# Age Declines in Numeracy: An Analysis of Longitudinal Data

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**Abstract**

Numeracy, the ability to understand and use basic probability and numerical concepts, is associated with diverse positive outcomes across the lifespan. Prior cross-sectional research on numeracy has generally found a negative association with age, but positive correlations with male gender, education attainment, and measures of fluid and crystallized intelligence have been more robust. Age effects on cognitive functioning are well established, but little is known about longitudinal trends of numeracy into older age. The current study investigates longitudinal age effects on numeracy using a sample of 524 adults (2008 $Age_{range}$ = 20-78) from the RAND American Life Panel. Participants completed a numeracy measure in both 2008 and 2019, a span of 11 years. Using a linear mixed-effect model to predict numeracy scores, a significant interaction between the year of testing and the quadric age term shows a decline in numeracy scores beginning in later middle-age, a trend that falls in between those previously found for crystallized and fluid cognitive abilities. Numeracy declines are somewhat mitigated for males and those with higher education, but the interaction of the two variables did not return a clear pattern of results. Prior research has shown that numeracy is positively related to the quality of health and financial decisions and, ultimately, more positive health and economic outcomes. The implications of age declines in numeracy are discussed in relation to health and financial decision-making, tasks that remain relevant into old age.

*Keywords*: Numeracy, aging, longitudinal analyses, cognitive aging

**Age Declines in Numeracy: An Analysis of Longitudinal Data**

As literacy is defined by the ability to use and engage with written text, numeracy is likewise the ability to effectively understand and use numbers and mathematical concepts (e.g., Peters, 2020). Higher numeracy is associated with higher levels of educational attainment, better health, economic success, and improved performance in a litany of tasks related to the management of daily life, including financial and health-related decisions and outcomes (Banks & Oldfield, 2007; Garcia-Retamero & Cokely, 2017; Peters et al., 2007; Reyna et al., 2009; Wood et al., 2016). Numeracy also demonstrates causal effects on financial literacy, healthy behaviors, and the consistency of risk perceptions (Chesney et al., in press; Peters et al., 2017). The study of numeracy as a cognitive construct has uncovered a number of demographic trends, robustly showing greater levels in males and individuals with higher levels of education (e.g., Galesic & Garcia-Retamero, 2013; Peters & Bjalkebring, 2015). For example, in the schooling-decision-making model, formal education appears to directly increase numeracy among other cognitive abilities (Peters et al., 2010). However, comparatively little is known about adult age effects on numeracy, particularly in older adulthood, even though age is a well-studied demographic predictor of cognition.

Numeracy is associated with, but distinct from, other aspects of intelligence (Peters, 2020). For example, impairment to numerical knowledge, but not non-numerical knowledge, occurs with inferior-parietal lesions (Dehaene, 2011). Studies showing relationships between numeracy scores and measures of intelligence routinely find that numeracy, after statistically controlling for various facets of intelligence, is independently predictive of various judgement and decision-making outcome measures (e.g., Låg et al., 2014; Peters et al., 2006; Sinayev & Peters, 2015). Similarly, though associated with many other cognitive abilities, numeracy is an independent construct predictive of risk comprehension (Cokely et al., 2012), performance in decision-making tasks (Peters, 2012; Peters et al., 2006), and susceptibility to biases and fallacies in judgment (Liberali et al., 2012).

Less clear is whether to make predictions about age effects on numeracy based on fluid intelligence (defined as the ability to solve novel reasoning problems with minimal reliance on past experience) or crystalized intelligence (characterized by the ability to solve problems by applying past experience). This distinction is important in the study of aging because aging is generally associated with stability in crystalized cognitive abilities and declines in fluid cognitive abilities and performance on associated tasks, with many fluid abilities showing declines beginning in one’s 20s and 30s (for a review, see Salthouse, 2010). Limited available evidence points towards a predominately negative association between age and general numeracy (Chen et al., 2014; Peters, 2008; Schaie & Zanjani, 2006) as well as domain-specific numeracies (e.g., health numeracy, Delazer et al., 2013). Mechanisms for this relationship between age and numeracy are unclear, but some evidence exists that the relationship is mediated by motivational factors (e.g., need for cognition; Bruine de Bruin et al., 2015). Age declines in fluid intelligence could also play a role. Fluid intelligence measures significantly correlate with measures of objective numeracy (Dieckmann et al., 2015; Peters et al., 2010) and a meta-analysis has shown a significant, moderately sized link between fluid intelligence and performance in mathematics (Peng et al., 2019). Looking at other cognitive constructs, some evidence also exists that decreases in episodic memory and visuospatial ability significantly predict decreases in numeracy; decreases in perceptual speed similarly had moderate associated decreases in numeracy (Gamble et al., 2015). It is important to note that declines in domain-general cognitive abilities are not necessarily associated with declines in performance in more specific abilities, including those that are associated with numeracy. For example, Li et al. (2013) found that older adults' performance on decision-making measures, including a measure of financial literacy, was better than younger adults' performance despite the older adults' lower fluid cognitive abilities – a result the authors attributed to older adults' comparatively greater crystalized abilities.

With normative cognitive declines being well-studied and age differences in numeracy being established to a lesser degree, it remains an open question whether age differences in numeracy can be primarily attributed to cohort differences or if a decline exists across adulthood within individuals. This gap in our knowledge is, in part, due to the lack of available longitudinal data on numeracy. To our knowledge, only one published study has reported longitudinal numeracy data (Schaie & Zanjani, 2006), which reported on data collected from the Seattle Longitudinal Study in the latter half of the 20$^{th}$ century and which quantified numeracy using timed mental arithmetic tasks. In that study, numeracy abilities and perceptual speed were the first "primary mental abilities" to show declines, beginning in the mid-fifties. Although these results are informative to our understanding of the longitudinal trend of numeracy across adulthood, objective numeracy is often contemporarily quantified using measures that are not timed and seem less likely to rely on processing speed. These contemporary tasks (e.g., Cokely et al., 2012; Lipkus et al., 2001; Weller et al., 2013) use items that rely on the comprehension of higher order mathematical concepts (e.g., probability, ratios, arithmetic, etc.) along with the ability to complete mental arithmetic.

Numeracy is a multidimensional construct, requiring knowledge of different mathematical concepts (e.g., probability, arithmetic, algebra), the understanding of how and when to apply these concepts, and the ability to successfully process numerical information. Contemporary numeracy measures also require reading ability. As older adulthood is generally associated with declines in fluid intelligence and maintenance of crystalized intelligence, it is unclear how aging may affect numeracy. However, it seems reasonable to expect declines in numeracy across adulthood given the need to process novel information during numerical tasks. Additionally, spatial and math skills have long been linked (Verdine et al., 2014), and large age-related decreases exist in spatial performance (Techentin et al., 2014). At the same time, it is also reasonable to expect stability in numeracy across adulthood given numeracy's reliance on reading ability as well as knowledge of mathematical concepts and how to apply them. Furthermore, age-related declines in fluid cognitive abilities do not necessarily manifest as decreases in performance. Evidence exists that general crystalized abilities (Li et al., 2013) and domain-specific crystalized abilities (Li et al., 2015) can make up for age-related declines in fluid cognition, allowing for maintenance or improvements in behavioral outcomes into older adulthood. Existing data demonstrate lower numeracy in older adults compared to younger age groups (Chen et al., 2014; Peters, 2008; Schaie & Zanjani, 2006), but it is unclear if lower numeracy is the product of decline or stability at a lower plateau – longintudinal or cohort effects, respectively. In an effort to address this question, the current study reports an analysis of the first longitudinal data collected using untimed, objective numeracy measures.

## Method

Data was collected from members of the RAND American Life Panel (ALP) at two time points separated by 11 years. The ALP is an internet sample of approximately 4000 members generalizable to the U.S. population that was constructed through probability sampling. Most ALP members use their own internet connection, but those without are provided tablets, internet access, or both. Further information about the ALP can be found in the technical description (Pollard & Baird, 2017). The first questionnaire used in the analysis, titled "ms32 Dietary

Supplements and Numeracy Scale", was completed by participants between May and June of 2008. The second questionnaire, titled "ms521 Current Events [Truth Decay & Cognitive Bias]", was part of a separate study and completed between February and March of 2019. Data for both surveys are publicly and freely available (https://alpdata.rand.org/).

**Participants**

A group of 1302 ALP members ($M_{age2008}$ = 52.97, $SD_{age}$ = 13.30, 90.4% Caucasian, 45.4% male), recruited through probability sampling, completed the 2008 survey which included a set of 17 numeracy items (see Weller et al., 2013). Of these participants, 527 also responded to a 2019 survey which included eight of the 17 initial numeracy items. The flow of participants from the 2008 survey to the 2019 survey is illustrated in Figure 1. Of this final group, 524 participants ($M_{age2019}$ = 53.78, $SD_{age}$ = 10.57, 92.8% Caucasian, 46.6% male) completed the full set of 8 numeracy items from both time points and were included in the analyses reported in the current manuscript. A summary of the demographics of the final sample is listed in Table 1. Across the two time points, sample demographics were relatively stable and numeracy scores slightly decreased on average.

It is important to note demographic differences between individuals that participated in both surveys and those that voluntarily did not complete the 2019 survey (defined as those that were invited but did not participate or those that dropped out of the ALP; see Figure 1). As a group, individuals that complete both surveys scored significantly higher in numeracy, attained higher levels of education, and had greater incomes relative to the individuals that did not participate in the 2019 survey due to their own volition (Table S1).

***Weights***

The demographics of the 524 participants that completed both surveys differed both from the general population as well as the 775 participants that completed the 2008 survey but not the 2019 survey (see Figure 1). These demographic differences were addressed through a two-step calculation of weights for use in the statistical analyses. In the first step, to address differences between the sample population and the general US population, a raking algorithm was used to match as closely as possible the 2008 survey sample demographics to data from the 2008 Current Population Survey (US Census Bureau, 2020). Weights were calculated to match population proportions across five parameter interactions: age by sex, sex by race/ethnicity, sex by education, sex by income, and number of household members by income. Raked weights were calculated using the "anesrake" package (Pasek, 2018) in R (R Core Team, 2019) using the RStudio interface (RStudio Team, 2019). The first step matches the procedure used to produce weights for other ALP surveys. For additional information on the raked weighting process employed by the ALP and recalculated for the current study, please see Pollard and Baird (2017).

In a second step, to address differences between participants that completed both the 2008 and 2019 surveys and those that only completed the 2008 survey, we created non-response weights. These inverse probability weights account for differences between participants that completed the 2019 survey and those that did not in demographic variables used to predict participation in the 2019 survey. Factors included in the inverse probability weights were age, numeracy, marital status, gender, income, and education. The final weights used in the analyses were calculated by dividing the raked population weights calculated in the first step by the survey retention probability weights calculated in the second step. Further information on this two-step approach to weighting can be found in the Methodology Appendix of Carman et al. (2015).

**Materials**

At each testing point, participants completed numeracy items included as part of a larger, unrelated survey. Within the 2008 survey, participants completed 17 numeracy items described in Weller et al. (2013). The eight Rasch-based numeracy items identified in the Weller et al. publication were included as part of the 2019 survey, dictating the final items included in the longitudinal analysis (see Table S2 for study items). Numeracy scores were calculated as the number of correct answers, ranging from zero to eight. Panel members consent to participate in regular surveys, and both surveys were approved by the RAND Human Subjects Review Committee.

**Analyses**

To investigate the longitudinal effect of age on numeracy scores, the data were fit to a weighted linear mixed-model predicting numeracy scores including participant as a random factor and year of testing, age, quadratic age, sex, marital status, income, education, and the interactions of year of testing with age and the quadratic age term as fixed factors. The quadratic age term was included to test for non-linear age effects similar to those found in other domains of cognition (for review, see Salthouse, 2010). Education was dummy coded into multiple categories, using a high school diploma or less as the reference group. Due to the design of the survey items distributed in the 2008 survey, income was included as a binary variable indicating an annual household income of less than $75,000 or greater than or equal to $75,000. Mixed-model analyses were conducted using the lme4 (Bates et al., 2015) and lmerTest (Kuznetsova et al., 2017) packages in R (R Core Team, 2019) using the RStudio interface (RStudio Team, 2019). See Table S3 for a correlation table of variables included in the mixed-model analyses.

A secondary analysis was also conducted to determine if higher education and male gender, factors previously found to be associated with higher numeracy scores (Galesic & Garcia-Retamero, 2013; Peters & Bjalkebring, 2015), had protective effects on age-related declines in numeracy. These variables were selected as predictors due to their robust correlations with numeracy in the literature. While other characteristics are likely to be important predictors of declines in numeracy, we were limited in the set of variables available – studying the longitudinal trend of numeracy across adulthood was not the purpose of the two surveys and the only other common variables were demographic. Sex, education, 2008 numeracy scores, and their interaction terms were entered into a weighted (see above sections) three-way ANCOVA, including 2019 numeracy scores as the dependent variable and age as a covariate. ANCOVA analyses were conducted using the car package (Fox & Weisberg, 2019) in R (R Core Team, 2019). Difference scores were not used as the dependent variable due to the bounded nature of the scale; individuals with higher numeracy scores in 2008 had the possibility of greater decreases in numeracy compared to low scoring individuals. Likewise, individuals with lower numeracy scores in 2008 had the possibility to show a greater increase in scores compared to high scoring individuals. For example, individuals with a score of “7” could only increase by 1 point in 2019 but had the possibility of falling 7 points. The inverse is true for low scoring individuals.

## Results

The weighted linear mixed-model predicting numeracy scores returned numerous significant predictors, including the expected interaction between survey year and the quadratic age term (Table 2). The significant interaction term was interpreted using Figure 2. As seen in Figure 2A, age was generally associated with a quadratic decrease in numeracy, but the negative relationship was more pronounced in the 2019 testing period when participants were 11 years older. As these results were based on longitudinal analysis on the same participants, this relationship indicates that the older members of the sample recorded a greater decrease in numeracy scores compared to the younger members. Figure 2B visually separates the sample into 5-year age groups to aid interpretation; with this alternative display the result was even more clear. In the 11-year period between the testing points, numeracy scores were generally stable across time for adults up to middle age in 2008. For adults already in the late middle-age and older-age groups in 2008, numeracy scores decreased over the 11-year period. As seen in Figure 2A, the rate of this decline increased with age.

Males also scored approximately two thirds of a point higher on the numeracy test ($b = .66$, $p < .001$) and individuals with household incomes greater than $75,000 also scored higher in numeracy ($b = .44$, $p < .001$). In general, more education was significantly related to higher numeracy scores.

**Protective factors in this age-related numeracy decline**

The previous analysis reported an increasing rate of numeracy decline with age when controlling for sex, marital status, income, and education. A weighted three-way ANCOVA was used to determine if these factors also had protective effects on age-related declines in numeracy. As expected, the ANCOVA results indicated that 2019 numeracy scores were significantly related to the main effect of age, $F(1, 507) = 47.08$, $p < .001$. Controlling for age, a significant effect emerged of the three-way interaction between 2008 numeracy scores, sex, and education on 2019 numeracy scores, $F(3, 507) = 3.38$, $p = .02$. This interaction was interpreted by separately analyzing the two-way interactions using additional posthoc ANCOVA analyses as visualized in Figures 3 and 4.

First, ANCOVAs including the interaction between sex and 2008 numeracy scores were conducted for each level of education including age as a covariate. The model was not significant for individuals with a high school diploma or less (Figure 3A), $F(1, 173) = 0.01$, $p = .92$ and those with a bachelor's degree (Figure 3C), $F(1, 151) = 1.27$, $p = .26$. For individuals with some college or an associate degree (Figure 3B), $F(1, 173) = 11.89$, $p < .001$, and with graduate degrees (Figure 3D), $F(1, 138) = 8.09$, $p = .005$, sex was related to 2019 numeracy scores differently depending on numeracy scores from 2008. For individuals with some college experience or with an associate degree (Figure 3B), being male was comparatively protective of numeracy ability for those that had previously scored high on the numeracy test. For individuals with a graduate degree (Figure 3D), being male was protective of numeracy ability, though that effect of sex diminished among those individuals that had previously displayed higher numeracy abilities.

A similar analysis was conducted using a series of ANCOVAs to investigate the interaction between education and 2008 numeracy scores on 2019 numeracy scores for each sex, controlling for age. As seen in Figure 4, a significant interaction between education and initial numeracy scores was found in the two-way ANCOVA analyses for both females, $F(1, 271) = 3.76$, $p = .01$, and males, $F(3, 235) = 5.33$, $p= .001$. Higher levels of education (those with bachelor's or graduate degrees compared to individuals with some college or an associate degrees) appeared protective of numeracy abilities in females, particularly among those with high initial numeric ability. Interestingly, females with a high school education or less displayed a similar relationship between 2008 and 2019 numeracy scores as those with college degrees and higher. Conversely, males with lower numeracy scores in 2008 were more likely to score higher on the numeracy items in 2019 if they were more educated (bachelor's or graduate degrees). This finding may represent a regression towards the mean for those individuals that tested poorly in 2008.

## Discussion

The data reported in the current study represents, to the authors' best knowledge, the first longitudinal data collected on objective numeracy measured using contemporary, untimed items (e.g., Lipkus et al., 2001; Weller et al., 2013). The results show that numeracy abilities do indeed decline in older adulthood after remaining stable into advanced middle-age. This pattern differs from two other patterns most often reported in cognitive aging research: the first, the relative stability of crystalized cognitive abilities (i.e., those related to knowledge and vocabulary); the second, cognitive decline in fluid abilities (i.e., working memory, reasoning, speeded processing, and novel problem solving), often beginning in one's 20's (Li et al., 2013; Salthouse, 2010). For numerical problems that require reading ability and the use of stored knowledge to solve novel problems, the longitudinal trend of numeracy ability across adulthood may be an amalgamation of the trends of cognitive aging for crystalized and fluid abilities; numeracy ability is stable until advanced middle age when declines in ability begin to appear. The age of onset of numeracy decline is similar to that found by Schaie and Zanjani (2006), who used a different operationalization of numeracy as a set of timed mental arithmetic tasks. It is important to note that other cognitive constructs reported in Schaie and Zanjani (2006) follow a similar or later age of onset of decline in contrast to the trends reported by Salthouse (2010), where declines begin in an individual's 20s and 30s.

In line with previous research showing relatively higher numeracy scores in males and individuals with higher education (e.g., Galesic & Garcia-Retamero, 2013; Peters & Bjalkebring, 2015), these factors also were found to be protective of declines in numeracy in certain demographic cross-sections (e.g., females with higher education). Importantly, these effects do not appear to be additive. For instance, education was not additionally protective of numeracy decline in males; rather, having an undergraduate or graduate degree was related to a comparatively larger increase in numeracy among males with lower initial scores (see Figure 4B). This finding may indicate a regression toward the mean for males with lower than expected numeracy scores in 2008, given their level of education. Additionally, the protective effect of education among females was not entirely clear. Women with bachelor's and graduate degrees saw less age decline in numeracy compared to women with some college experience or an associate degree, but no difference in the rate of decline compared to those with high school education or less. It is important to note that individuals reporting a high school education or less were the smallest sized sample among the education levels and the trends may be influenced by outlier scores (e.g., the top right-hand corner of Figure 3A).

Considering the lack of pattern in results for the protective effect of education, it is important to note that replication of these results in an independent sample is recommended to determine their validity. This recommendation particularly holds in the case of female participants, where individuals with some college or an associate degree were shown to have greater reductions in numeracy scores between the two testing periods compared to the other education groups. Considering the similarity of the numeracy score trends in females with higher and lower education, this significant interaction could have been due to an outlier effect (see lower right quadrant of Figures 3B and 4A) or regression to the mean within the female subgroup that had some college or an associate degree. Likewise, other significant effects in males may be driven by regression to the mean. As seen in Figures 3C and 4B, education-age interactions in males may be driven by lower-scoring, more educated individuals in 2008 rebounding in the 2019 measurement rather than higher education protecting an age decline between measurement occasions.

**Limitations**

Several other limitations are associated with the current study. First and foremost, the current study reports a secondary analysis of data available from the RAND American Life Panel. The two surveys, conducted for separate research projects, collected numeracy data alongside unrelated items, and the 2019 survey included the Rasch-based subset of numeracy items from Weller et al. (2013) as a potential predictive factor rather than a topic of primary interest. Numeracy data was collected in 2008 along with behavioral information pertaining to dietary supplement use and in 2019 with various items related to the concept of truth decay. More importantly, the 2008 survey included 17 numeracy items. The 2019 survey was substantially longer, and the eight Rasch-based numeracy items (Weller et al., 2013) were used to fit within the logistic constraints. This left only the eight items for inclusion into the longitudinal analysis. Had the longitudinal analysis been planned as a primary research project, the original 17-item numeracy scale would have likely been retained, perhaps allowing for an increased sensitivity of measurement despite item selection being done with Rasch analysis. A primary design would have also included additional points of measurement. Numerous other measures of numeracy exist (for a review, see Peters, 2020). As Peters notes, there is no one best measure for numeracy, but the Rasch-based measure is among those recommended for use with older adult populations who tend to be less numerate (p. 272). This measure is of moderate difficulty and should be able to capture variance in numeracy across the spectrum of ability for individuals in the study sample. Indeed, the measure did not appear to be too difficult for older adults in the current study as a range of numeracy scores was observed across the age distribution.

Furthermore, though demographic corrections were included in the analyses in the forms of raked and inverse probability weights, the sample itself was not representative of the US population or the greater ALP sample. Compared to the US population, the study sample was more female, Caucasian, higher income, and educated. Likewise, the individuals that completed both surveys within the ALP were more numerate, higher income, and more educated than ALP members that completed the 2008 survey but voluntarily did not complete the 2019 survey or had dropped out of the sample (Table S1). Although the current analysis provides initial evidence of a decline in numeracy in older adults, further research including additional measurement points is necessary to map the longitudinal trajectory of numeracy within a representative sample of individuals.

**Conclusion**

Although the study is limited by the secondary nature of the analysis, it was also marked by numerous strengths compared to the previous literature investigating aging and numeracy. Data were collected from a comparatively large adulthood sample, with a large age range, and recruited as part of a probability-sampled panel, thus improving the generalizability of the study. Furthermore, the analyses were weighted to correct for sample differences compared to the general US population and to control for demographic differences between the final study sample and the individuals that completed the 2008 survey but not the 2019 survey. Age comparisons were not just cross-sectional, but longitudinal within respondent, and the time period between testing periods was large, allowing for relatively slow rates of decline to be detected. Additionally, due to the time between testing points, retest effects are likely to be eliminated (Salthouse et al., 2004).

In conclusion, the results of the current analysis reinforce results from previous studies investigating numeracy trends across demographic groups, including higher numeracy scores in individuals that are younger, male, and with higher levels of education (Galesic & Garcia-Retamero, 2013; Peters & Bjalkebring, 2015). The contribution of this analysis to the literature is in the investigation of more complex untimed numeracy items relative to the prior literature, the source of the age difference in numeracy scores, and whether they reflect differences in age cohort or longitudinal declines. The results show a longitudinal decrease in numeracy but, unlike other cognitive constructs marked by age-related declines, declines become apparent in later middle-age rather than late young-adulthood. This later decline may be due to the verbal component inherent to numeracy items (they're word problems), and the relative stability of crystallized intelligence across the lifespan.

The onset of decline, however, is unfortunate given that numeracy is a robust predictor of performance in health-related tasks relevant to older adults (e.g., Medicare Part D program choice [Wood et al., 2011], completing health management tasks using an online patient portal [Taha et al., 2014], and managing disease and medication [Estrada et al., 2004; Gutierrez & Cohn, 2019]). In the case of older adults experiencing a decline in numeracy, the communication of health information could be adjusted to better promote informed choice (Peters et al., 2014).

Likewise, numeracy has a causal effect on financial literacy (Peters et al., 2017) and poor financial choices could serve as a barrier to financial wellbeing in retirement for older adults. Future research should examine this possible association between age declines in numeracy and negative financial outcomes. Of course, age declines in numeracy may not affect financial outcomes given that age-related fluid cognitive declines are not always related to worse performance, including in the area of financial literacy (Li et al., 2013). Evidence also exists that lower numeracy is associated with increased risk of financial fraud and exploitation (Wood et al., 2016). The potential relationship between declines in numeracy and financial fraud and exploitation among older adults warrants future research.

More generally, interesting future research directions exist in both health and personal finances concerning effects of changes in one's numeracy level as opposed to one's current numeracy level, which has been the focus of most past research. Numeracy changes may have additive effects on individuals accustomed to their own decision-making competence. In particular, negative effects may accrue if people's expectations about their numeric abilities are based on the past and become mis-calibrated relative to their actual ability (Peters et al., 2019). Thus, longitudinal research is required to determine if results are driven by differences in baseline ability and/or whether age declines in numeracy result in an increased risk of poor outcomes over time.

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**Table 1**

*Demographic Variables of Sample across both Testing Points.*

| | 2008 *n* = 524 | | 2019 *n* = 524 | |
|---|---|---|---|---|
| | *M* | (*SD*) | *M* | (*SD*) |
| Age | 53.78 | 10.57 | 63.98 | 10.60 |
| Numeracy | 4.74 | 1.68 | 4.50 | 1.72 |
| | *n* | (%) | *n* | (%) |
| Male | 244 | 46.6 | 244 | 46.6 |
| Married | 353 | 67.4 | 339 | 64.7 |
| Income >$75k | 252 | 48.1 | 257 | 49.0 |
| Education | | | | |
| <High School | 2 | 0.4 | 2 | 0.4 |
| High School | 45 | 8.6 | 43 | 8.2 |
| Some College or Associate Degree | 178 | 34.0 | 174 | 33.2 |
| Bachelors Degree | 156 | 29.8 | 153 | 29.2 |
| Graduate Degree | 143 | 27.3 | 152 | 29.0 |

**Table 2**

*Linear Mixed-effects*

| | *b* | *SE* | *t* | *p* |
|---|---|---|---|---|
| Intercept | 6.50 | 1.22 | 5.32 | <.001 |
| Year | -0.35 | 0.09 | -4.05 | <.001 |
| Age | -0.13 | 0.05 | -2.55 | .01 |
| Age$^2$ | 0.001 | 0.001 | 2.11 | .04 |
| Male | 0.66 | 0.19 | 3.50 | <.001 |
| Married | -0.04 | 0.12 | -0.36 | .72 |
| Income > $75k | 0.44 | 0.09 | 4.91 | <.001 |
| Education | | | | |
| Some College / Associate Deg. | 1.18 | 0.19 | 6.10 | <.001 |
| Bachelors Deg. | 1.33 | 0.24 | 5.59 | <.001 |
| Graduate Deg. | 1.50 | 0.24 | 6.20 | <.001 |
| Year*Age | 0.02 | 0.003 | 5.56 | <.001 |
| Year*Age$^2$ | <.001 | <.001 | -6.45 | <.001 |

*Note*. Binary predictors were coded as follows – Year: 0 = 2008, 11 = 2019; Male: 0 = Female, 1 = Male; Married: 0 = Not Married, 1 = Married; Income > $75k: 0 = annual income ≤ $74,999, 1 = annual income ≥ $75,000. Educational items are dummy coded using "high school education or less" as the reference group.

**Figure 1**

*Flow of Participants from Completion of the 2008 Survey to Completion of the 2019 Survey.*

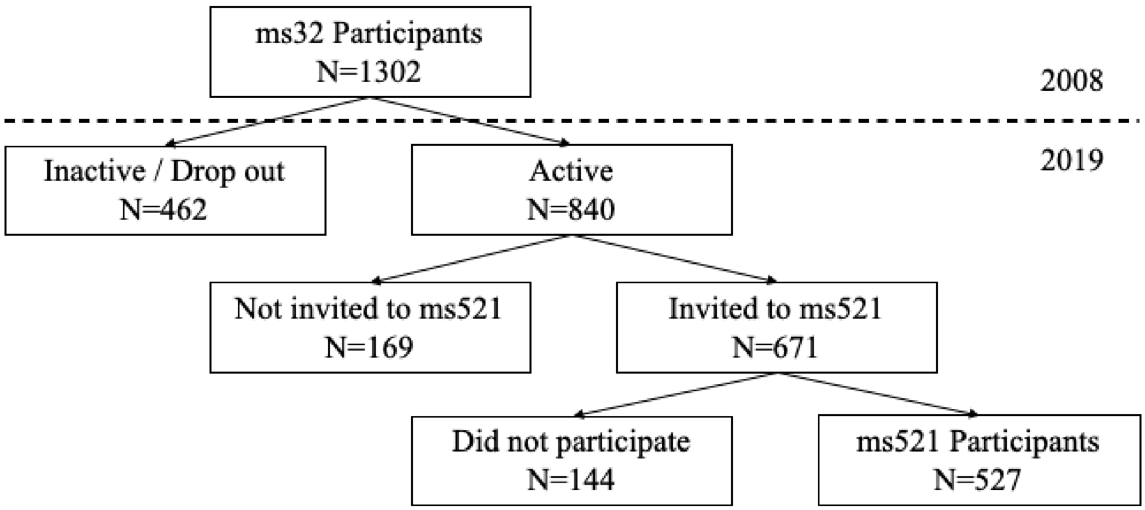
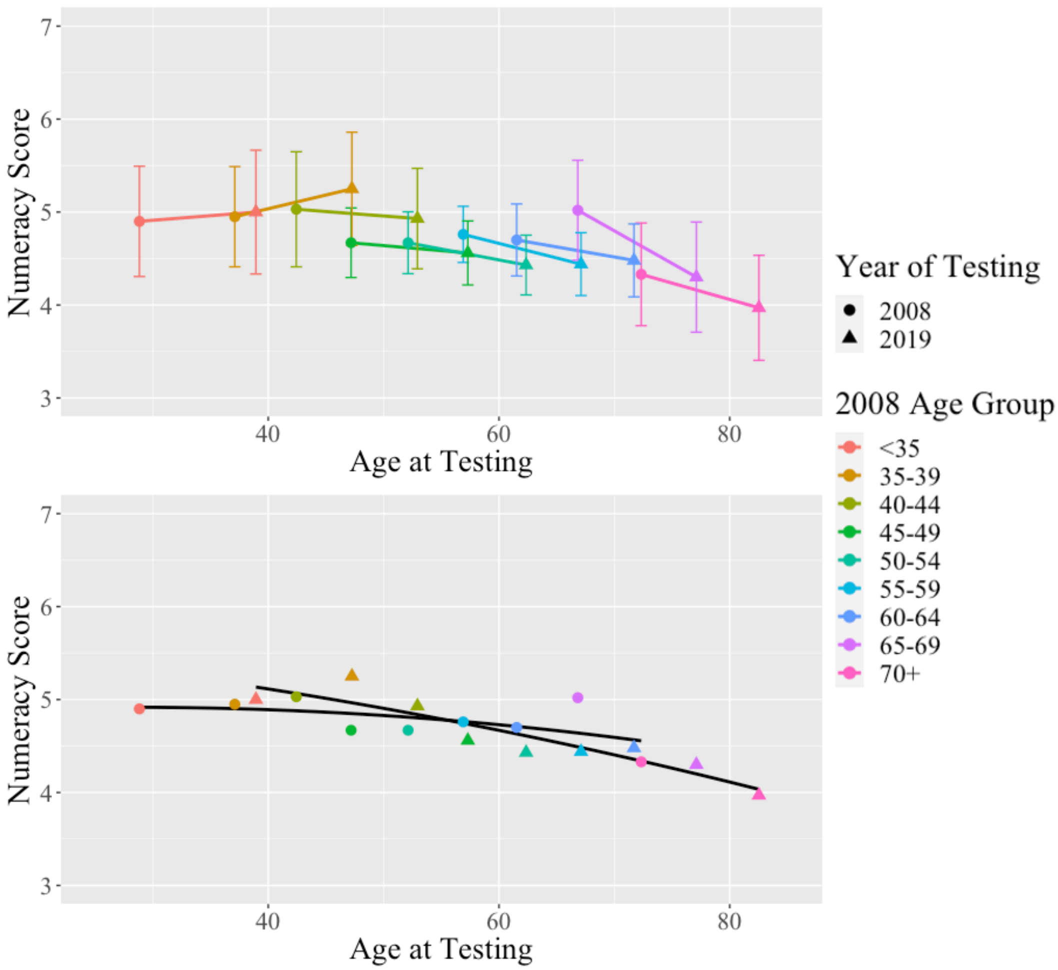


**Figure 2**

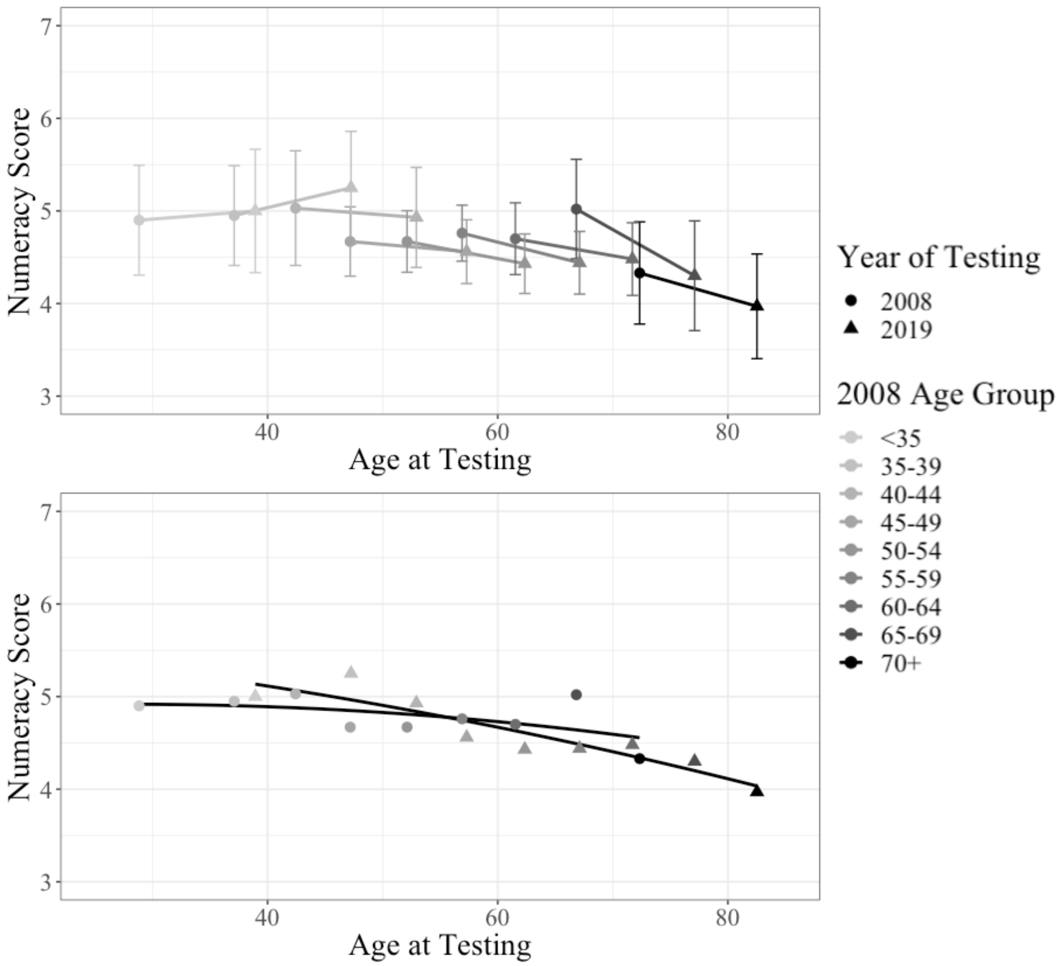
*Longitudinal Trends of Numeracy*




*Note*. Both panels reflect the same data and results. A) Highlights longitudinal relationship between age and numeracy. Shapes of the points indicate year of testing (circle=2008, triangle=2019). Colors (or shades) of points and lines indicate age cohort. Error bars represent 95% confidence intervals. Analyses reported in manuscript include age as a continuous variable. Age cohorts were created for the figure to aid interpretation of results. B) Highlights cross-sectional relationship between age and numeracy. Together, the two curved lines indicate a quadratic trend of age on numeracy at each testing year. The line further to the left represents the 2008 data; the line further to the right represents the 2019 data.

**Figure 2**

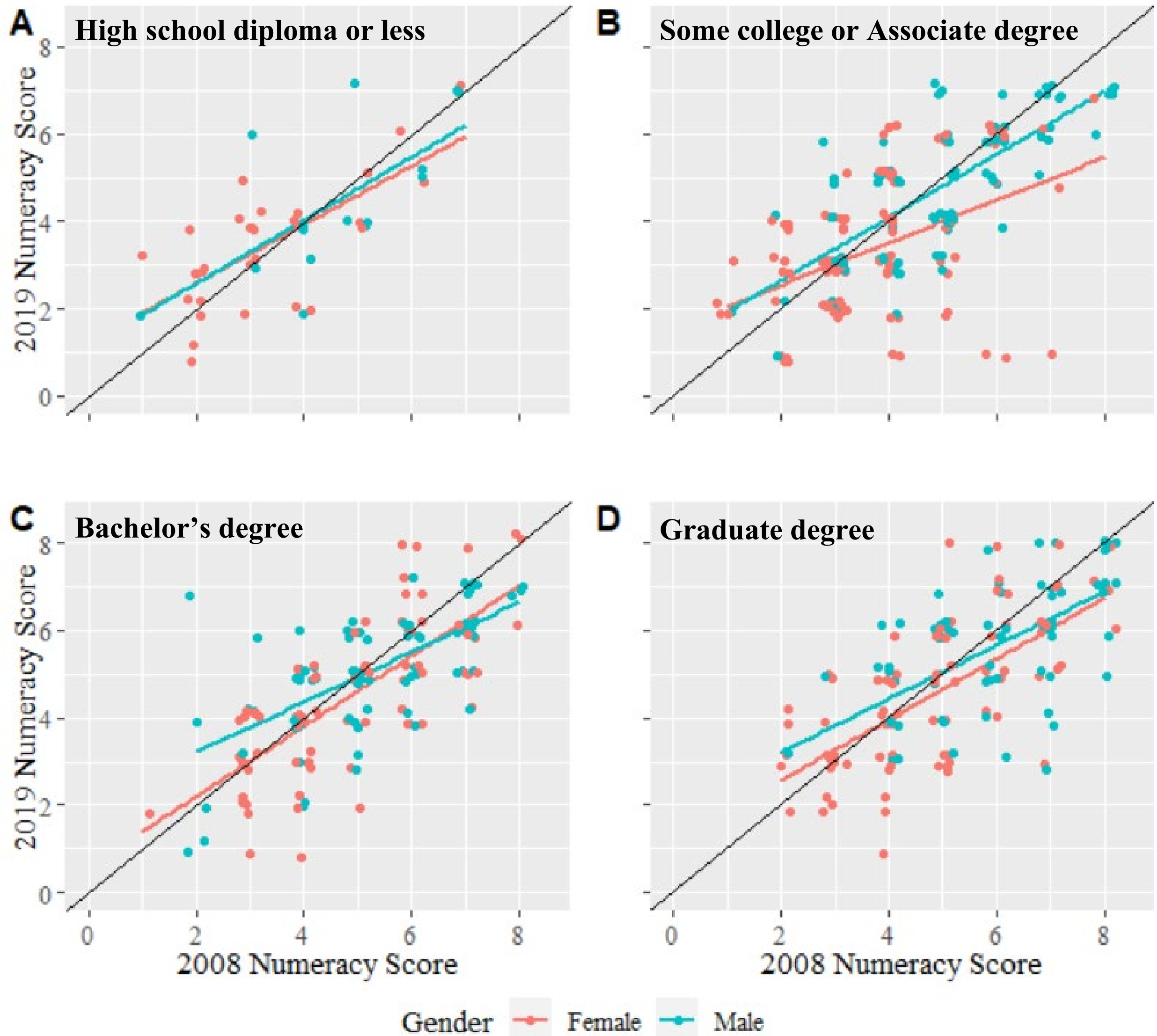
*Longitudinal Trends of Numeracy*




*Note*. Both panels reflect the same data and results. A) Highlights longitudinal relationship between age and numeracy. Shapes of the points indicate year of testing (circle=2008, triangle=2019). Colors (or shades) of points and lines indicate age cohort. Error bars represent 95% confidence intervals. Analyses reported in manuscript include age as a continuous variable. Age cohorts were created for the figure to aid interpretation of results. B) Highlights cross-sectional relationship between age and numeracy. Together, the two curved lines indicate a quadratic trend of age on numeracy at each testing year. The line further to the left represents the 2008 data; the line further to the right represents the 2019 data.

**Figure 3**

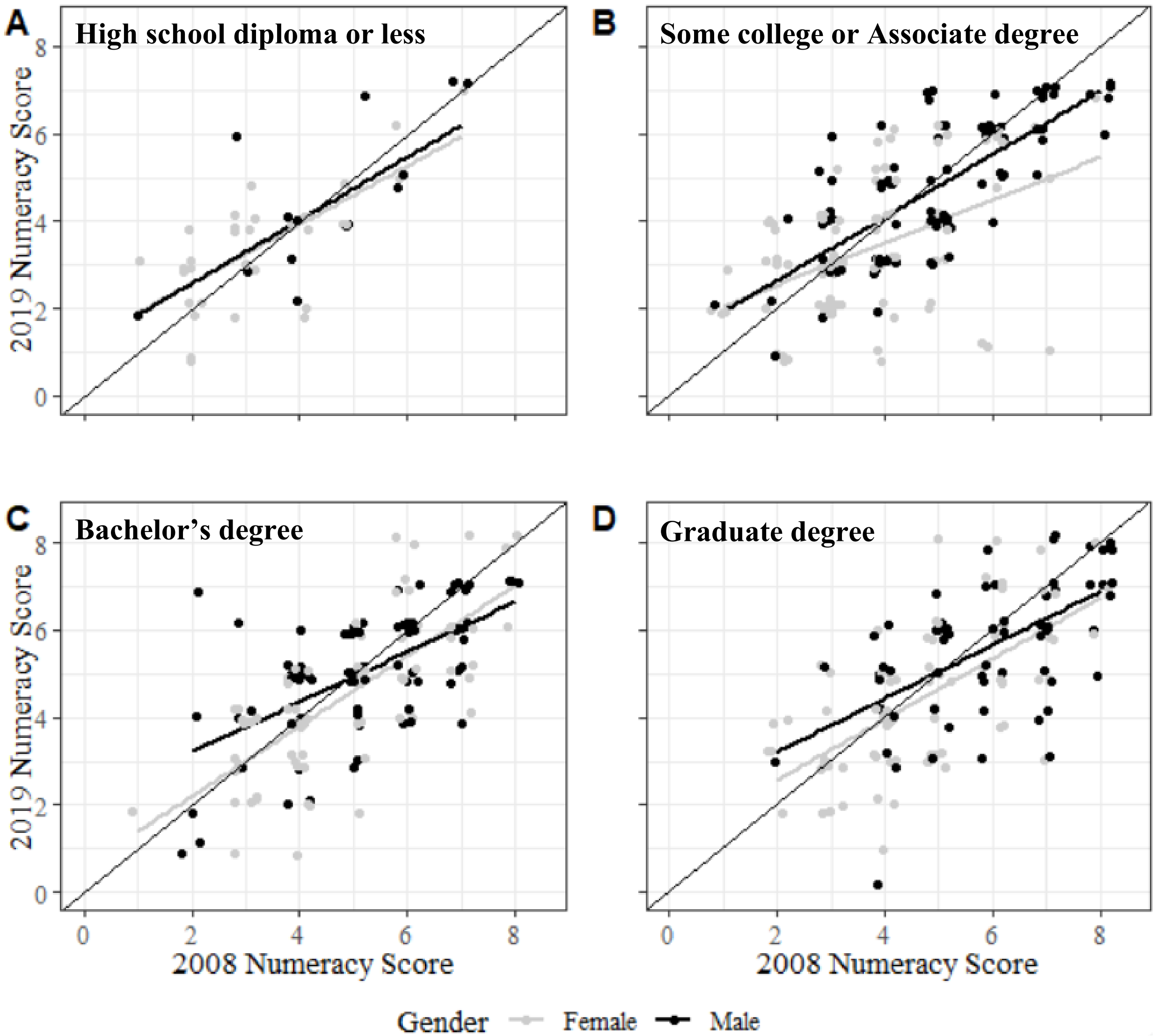
*Effects of Sex and Education on Numeracy*




Colored (or shaded) lines represent sex, separate figures represent different levels of education where A) High school diploma or less, B) Some college or associate degree, C) Bachelor's degree, D) Graduate degree. Solid black lines running from extreme lower left to upper right in each panel represent a reference line at y=x. Points that appear above the line represent participants with higher numeracy scores in 2019 compared to 2008. Points that appear below the line represent participants with lower numeracy scores in 2019 compared to 2008.

**Figure 3**

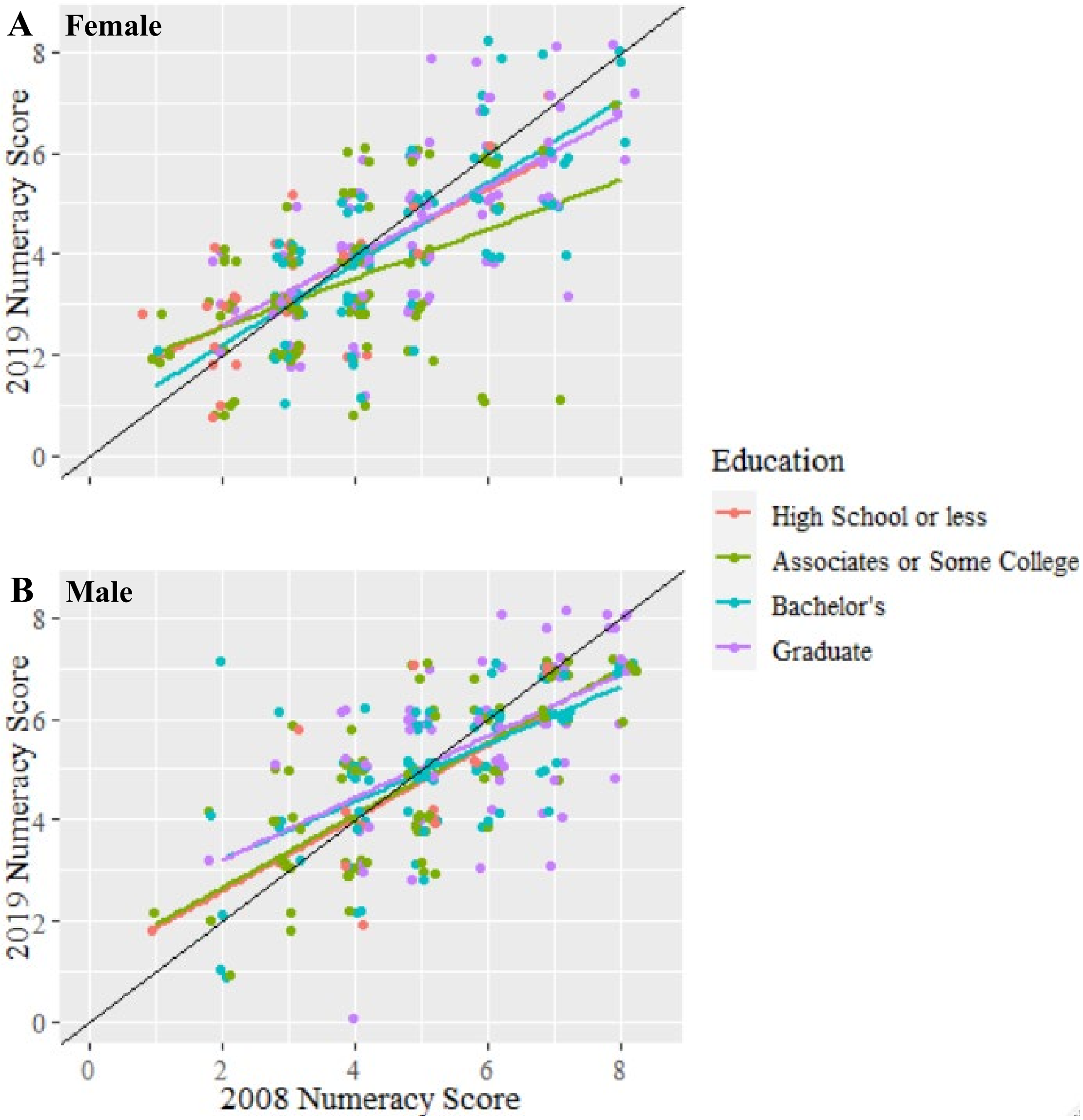
*Effects of Sex and Education on Numeracy*




Colored (or shaded) lines represent sex, separate figures represent different levels of education where A) High school diploma or less, B) Some college or associate degree, C) Bachelor's degree, D) Graduate degree. Solid black lines running from extreme lower left to upper right in each panel represent a reference line at y=x. Points that appear above the line represent participants with higher numeracy scores in 2019 compared to 2008. Points that appear below the line represent participants with lower numeracy scores in 2019 compared to 2008.

**Figure 4**

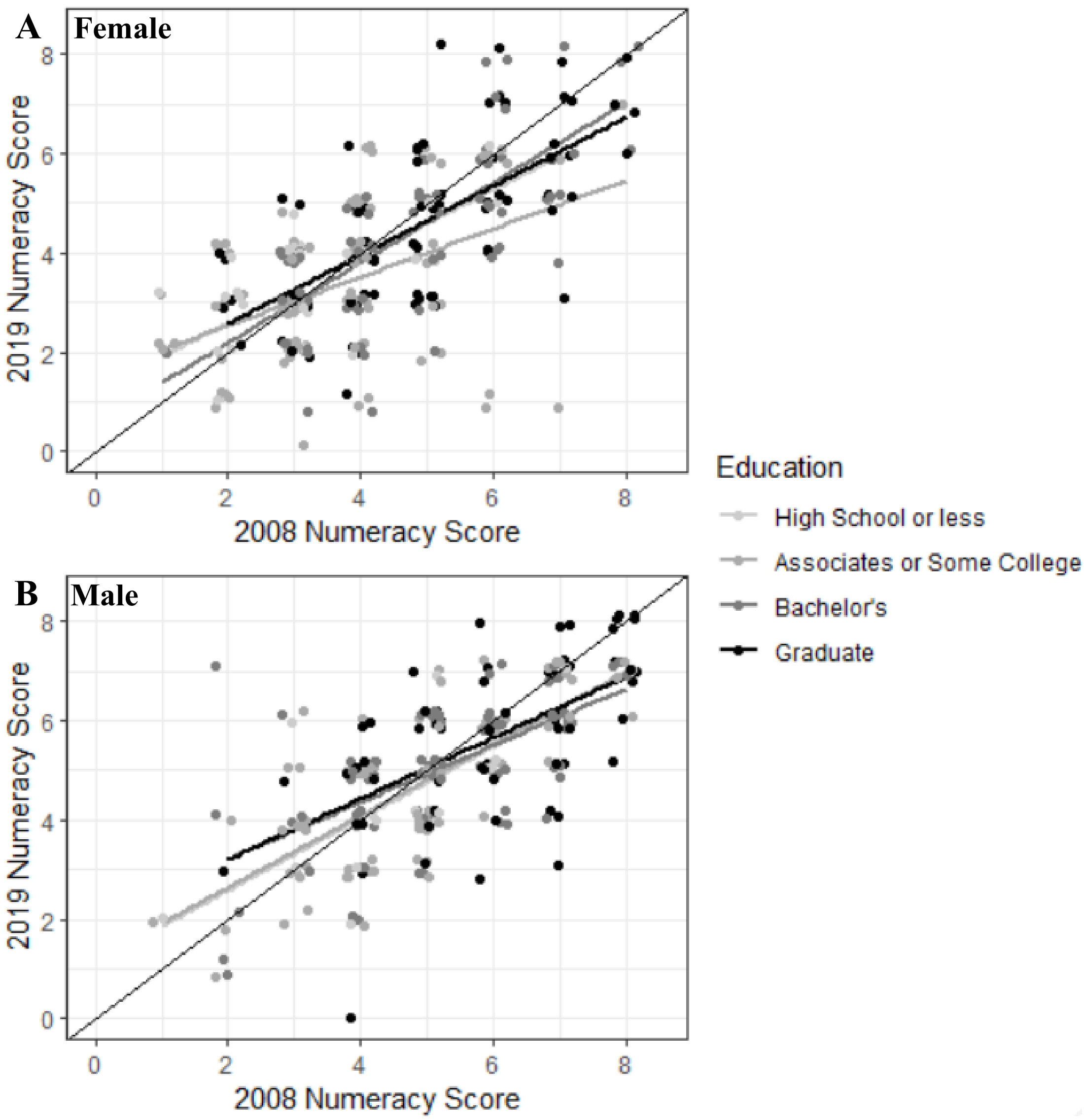
*Effects of sex and education on numeracy*




*Note*. Colored (or shaded) lines represent education, separate figures represent sex. Solid black lines running from lower left to upper right in each panel represent a reference line at y=x. Points that appear above the line represent participants with higher numeracy scores in 2019 compared to 2008. Points that appear below the line represent participants with lower numeracy scores in 2019 compared to 2008.

**Figure 4**

*Effects of sex and education on numeracy*




*Note*. Colored (or shaded) lines represent education, separate figures represent sex. Solid black lines running from lower left to upper right in each panel represent a reference line at y=x. Points that appear above the line represent participants with higher numeracy scores in 2019 compared to 2008. Points that appear below the line represent participants with lower numeracy scores in 2019 compared to 2008.

**Table S1**

*Demographic Variables of Sample in 2008 by Sample Retention.*

| | Not Retained | | Retained | | Comparison | | |
|---|---|---|---|---|---|---|---|
| | $n$ = 606 | | $n$ = 524 | | | | |
| | *M* | *M* | *M* | (*SD*) | *t* | *df* | *p* |
| Age | 53.42 | 15.36 | 53.78 | 10.57 | -0.46 | 1078.1 | .64 |
| Numeracy | 4.17 | 1.76 | 4.74 | 1.68 | -5.55 | 1120.7 | <.001 |
| | *n* | (%) | *n* | (%) | $\chi^2$ | *df* | *p* |
| Male | 286 | 47.2 | 244 | 46.6 | 0.03 | 1 | .86 |
| Married | 398 | 65.7 | 353 | 67.4 | 0.22 | 1 | .64 |
| Income >$75k | 251 | 41.8 | 252 | 48.1 | 4.28 | 1 | .04 |
| Education | | | | | 37.47 | 4 | <.001 |
| <High School | 13 | 2.1 | 2 | 0.4 | | | |
| High School | 111 | 18.3 | 45 | 8.6 | | | |
| Some College or Associate Degree | 216 | 35.6 | 178 | 34.0 | | | |
| Bachelor's Degree | 150 | 24.8 | 156 | 29.8 | | | |
| Graduate Degree | 116 | 19.1 | 143 | 27.3 | | | |

*Note*. All data from 2008 measurement. The "Not Retained" group completed the 2008 survey but either dropped out of the sample or declined to take the 2019 survey. The "Retained" group completed both surveys.

**Table S2**

*Results for Numeracy Items*

| | | Percent Correct | |
|---|---|---|---|
| | Item | 2008 | 2019 |
| 1 | If the chance of getting a disease is 10%, how many people out of 1000 would be expected to get the disease? | 96.4 | 94.3 |
| 2 | If the chance of getting a disease is 20 out of 100, this would be the same as having a _____% chance of getting the disease. | 89.5 | 89.9 |
| 3 | Imagine that we roll a fair, six-sided die 1000 times. Out of 1000 rolls, how many times do you think the die would come up as an even number? | 86.3 | 75.8 |
| 4 | In the BIG BUCKS LOTTERY, the chances of winning a $10.00 prize are 1%. What is your best guess about how many people would win a $10.00 prize if 1000 people each buy a single ticket from BIG BUCKS? | 79.4 | 81.7 |
| 5 | In the ACME PUBLISHING SWEEPSTAKES, the chance of winning a car is 1 in 1000. What percent of tickets of ACME PUBLISHING SWEEPSTAKES win a car? | 43.1 | 39.5 |
| 6 | A bat and a ball cost $1.10 in total. The bat costs $1.00 more than the ball. How much does the ball cost? | 24.8 | 20.8 |
| 7 | In a lake, there is a patch of lily pads. Every day, the patch doubles in size. If it takes 48 days for the patch to cover the entire lake, how long would it take for the patch to cover half of the lake? | 42.9 | 40.3 |

| | | | |
|---|---|---|---|
| 8 | Suppose you have a close friend who has a lump in her breast and must have a mammogram. Of 100 women like her, 10 of them actually have a malignant tumor and 90 of them do not…* | 11.8 | 8.2 |

Note: *See Peters (2020) for full text of item.

**Table S3**

*Correlation Matrix for Model Variables*

| | | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|
| 1 | Numeracy 2008 | | | | | | |
| 2 | Numeracy 2019 | .70*** | | | | | |
| 3 | Age | -.04 | -.13** | | | | |
| 4 | Male | .29*** | .31*** | .12** | | | |
| 5 | Married | .12** | .14** | -.09* | .15*** | | |
| 6 | Income >75k | .20*** | .22*** | -.15*** | .09* | .34*** | |
| 7 | Education | .32*** | .27*** | -.01 | .03 | < -.01 | .32*** |

*Note*. Values reflect responses from the 2019 survey, except for 2008 numeracy scores. Correlations reported as Pearson's $r$ except for the last row reported as Spearman's $\rho$ for correlations with the ordinal education variable. The education variable is coded as four categories in ascending order from high school diploma, some college or Associate degree, Bachelor's degree, to Graduate degree. * $p < .05$ ** $p < .01$ *** $p < .001$