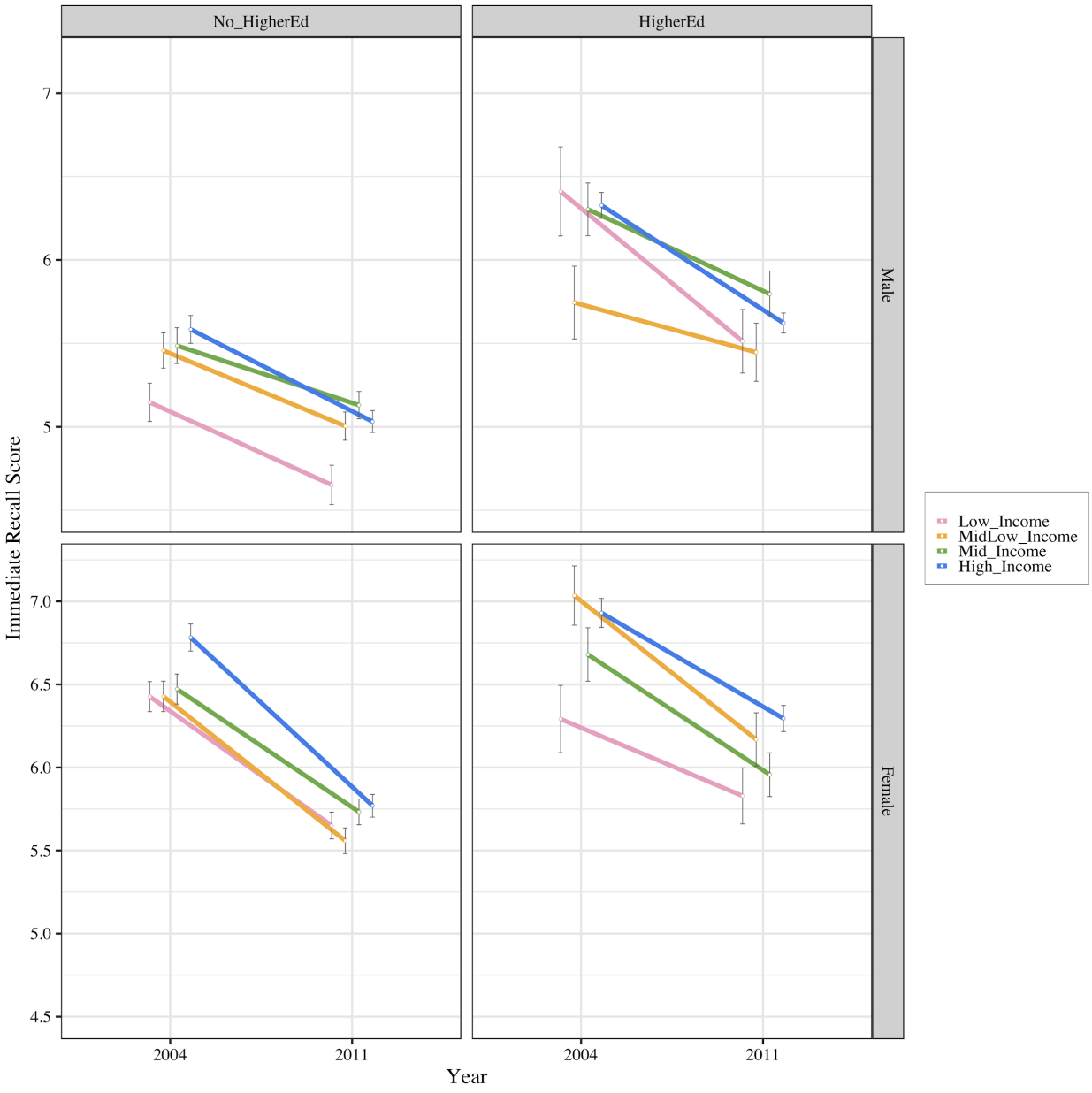

**Supplementary Figure 6.** Effect of age, education, and adult income over time on letter fluency scores. Low income grouping is < $32k, MidLow income grouping is $32k - $48.5k, Mid income grouping is $48.5k -$ 65k, and High income grouping is > $65k.



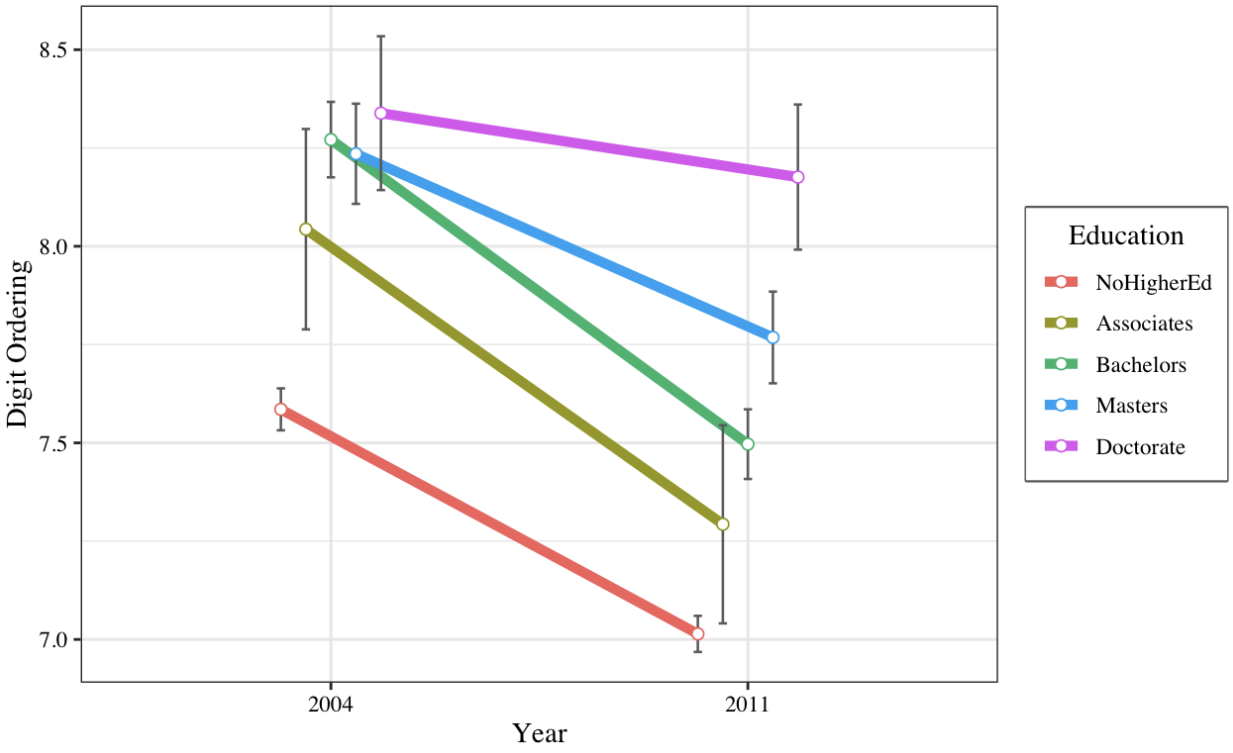

**Supplementary Figure 7.** Income on immediate recall scores over time. Low income grouping is < $32k, MidLow income grouping is $32k - $48.5k, Mid income grouping is $48.5k -$ 65k, and High income grouping is > $65k.



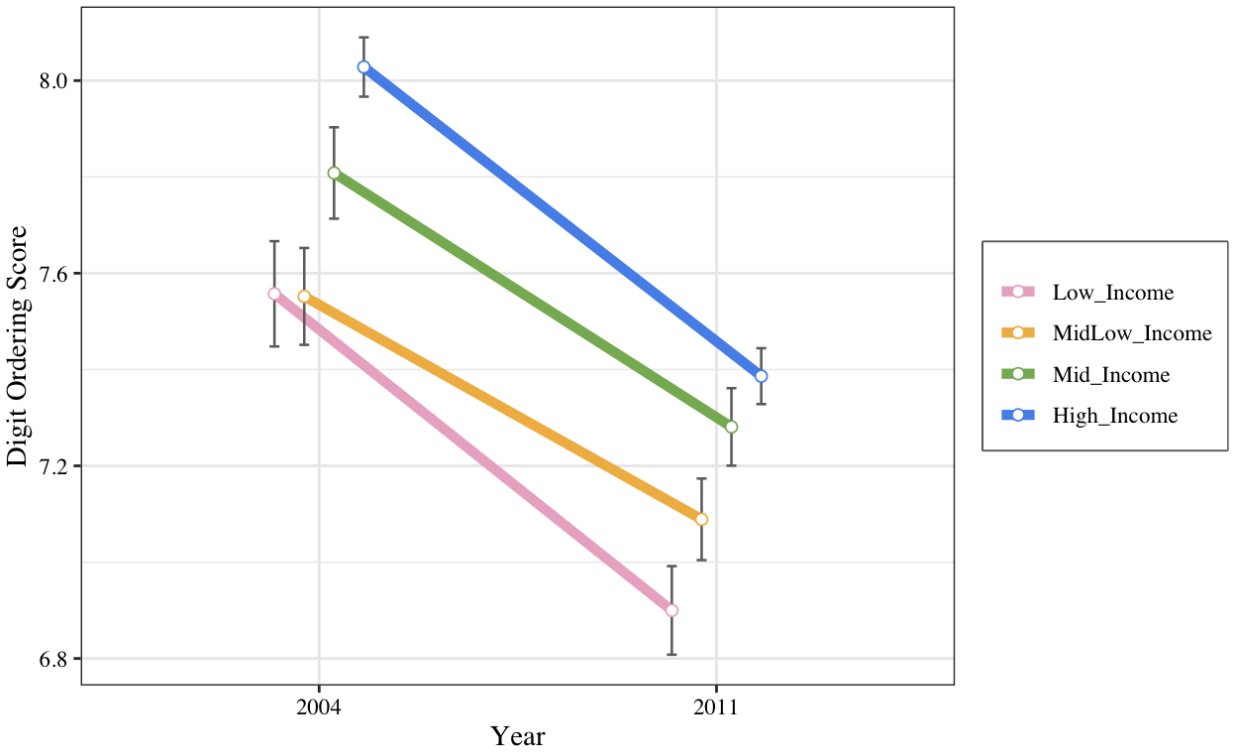

**Supplementary Figure 8.** Childhood income comparison on immediate recall scores over time.



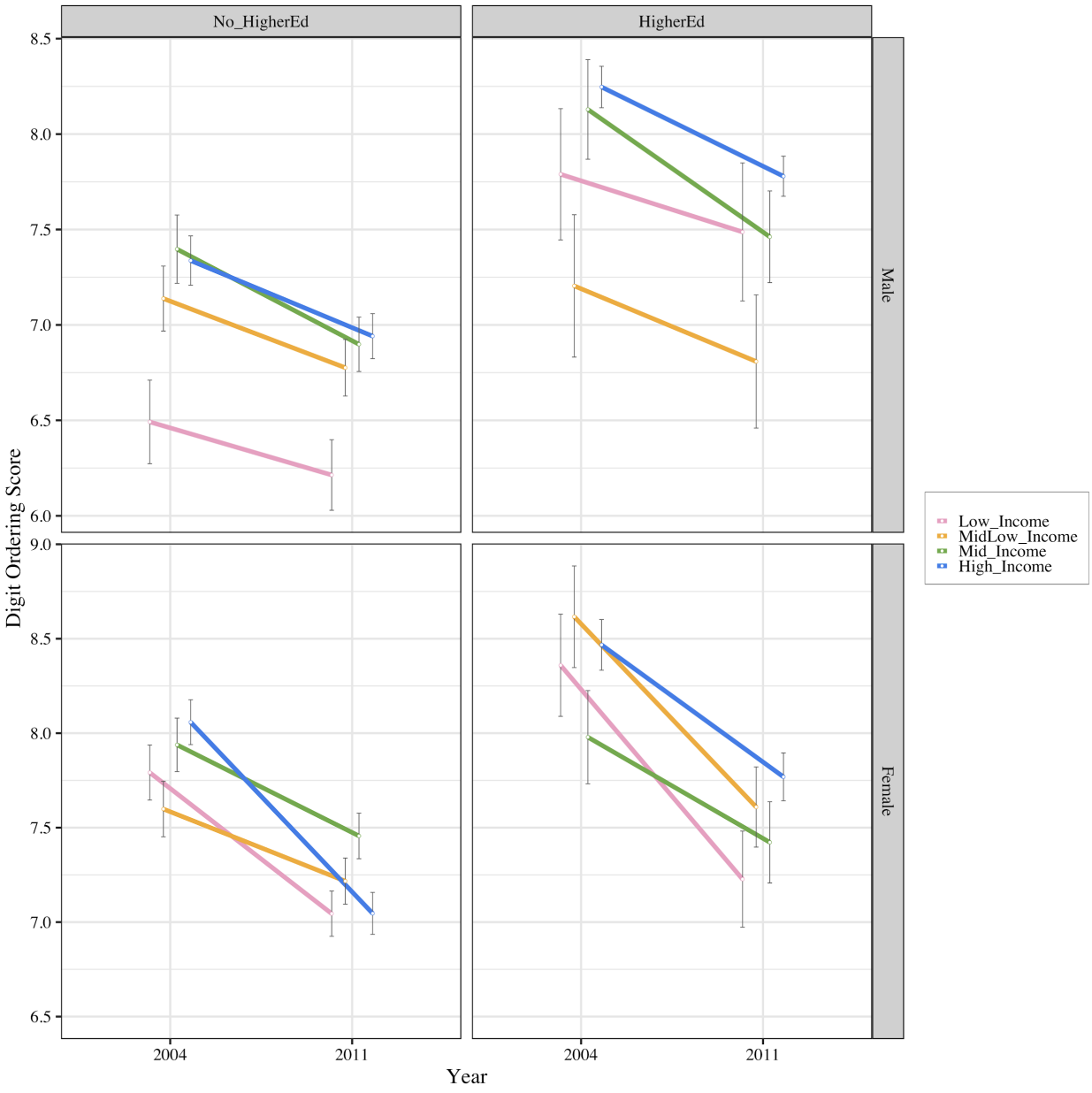

**Supplementary Figure 9.** Effect of age, education, and adult income over time on immediate recall scores. Low income grouping is < $32k, MidLow income grouping is $32k - $48.5k, Mid income grouping is $48.5k -$ 65k, and High income grouping is > $65k.




**Supplementary Figure 10.** Education on digit ordering scores over time.




**Supplementary Figure 11.** Income on digit ordering scores over time. Low income grouping is < $32k, MidLow income grouping is $32k - $48.5k, Mid income grouping is $48.5k -$ 65k, and High income grouping is > $65k.




**Supplementary Figure 12.** Effect of age, education, and adult income over time on digit ordering scores. Low income grouping is < $32k, MidLow income grouping is $32k - $48.5k, Mid income grouping is $48.5k -$ 65k, and High income grouping is > $65k.