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Education Does Not Slow Cognitive Decline with Aging: 12-Year Evidence from the Victoria Longitudinal Study

Laura B. Zahodne,[1] M. Maria Glymour,[2] Catharine Sparks,[3] Daniel Bontempo,[4] Roger A. Dixon,[5]
Stuart W.S. MacDonald,[3] AND Jennifer J. Manly[6]

[1]Department of Clinical & Health Psychology, University of Florida, Gainesville, Florida
[2]Department of Society, Human Development, and Health, Harvard School of Public Health, Boston, Massachusetts
[3]Department of Psychology, University of Victoria, Victoria, British Columbia
[4]Center for Biobehavioral Neurosciences in Communication Disorders, University of Kansas, Lawrence, Kansas
[5]Department of Psychology, University of Alberta, Edmonton, Alberta
[6]Gertrude H. Sergievsky Center, Taub Institute for Research on Alzheimer's Disease and The Aging Brain, and Department of Neurology, Columbia University Medical Center, New York, New York

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Abstract

Although the relationship between education and cognitive status is well-known, evidence regarding whether education moderates the trajectory of cognitive change in late life is conflicting. Early studies suggested that higher levels of education attenuate cognitive decline. More recent studies using improved longitudinal methods have not found that education moderates decline. Fewer studies have explored whether education exerts different effects on longitudinal changes within different cognitive domains. In the present study, we analyzed data from 1014 participants in the Victoria Longitudinal Study to examine the effects of education on composite scores reflecting verbal processing speed, working memory, verbal fluency, and verbal episodic memory. Using linear growth models adjusted for age at enrollment (range, 54–95 years) and gender, we found that years of education (range, 6–20 years) was strongly related to cognitive level in all domains, particularly verbal fluency. However, education was not related to rates of change over time for any cognitive domain. Results were similar in individuals older or younger than 70 at baseline, and when education was dichotomized to reflect high or low attainment. In this large longitudinal cohort, education was related to cognitive performance but unrelated to cognitive decline, supporting the hypothesis of passive cognitive reserve with aging. (*JINS*, 2011, *17*, 1039–1046)

Keywords: Cognitive reserve, Memory, Short term, Mental recall, Language, Reaction time

INTRODUCTION

The hypothesis of cognitive reserve asserts that older individuals with greater experiential resources exhibit better cognitive functioning and are able to tolerate higher levels of brain pathology before displaying clinical symptoms (Scarmeas & Stern, 2004; Stern, Alexander, Prohovnik, & Mayeux, 1992). One of the most well-established proxy measures of reserve capacity in the elderly is educational attainment, which is thought to reflect more effective use of brain networks or cognitive paradigms (Stern, 2009). In line with the hypothesis of cognitive reserve, many studies in both North America and Europe have suggested that educational attainment is associated with better cognitive performance and reduced risk for cognitive impairment and dementia in late life (Brayne & Calloway, 1990; De Ronchi et al., 1998; Evans et al., 1997; Fratiglioni et al., 1991; Gatz et al., 2001; Katzman, 1993; Launer, Dinkgreve, Jonker, Hooijer, & Lindeboom, 1993; Mortel, Meyer, Herod, & Thornby, 1995; Prencipe et al., 1996; Raiha, Kaprio, Koskenvuo, Rajala, & Sourander, 1998; Stern, 2007; Stern et al., 1994).

Results with respect to whether educational attainment moderates the trajectory of age-related cognitive decline have been mixed (Antsey & Christensen, 2000). Several studies reported that educational attainment attenuates cognitive decline in samples of non-demented, older adults (Albert et al., 1995; Arbuckle, Maag, Pushkar, & Chaikelson, 1998; Bosma et al., 2003; Butler, Ashford, & Snowdon, 1996; Evans et al., 1993; Farmer, Kittner, Rae, Bartko, & Regier, 1995; Lyketsos, Chen, & Anthony, 1999). Such results support

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Correspondence and reprint requests to: Laura B. Zahodne, Department of Clinical & Health Psychology, University of Florida, PO Box 100165, Gainesville, Florida 32610. E-mail: lzahodne@phhp.ufl.edu

an *active cognitive reserve* hypothesis in which education promotes more efficient cognitive processing and use of brain networks, which results in smaller cognitive declines in the face of neuropathology, effectively *slowing* the process of age-related cognitive decline (Stern, 2002).

These findings have been challenged by several subsequent studies that used more sophisticated statistical methodologies (Christensen et al., 2001; Glymour, Weuve, Berkman, Kawachi, & Robins, 2005; Karlamangla et al., 2009; Tucker-Drob, Johnson, & Jones, 2009; Van Dijk, Van Gerven, Van Boxtel, Van der Elst, & Jolles, 2008; Wilson et al., 2009). These reports support a *passive cognitive reserve* hypothesis, in which individuals with greater educational attainment continue to perform at a higher level than similarly aged individuals with less education, but decline at a similar rate (Stern, 2002). Still other studies have found that educational attainment accelerated cognitive decline in populations with confirmed Alzheimer's disease (Andel, Vigen, Mack, Clark, & Gatz, 2006; Stern, Albert, Tang, & Tsai, 1999). These results may support a *compensation* hypothesis, in which intact domains compensate for declines in other cognitive abilities until they, too, begin to deteriorate, leading the way for more rapid decline (Christensen et al., 1997; Reuter-Lorenz & Mikels, 2006).

Likely explanations for these discrepant findings relate to cohort differences and/or differing statistical methodologies. For example, some studies used regression-based techniques, while others used multilevel or structural equation modeling frameworks. Also, some studies adjusted models for baseline cognitive status, while others did not (see Glymour et al., 2005). Another possible contributor to discrepant findings is that education may exert different effects on the trajectories of different cognitive domains. For example, Alley, Suthers, and Crimmins (2007) used growth curve modeling to show that higher levels of education attenuated decline in overall global cognition, accelerated decline in verbal memory, and were unrelated to decline in working memory. Taken together, the aforementioned studies demonstrate that the effects of education on the rate of cognitive aging have not yet been fully established. The present study sought to contribute to this highly conflicting literature by examining the influence of educational attainment on trajectories of four cognitive abilities (i.e., processing speed, working memory, verbal fluency, and verbal episodic memory) over 12 years in a large sample of initially healthy, community-dwelling older adults who participated in the Victoria Longitudinal Study (VLS).

METHOD

Participants

The VLS included adult residents of greater Victoria, British Columbia, between 54 and 95 years of age without serious health conditions who were community-dwelling at study entry. Participants were recruited using newspaper and television advertisements and direct appeals to community groups (newsletters and oral presentations). Inclusion criteria were: (a) self-reported good health without recent illness such as stroke or heart attack; (b) ability to read newspaper-size print, hear normal spoken conversation, and produce written responses; and (c) ability to travel to testing site. The VLS followed a longitudinal-sequential design: the original cohort sample was enrolled in 1986–1987 and interviewed approximately every three years; in year 6, a second cohort was enrolled and followed on the same re-interview schedule as the original cohort (Baltes, Cornelius, & Nesselroade, 1979; Dixon & De Frias, 2004). All participants were followed up at approximate 3-year intervals (see Dixon & De Frias, 2004, for a description of the design and measures of the VLS). Data were obtained in compliance with the Helsinki Declaration (http://www.wma.net/en/20activities/10ethics/10helsinki/index.html).

The present study included data available from 1014 individuals (99.3% Caucasian) from VLS Sample 1 ($N = 484$; waves 1–5; >12 years follow-up) and Sample 2 ($N = 530$; Waves 1–3; >6 years follow-up). Sample 1 comprised a greater proportion of males (41% *vs.* 33%; $\chi^2(1) = 6.39$; $p = .01$) and evidenced a lower level of education, on average (13.4 *vs.* 14.7 years; $t(998) = -7.02$; $p < .001$). There were no significant differences between Samples 1 and 2 with regard to age at study entry.

Independent Variables

Age, gender, and education, as years of completed schooling, were self-reported at baseline. Education values greater than 20 were top-coded as 20, reflecting completion of a doctoral degree. In primary models, we considered education as a continuous variable. In supplementary models, we examined results dichotomizing education at 13 or fewer years versus 14+ years, as 13 years represents the equivalent of high-school completion for students from these cohorts in most of Canada. Finally, we considered an alternative indicator of cognitive reserve with a vocabulary test (correlated with crystallized intelligence) completed at the baseline occasion (Hultsch, Hertzog, Dixon, & Small, 1998). In supplementary models, performance on this vocabulary test was included as a continuous primary predictor, instead of education.

Cognitive Outcomes

Composite scores were created for each cognitive domain of interest. Previous studies of VLS data have used similarly constructed composites to index verbal processing speed and episodic memory based on confirmatory factor analysis (Hertzog, Dixon, Hultsch, & MacDonald, 2003; Small, Dixon, McArdle, & Grimm, under revision). Briefly, the verbal processing speed composite comprised two tests: lexical decision (speeded word/non-word; Baddeley, Logie, Nimmo-Smith, & Brereton, 1985) and sentence verification (speeded plausible/implausible sentence; Palmer, MacLeod, Hunt, & Davidson, 1985). The working memory composite comprised three tests: sentence construction (Hultsch et al., 1998) and two span tests (listening and computation; Salthouse & Babcock, 1991). The verbal fluency composite comprised three written fluency tests from the Kit of Factor Referenced Cognitive

Tests (Ekstrom, French, Harman, & Dermen, 1976): controlled associates, opposites, and figures of speech. The verbal episodic memory composite comprised immediate recall scores from two word list learning and two story memory tasks (Dixon et al., 2004).

For all measures, raw scores were standardized to *Z*-score metric using means and standard deviations derived from baseline scores on the respective test. Composite scores were computed by averaging standardized scores on the tests within each domain. Reliability estimates of all tests were established in previous studies and ranged from acceptable to very good (Hultsch et al., 1998). Specifically, split-half reliability of the verbal processing speed tasks computed using the Spearman-Brown formula ranged from .93 to .95 for lexical decision and .96 to .96 for sentence verification (Hultsch et al., 1998). With regard to the three working memory tasks, split-half reliability calculated using the Spearman-Brown formula was reported to be .90 for computation span and .86 for listening span (Salthouse & Babcock, 1991). Reliability of the sentence construction task was estimated to be .67 after applying the Spearman-Brown formula to random item pairs (Hultsch et al., 1998). Reliability estimates of the verbal fluency tasks were calculated in groups of young adults and were reported in the manual for the Kit of Factor Referenced Cognitive Tests as ranging from .81 to .83 across the three tests (Ekstrom et al., 1976). With regard to measures of episodic memory, average correlations between pairs of lists used in the word list learning task ranged from .66 to .73, and average correlations between pairs of stories used in the story memory task ranged from .71 to .76 (Hultsch et al., 1998).

Statistical Analyses

Modeling was carried out using Mplus 6.0 maximum likelihood (MLR) estimation. First, unconditional growth models were built in which the linear and quadratic effects of time were examined separately for each of the four cognitive composites. Nested model comparisons using the chi square test were used to evaluate whether including quadratic time improved model fit. Next, age at baseline (centered at age 70), self-reported education at baseline (in years), and gender were added to the model as continuous (age and education) or dichotomous (gender) variables. As described above, we also examined supplementary models in which education was either dichotomized to reflect high and low attainment or replaced with a baseline vocabulary measure. We also examined primary models separately for younger (<70 years) and older (≥ 70) participants. In all models, time was parameterized with time scores representing years since study entry. All models were estimated with random intercepts and random slopes for time.

Attrition and Missing Data

Collapsing across samples 1 and 2, attrition rates in the present dataset were as follows: wave 1 to 2: 27.6%; wave 2 to 3: 21.1%; wave 3 to 4: 28.2%; and wave 4 to 5: 30.5%. Data for at least one cognitive domain at all five waves were available for 28.5% participants (38% male). Whereas the range of education within this subset (i.e., 7 to 20 years) was similar to the greater sample, the range of age (i.e., 55 to 83 years) was more restricted. On average, participants with five waves of data available were younger (65.40 *vs.* 70.21 years; $t(682.407) = 11.880$; $p < .001$) and reported higher educational attainment (14.49 *vs.* 13.94 years; $t(998) = -2.610$; $p < .01$). To explore whether selective attrition reduced our ability to detect an effect of education on cognitive trajectories, we re-ran primary models using only a subset of participants with five waves of data (N = 289) who did not differ from participants without five waves of data (N = 675) in terms of education ($p > .1$). The pattern of results obtained with the subsample (N = 964) was identical to that obtained with the full sample.

Given that attrition in this study was related to age and education, missing data in the present study did not meet the definition of "missing completely at random." For this reason our analyses are conditioned on age and education, and we use full information maximum likelihood (FIML) estimation. Unlike listwise or pairwise deletion, FIML produces unbiased parameter estimates and preserves the overall power of the analysis under the more plausible "missing at random" assumption (Schafer, 1997; Wothke, 1999). FIML uses the entire observed data matrix to estimate parameters with missing data. FIML procedures are advantageous because they allow inclusion of all observations, even for participants who did not complete all five assessments and are thought to provide better treatment of missing data than traditional approaches such as mean substitution and listwise deletion (Schafer & Graham, 2002).

RESULTS

The sample comprised 642 females and 372 males who ranged in age from 54 to 95 years at baseline (mean = 68.8 years; $SD = 6.8$). This under-representation of males (37%) persisted throughout the study period, as only 34% of participants who participated in all five study visits were male. At study entry, participants reported attaining 6 to 20 years of education (mean = 14.1 years; $SD = 3.1$). There was a significant negative correlation between age and educational attainment ($r = -.117$; $p < .001$). Compared to women, men reported significantly higher levels of education (14.5 *vs.* 13.9 years; $t(683.420) = -3.343$; $p = .001$) at study entry. This difference in education level between men and women persisted throughout the study period, as men who participated in all five follow-up visits also reported significantly higher levels of education than women who completed all five waves (14.9 *vs.* 14.2 years; $t(659) = -2.828$; $p = .005$). Men with incomplete data also reported more education than women with incomplete data (13.9 *vs.* 13.0; $t(255.929) = -2.408$; $p = .017$). There was no difference in age at study entry between men and women in the whole sample or within the subgroup of participants with complete data.

Unconditional Growth Models

Unconditional models for each composite containing only linear slopes were compared to corresponding models with both linear and quadratic slopes. For verbal fluency, verbal episodic memory, and working memory, models that included both fixed and random effects of a quadratic slope did not converge. Thus, the model used in nested model comparisons for these three domains included only quadratic fixed effects. Adding quadratic change failed to improve model fit for any of these three cognitive domains. Thus, subsequent models included only linear slopes for verbal fluency, verbal episodic memory, and working memory. For processing speed, including a quadratic slope improved model fit ($\Delta\chi^2(4) = -43.884$; $p < .001$).

As shown in Table 1, significant linear decline over time was evident for verbal fluency, verbal episodic memory, and working memory. Comparing across domains, scores declined approximately 2–4% of one standard deviation (*SD*) per year. The fastest decline (3.5% *SD* per year) occurred in the working memory domain, and the slowest decline (1.5% *SD* per year) occurred in the verbal fluency domain. Significant positive quadratic (U-shaped) change was evident for processing speed, indicating slight improvements in speed (lower scores) between the first and second assessment waves, but slowing of performance (higher scores) thereafter. There was significant individual variation in cognitive ability in all four domains at baseline. Random effects in slopes were significant for working memory ($p = .011$) and verbal episodic memory ($p < .001$). Intercepts and slopes were not significantly correlated within any domain.

Effects of Age, Gender, and Education on Cognitive Performance and Decline

Next, the three independent variables were added simultaneously to the best-fitting models described above. The conditional model for processing speed would not converge without constraining the random variance of the quadratic slope to 0. To obtain estimates of the effects of interest (i.e., regression paths between the independent variables and cognitive change), the quadratic slope was removed from the model. The fixed effect of the linear slope in the unconditional model that did not include the quadratic slope was positive and significant (0.029; $p < .001$), which reflects increasing scores (slowing) of approximately 3% *SD* per year. Simple correlations between the cognitive variables and demographic variables of age and education are shown in Table 2.

Controlling for the other independent variables, older age at baseline was associated with worse cognitive performance in all four domains (Table 3). Age appeared to exert the greatest effect on processing speed, as each year of age greater than 70 reduced performance by nearly 5% *SD*. Age appeared to exert the smallest effect on verbal fluency, as each year of age greater than 70 reduced performance by only 2.3% *SD*. Older age was also associated with accelerated decline in all four domains.

Table 1. Fixed effects from the four separate unconditional growth models

Domain	Estimate	*SE*	*p*
Processing speed			
Intercept/baseline score	−0.014	0.030	.644
Linear annual rate of change	−0.011	0.008	.146
Quadratic annual rate of change	0.003	0.000	<.001
Working memory			
Intercept/baseline score	0.039	0.029	.182
Linear annual rate of change	−0.035	0.004	<.001
Verbal fluency			
Intercept/baseline score	0.028	0.026	.282
Linear annual rate of change	−0.015	0.003	<.001
Verbal episodic memory			
Intercept/baseline score	0.027	0.026	.312
Linear annual rate of change	−0.028	0.003	<.001

Note. SE = standard error.

Controlling for the other independent variables, gender was not associated with cognitive performance in processing speed, working memory, or verbal fluency. Gender was associated with poorer verbal episodic memory such that males performed approximately one-third *SD* worse on this composite, as compared to females. Gender was unrelated to the rate of decline in any domain.

Controlling for the other independent variables, higher education was associated with better performance in all four cognitive domains. This beneficial effect of education appeared to be greatest in the verbal fluency domain, for which each year of education was associated with higher scores of nearly 11% *SD*. The influence of education on cognitive performance was smallest for the processing speed domain, for which each year of education was associated with higher scores of only 3.7% *SD*. Education was unrelated to the rate of decline in any domain, which can be visualized as parallel model-predicted trajectories in Figure 1. The pattern of results did not change when the education variable

Table 2. Zero-order correlations between cognitive variables and age and education

Parameter	Age	Education
Processing Speed		
Wave 1	.354 **	−.146 **
Wave 5 – Wave 1	.204 **	.071 *ns*
Working Memory		
Wave 1	−.337 **	.242 **
Wave 5 – Wave 1	−.005 *ns*	.046 *ns*
Verbal Fluency		
Wave 1	−.239 **	.414 **
Wave 5 – Wave 1	−.294 **	−.014 *ns*
Verbal Episodic Memory		
Wave 1	−.366 **	.310 **
Wave 5 – Wave 1	−.222 *	.128 *ns*

* $p < .05$.
** $p < .001$.

Table 3. Covariate effects in the four separate conditional models

	Intercept/baseline score			Annual rate of change		
Domain	Estimate	*SE*	*p*	Estimate	*SE*	*P*
Processing speed						
Age	0.048	0.005	<.001	0.004	0.001	<.001
Gender	−0.029	0.054	.595	0.003	0.006	.674
Education	−0.037	0.009	.001	0.000	0.001	.649
Working memory						
Age	−0.036	0.004	<.001	−0.001	0.000	.002
Gender	−0.025	0.057	.654	0.008	0.006	.184
Education	0.059	0.009	<.001	0.000	0.001	.984
Verbal fluency						
Age	−0.023	0.003	<.001	−0.002	0.000	<.001
Gender	−0.066	0.048	.163	−0.003	0.005	.451
Education	0.108	0.007	<.001	0.001	0.001	.251
Verbal episodic memory						
Age	−0.042	0.004	<.001	−0.003	0.000	<.001
Gender	−0.331	0.049	<.001	0.004	0.005	.411
Education	0.075	0.008	<.001	−0.001	0.001	.358

Note. SE = standard error.

was dichotomized at the sample median or split into tertiles (Table 4). The pattern of results did not change in conditional models that did not control for age or gender.

Because younger individuals in the present sample reported higher levels of education than did older individuals, we examined the possibility that cohort effects masked association between education and cognitive decline. First, we ran all four conditional models excluding the covariate of baseline age. We also ran these models separately in subgroups of younger (<70 years) and older (≥70 years) adults. In all cases, we failed to find an association between education and change on any of the cognitive composites (Table 4). We also explored the potential for an alternative indicator of cognitive reserve (i.e., crystallized intelligence) to moderate cognitive decline. Crystallized intelligence was indexed with scores on a vocabulary test at baseline, which was significantly correlated with education ($r = .341$; $p < .001$). We ran the four conditional models using baseline vocabulary in place of the education variable and found no differences in the pattern of results. That is, baseline vocabulary was positively associated with intercepts in all four conditional models, but unrelated to slopes.

DISCUSSION

The present study contributes to the debate regarding a potential influence of educational attainment on the trajectory of cognitive aging by reporting results from longitudinal

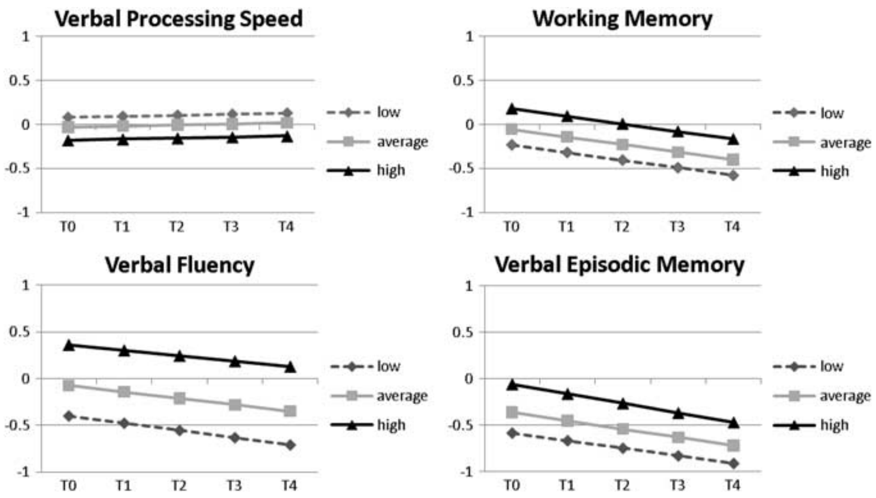

Fig. 1. Model-predicted trajectories over 12 years for individuals with low, average, and high educational attainment. *Note:* Increase in timed values indicates a slowing of processing speed. Time scores along the x-axis represent approximately 3-year intervals.

Table 4. Effects of education (or crystallized intelligence) on linear slopes in the supplementary models

	Verbal processing speed			Working memory			Verbal fluency			Verbal episodic memory		
Model	Estimate	*SE*	*p*	Estimate	*SE*	*p*	Estimate	*SE*	*p*	Estimate	*SE*	*p*
Dichotomized	0.004	0.006	.508	0.002	0.006	.704	0.008	0.005	.103	−0.005	0.005	.375
Trichotomized	0.001	0.004	.854	0.001	0.004	.806	0.006	0.003	.064	−0.006	0.004	.116
Older (≥70) cohort	0.001	0.004	.853	0.000	0.002	.865	0.001	0.002	.478	−0.002	0.002	.327
Younger (<70) cohort	0.000	0.001	.975	0.000	0.001	.663	0.001	0.001	.352	0.000	0.001	.624
Crystallized intelligence	0.000	0.000	.517	0.000	0.000	.788	0.000	0.000	.666	0.001	0.000	.117

Note. SE = standard error.

analyses featuring (a) a long-term follow-up period (i.e., 12 years) for (b) a large sample covering a broad, 40-year band of older adults on (c) specific cognitive domains. In this Canadian sample, education was related to the cognitive abilities of processing speed, working memory, verbal fluency, and verbal episodic memory, but we did not find evidence that educational attainment moderates declines in any of these domains. These results support a passive cognitive reserve hypothesis, in which individuals with greater educational attainment continue to perform at a higher level compared to similarly aged individuals with less education, but decline at a similar rate (Stern, 2002).

These findings are consistent with and extend several recent studies that observed no moderating effect of education on cognitive decline with aging. Applying longitudinal structural equation modeling to data obtained through the Advanced Cognitive Training for Independent and Vital Elderly (ACTIVE) study, Tucker-Drob et al. (2009) reported that education did not moderate the trajectories of reasoning or processing speed over a 5-year period. Using both latent growth curve models and more traditional regression, Christensen et al. (2001) found that education was not related to change in crystallized intelligence, memory, cognitive speed, or global cognition over 8 years in the Canberra longitudinal study. Reporting 6-year follow-up data from the Maastricht aging study, Van Dijk et al. (2008) reported no significant time by education interaction for individual cognitive tests assessing learning and memory, interference control, set shifting, fluency, mental speed, or global cognition.

Many previous studies adjusted for baseline performance in their analyses, which could account for positive results, particulary if only two timepoints and/or measures with low reliability were used. Conditioning on baseline status can be carried out by using regression adjustment, stratification, restriction, or matching (Glymour et al., 2005). Briefly, the following two baseline adjusted regression models, in which Y_1 represents cognitive score at time 1 and Y_2 represents cognitive score at time 2, provide identical coefficient estimates for education (i.e., $\alpha_1 = \beta_1$):

$$E(Y_2) = \beta_0 + \beta_1{}^* \text{ Education} + \beta_2{}^* Y_1$$

$$E(Y_2 - Y_1) = \alpha_0 + \alpha_1{}^* \text{ Education} + \alpha_2{}^* Y_1$$

Consider the common situation in which: Y_1 is a measure of a latent variable C_1; Y_1 is subject to some measurement error or instability (e.g., reliability is imperfect), and education is highly correlated with C_1, the baseline cognitive function. In this case, β_1 is biased toward the association between education and C_1 (the cross-sectional association). Under these assumptions, neither regression equation above can generally provide an unbiased estimate of the effect of education on change in cognition, even if other assumptions (e.g., no confounding due to an unmeasured variable), are fulfilled. This result has previously been proven (Glymour et al., 2005; Yanez, Kronmal, & Shemanski, 1998) and illustrated in applied examples with respect to education and cognitive aging (Dugravot et al., 2009; Glymour et al., 2005). Intuitively, the bias occurs because adjusting for baseline Y_1 score implicitly compares high and low education individuals with the same Y_1 value. In such a comparison, it is likely that either the highly educated individual's Y_1 reflects a negative random error, or the less educated individual's Y_1 reflects a positive random error. At the Y_2 assessment, the less educated individual is likely to "regress" to his or her population mean, appearing to decline compared to the highly educated individual. This is a special case of "regression to the mean," the bias that arises when observing change in a subgroup of people selected specifically for high (or specifically for low) performance. Although this phrase is more commonly applied when the selection was based on defining a specific threshold of baseline performance for inclusion in the study, regression adjustment for the baseline score induces a similar phenomenon.

In one review of longitudinal studies of education and cognitive change, 12 of the 14 available studies reported a benefit of education (Antsey & Christensen, 2000). Of these, eight studies had explicitly conditioned on baseline performance. Because of the strong relationship between education and baseline cognitive status, it is likely that at least some of these studies suffered from the statistical artifact described above. That is, conditioning on the baseline measure could have produced biased effect estimates and the potential for a spurious correlation between the exposure variable (i.e., education) and change on a measure since the exposure variable is known to predict baseline level of the measure. Additionally, when cognitive assessments with low reliability are used, such as relatively crude cognitive screens, this bias can be much larger than any plausible causal effect of education on rate of cognitive change (Yanez et al., 1998). It should be noted that previous studies, including those reviewed by Antsey and Christensen (2000), differ in their potential susceptibility to this artifact. For example, those with more than two occasions of measurement and those that used more reliable measures are relatively less vulnerable. Our study advances on prior work by carefully modeling cognitive performance with composites rather than individual tests to improve measurement reliability, using unbiased longitudinal growth models, evaluating long-term cognitive changes, and demonstrating the consistency of results across theoretically distinct (albeit highly correlated) cognitive domains.

Limitations of the present study include under-representation of males (36.7%) and non-Caucasians (0.7%). It should be noted that analyses controlled for sex, which was unrelated to rates of change in any cognitive domain. Another important limitation lies in the relatively high mean educational attainment in the sample. Lyketsos et al. (1999) have highlighted the general lack of understanding regarding a potential incremental association between education and cognitive decline. They assert that individuals with the lowest levels of education may experience the greatest declines, whereas additional education beyond 9 years may not confer further attenuation of decline. Because the present sample included only a very small subset of individuals (3%) with fewer than 9 years of education, we were unable to fully evaluate this issue. However, the pattern of results did not change when the education variable was dichotomized at the sample median or split into tertiles. From these data, we can conclude that in this relatively well-educated sample (mean = 14.1 years), years of education did not appear to moderate cognitive trajectories. Future studies are needed to more fully examine the possibility of steeper decline among older adults with very low educational attainment.

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