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Article

The role of literacy in the association between educational attainment and depressive symptoms

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ABSTRACT

There is a consistent association between education and depressive symptoms, but research on the mechanisms to explain this association remains limited. No study has formally evaluated the extent to which the association between education and depressive symptoms is mediated through a foundational skill such as literacy. Inverse odds ratio weighting (IORW) was used to estimate total, natural direct, and natural indirect effects in examining literacy as a mediator of the association between education and depressive symptoms. Health and Retirement Study participants born in the U.S. between 1900 and 1947 were interviewed biennially for up to 12 years (N = 16,718). Literacy was assessed with a brief vocabulary measure. Depressive symptoms were measured using the 8-item Centers for Epidemiologic Studies-Depression (CES-D) scale. Decomposition estimates were derived using regression analyses of repeated measures of depressive symptoms. Standard errors were obtained using a non-parametric bootstrap with the individual as the independent unit to account for dependence of observations within an individual. In a large cohort of older Americans, a one standard deviation difference in educational attainment (~ 3 years) was associated with a 0.35-point decrement in CES-D score (95% CI: -0.38, -0.32). This decrement represents a 0.22 standard deviation difference in depressive symptoms. Using IORW, the estimated effect of education on depressive symptoms mediated through literacy was -0.10 (95% CI: -0.18, -0.01), which represents 28% of the total effect. Education confers many benefits; as demonstrated by this study for depressive symptoms, one important benefit is literacy.

Introduction

Extensive evidence indicates that lower educated individuals are at elevated risk for depression or elevated depressive symptoms (Akhtar-Danesh & Landeen, 2007; Bracke, 2000; Eaton, Muntaner, Bovasso, & Smith, 2001; Ladin, 2008; Sargeant J, 1990). Low educational attainment was related to first-time occurrence of major depression (Gallo, Royall, & Anthony, 1993), persistence of depression (Bracke, 2000; Sargeant J, 1990), and increased risk of recurrent depression (Gilman, Kawachi, Fitzmaurice, & Buka, 2003). A U.S. community-based longitudinal study demonstrated a graded relationship between education and incident depression. Participants with less than 9 years of education had nearly double the odds of developing depression over the 9 years of follow-up compared to those with at least a high school education. Participants with 9–11 years had 1.5 times the odds of developing depression compared to those with a high school education or higher (Kaplan, Roberts, Camacho, & Coyne, 1987). In the Survey of Health, Ageing and Retirement in Europe (SHARE), a panel survey of nationally representative probability samples of non-institutionalized adults 50 years and older in 10 European countries, education was associated with depression in all countries. Those with less than a high school education had approximately twice the odds of depression compared to those with greater educational attainment (Ladin, 2008). However there has been little research examining the mechanisms to explain this association. A meta-analytic review of studies examining socioeconomic status and depression reported a dose

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response relationship between education and depression such that each additional year of education was associated with a 3 percent reduction in the log odds ratio of being depressed (Lorant et al., 2003).

Literacy is a fundamental resource highly correlated with educational attainment. Broadly, literacy has been defined as using printed and written information to function in society, to achieve one's goals, and to develop one's knowledge and potential. Literacy enables individuals to gain knowledge about how to attain desired goals in any of the countless interactions that shape daily life e.g., in a clinical care setting, with utility companies, schools, nursing homes, family care providers, rental agencies, or banks. Literacy conceptually entails several skills, including obtaining, understanding, and using printed information. Results from the National Adult Literacy Survey indicate approximately 90 million adult Americans have limited levels of literacy (Kirsch, Jungeblut, Jenkins, & Kolstad, 2002).

Few studies have examined literacy as a possible mediator of the relationship between education and health. In 2006, Schillinger found that literacy partially mediated the relationship between education and glycemic control (Schillinger, Barton, Karter, Wang, & Adler, 2006). Literacy has also been shown to partially mediate the link between education and hypertension knowledge but not hypertension control (Pandit et al., 2009). Recently published work indicated that literacy partially mediates the relationship between education and mortality (Nguyen et al., 2016). To the authors' knowledge, these remain the only published studies formally evaluating literacy as a mediator between education and health, and no prior work has evaluated the role of literacy in mediating effects of education on mental health outcomes.

While there has been robust evidence linking education and depression or depressive symptoms, there has been limited understanding of the pathways that explain this association. Literacy is a foundational skill conferred by schooling. Literacy increases the capacity to obtain, process, and understand health information (Baker et al., 2007; Weiss, Hart, & Pust, 1991). Literacy facilitates the comprehension of prescriptions, health care worker's instructions for disease management, printed nutrition information, and publicly available health information (Weiss et al., 1991). Literacy can impact health by influencing access and utilization of health care, the patient-provider relationship, and self-care (Paasche-Orlow & Wolf, 2007). Lower adult literacy is associated with less knowledge of health outcomes such as smoking, hypertension, diabetes, lower use of screening and preventive services (DeWalt, Berkman, Sheridan, Lohr, & Pignone, 2004) as well as poorer mental and self-rated health, and higher hospital admissions (Berkman, Sheridan, Donahue, Halpern, & Crotty, 2011).

Literacy can impact depressive symptoms in a multitude of ways. Being able to understand and use written text facilitates tasks of daily living such as paying bills or completing job applications. Literacy enables comprehension of prescription and medical treatment instructions, obtaining and understanding provider and public health messages regarding health promoting behaviors, health care check-ups, and screenings, which can influence engagement in health promoting behaviors and health status. This is important for depression because physical inactivity (Fox, 1999; Strawbridge, Deleger, Roberts, & Kaplan, 2002) and poor health status (Tanaka, Sasazawa, Suzuki, Nakazawa, & Koyama, 2011) have been shown to predict depression. Furthermore, by enabling reading, literacy can provide individuals with a greater sense of self-efficacy. One study showed that self-efficacy among individuals with limited literacy improved as they participated in an adult literacy program. (Francis, Weiss, Senf, Heist, & Hargraves, 2007). A study of patients with type 2 diabetes found that patients with higher health literacy received more diabetes-related education and had greater self-efficacy (Bohanny et al., 2013). Lastly, low literacy is stigmatized in our society; thus, the shame or embarrassment connected to limited reading ability may impact mental health (Parikh, Parker, Nurss, Baker, & Williams, 1996). A qualitative study of low literacy adults found engagement with health care professionals was affected by persistent anxiety that their literacy difficulties would be discovered. Multiple strategies to feign understanding or leave situations where there would be a risk of discovery were utilized (Easton, Entwistle, & Williams, 2013).

There is evidence indicating literacy has a protective effect on depressive symptoms (Barnes, Tager, Satariano, & Yaffe, 2004; Gordon, Hampson, Capell, & Madhok, 2002; Sudore et al., 2006). A randomized controlled trial of adults with depression and limited literacy demonstrated combining depression care with literacy enhancement was more effective in reducing depressive symptoms than depression care alone at one year follow-up (Weiss, Francis, Senf, Heist, & Hargraves, 2006).Thus far, studies have provided evidence to support the link between education and depressive symptoms and literacy and depressive symptoms. These associations suggest that literacy may be a mediator of the effect of education on depressive symptoms, but no study has formally tested this hypothesis. The main objective of this paper is to test this hypothesis.

Methods

Sample

The sample included 16,718 participants from the Health Retirement Study (HRS), a longitudinal study of U.S. adults aged 50 and over and their spouses. The first survey wave was collected in 1992, with biennial interviews (or proxy interviews for decedent participants) available through 2010. Additional samples representing other birth cohorts were enrolled in 1993 and 1998. Since literacy assessments began in 1995-6, the analytic sample was restricted to members who were alive and interviewed in 1998, the earliest subsequent interview and the first HRS wave for which all birth cohorts from 1947 and earlier were represented. From an initial total sample of 21,384 members alive and interviewed in 1998, we made the following exclusions: not born between 1900 and 1947 (n = 961) to include in the analytic sample only participants who were 50 years or older in 1998, foreign-born (n = 2,847), missing place of birth (n = 71), missing literacy score (n = 1,387), missing self-reported childhood health (n = 25), and missing the outcome (n = 336) resulting in a final analytic sample of 16,718. The study design entailed a repeated measures analysis of depressive symptoms assessed from 1998 – 2010, educational attainment assessed at the respondent's first interview, and literacy measured in 1995-6 and 1998. HRS was approved by the University of Michigan Health Sciences Human Subjects Committee, and the Harvard T. H. Chan School of Public Health Human Subjects Committee determined the current analyses were exempt.

Measures

Exposures and mediator

The main exposure was educational attainment operationalized as self-reported years of schooling obtained when the participant was first interviewed. Literacy, assessed using a vocabulary test, was the mediator of focus. This measure has been previously described, and we coded this variable as we have in our previous research (Nguyen et al., 2016). Beginning in Wave 3 (1995/6), respondents were presented with a set of 5 vocabulary words associated with increasing literacy demand, and were asked to define each word. Their responses were evaluated and assigned scores based on degree of accuracy with 0 = incorrect, 1 = partially correct, 2 = completely correct. Scores ranged from 0 to 10 with a mean of 5.50 and standard deviation of 2.00. There were two sets of words, one of which was randomly assigned at the participant's first interview. Beginning at Wave 4 (1998), the vocabulary sets were alternated in subsequent waves and only asked of re-interviewees who were 65 years of age or older. For participants who entered the study in 1998, we used the 1998 (wave 4) literacy score. For participants with data prior to 1998, we used the average of the 1995/1996 (wave 3) and 1998 (wave 4) vocabulary scores. In a validation subsample (n = 382),

this measure was highly correlated with the Wide Range Achievement Test Version 3 (WRAT-3) Reading subtest raw score (r = 0.75) (Wilkinson, 1993), a widely used and validated measure of literacy.

Outcomes

Depressive symptoms were measured using the 8-item Center for Epidemiologic Studies Depression (CES-D) scale. The original scale consisted of 20 questions with each item having a value of 0 (rarely/none of the time) to 3 (most/all of the time) (Radloff, 1977). Since Wave 2, HRS has used the shortened 8-item CESD with yes/no response categories (Steffick, 2000), which have high internal reliability (Cronbach's alpha assessed in HRS Wave 3 was 0.81) (Steffick, 2000). The CES-D has been used widely to assess severity of depressive symptoms in adults (Radloff & Locke, 1986) and elders (Zauszniewski & Graham, 2009). Up to seven measurements of depressive symptoms were available on each HRS respondent. For example, if the respondent first enrolled in 1998, they could potentially have CES-D scores for 1998, 2000, 2002, 2004, 2006, 2008, and 2010. Scores ranged from 0 to 8 with a mean of 1.59 (median of 1) and standard deviation of 1.60.

Covariates

We attempted to control for variables likely to influence education, literacy, and depressive symptoms. Covariates included age in 1998, sex, race/ethnicity (Non-Hispanic White, Non-Hispanic Black, Hispanic, Other), self-rated childhood health status (excellent/very good/good vs fair/poor), and 5 indicators of early life socioeconomic status (SES) combined into a single scale (mother's and father's educational attainment, father's occupational status, birth in southern US. and rural residence during childhood). Birth in the Southern U.S. and rural residence during childhood were included as indicators because there are geographic variations in economic activity and opportunities, as well as educational quality that can influence early life conditions. For these birth cohorts, disadvantage and lower educational quality resulting from *de jure* segregation were concentrated in southern states (Glymour & Manly, 2008). Early life SES can influence educational attainment (Egerter, Braveman, Grossman-Kahn, & Dekker, 2009) and as a result, literacy. It can also influence depressive symptoms (Gilman, Kawachi, Fitzmaurice, & Buka, 2002), so for these analyses, early life SES was included as a potential confounder of the relationships between education and depressive symptoms and literacy and depressive symptoms. Confirmatory factor analysis with full information maximum likelihood (FIML) estimation was used to recreate factor scores from these 5 indicators, following previous research (Nandi, Glymour, Kawachi, & VanderWeele, 2012).

Mediation analyses

We used the inverse odds ratio weighting (IORW) approach developed by Tchetgen Tchetgen (2013) to conduct our mediation analyses. Strengths of IORW include being agnostic to presence or absence of exposure-mediator interactions and ease of implementation with any standard regression model that accommodates weights. This strength of IORW was especially important for these analyses as there was evidence for exposure- mediator interactions. The role literacy plays in the association between education and depressive symptoms can vary across education categories. For example, low literacy may be a barrier to higher educational attainment. IORW provides an alternative strategy to the well-known Baron and Kenny approach (Baron & Kenny, 1986) which has traditionally been used in the social sciences. The Baron and Kenny approach assumes exposure-mediator interactions are absent.

In assessing mediation, we estimated the natural direct, natural indirect, and total effects. In our analyses, the average natural direct effect is the mean change in depressive symptoms per unit change in education when literacy is set at the value it would naturally take at 12 years of schooling (the reference level of the exposure). The average natural indirect effect corresponds to changes in the literacy without changes in education: i.e., the mean difference in depressive symptoms

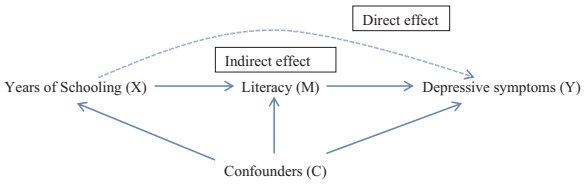

Fig. 1. Representation of the hypothesized relationships between years of schooling, literacy, and depressive symptoms.

expected if literacy were changed from the value it would take at 12 years of schooling to the value it would take at 15 years of schooling, but in both cases setting years of schooling at 15 (one standard deviation above the mean). We can imagine the natural indirect effect may correspond with the effect of an intervention such as improving school quality so the same years of schooling results in higher levels of literacy. Another intervention might be an adult literacy development program where years of schooling would be unchanged, but literacy would increase. The total effect of education on depressive symptoms is the sum of the natural direct and indirect effects (Pearl, 2012). Natural direct and indirect effects are identified with several assumptions. These, under a nonparametric structural equations interpretation of the causal diagram shown in Fig. 1, include no unmeasured confounding of exposure-mediator, mediator-outcome, and exposure-outcome relationships (Pearl, 2001). The method also assumes there are no confounders (measured or unmeasured) that are affected by the exposure (Avin, Shpitser, & Pearl, 2005; Pearl, 2001).

IORW condenses the association between education and literacy into a weight, removing the need to specify a regression model for depressive symptoms on education and literacy, including any education-literacy interactions. The weight, which is the inverse odds ratio of the association between education and literacy given the covariates, is used to estimate the natural direct effect in a regression analysis. Under the aforementioned assumptions, applying the weight deactivates any causal pathway from years of education to depressive symptoms that operates through literacy.

To implement IORW, the conditional odds ratio function OR(X,M|C) relating years of schooling (X) and our mediator, literacy (M), within levels of pre-exposure confounders (C) was computed using the following regression model

$$\mathrm{X|M},\ C = \beta_0 + \beta_1 M + \beta_2 C + \mathrm{e} \quad (1)$$

with $\mathrm{e} \sim \mathrm{N}(0, \sigma^2)$, so that for each participant we computed the inverse odds ratio weight $1/\mathrm{OR(X,M|C)} = \exp(-\beta_1 \times \mathrm{X} \times \mathrm{M}/\sigma^2)$ (Tchetgen Tchetgen, 2013). The estimated natural direct effect (NDE) is identified by the regression coefficient for the exposure (years of schooling) in the weighted regression model for the outcome (Y) on the exposure and covariates (Eq. (2)), with inverse odds ratio weight $1/\mathrm{OR(X,M|C)}$ (Tchetgen Tchetgen, 2013).

$$\mathrm{E(Y|X,\ C)} = \alpha_0 + \alpha_1 X + \alpha_2 C \quad (2)$$

The total effect is the coefficient for years of schooling in the corresponding unweighted regression analysis. The natural indirect effect (NIE) is estimated by taking the difference of the total effect and the natural direct effect. Non-parametric bootstrapping is used to obtain ninety-five percent confidence intervals for the total, NDE and NIE. For further details on the odds ratio formula with continuous variables, please see (Nguyen et al., 2016). For an application of this approach using a binary exposure, please see (Nguyen, Osypuk, Schmidt, Glymour, & Tchetgen Tchetgen, 2015). For a broad overview of IORW, please see (Tchetgen Tchetgen, 2013). IORW uses a counterfactual framework for mediation analyses. Lange and colleagues provide a concise introduction to the use of a counterfactual framework to estimate natural direct and indirect effects (Lange & Hansen, 2011).

As an alternative strategy, we implemented the Baron and Kenny

approach by fitting two sets of models for the outcome with (3) and without the mediator (4).

$$E(Y|X, M, C) = \sigma_0 + \sigma_1 X + \sigma_2 M + \sigma_2 C \quad (3)$$

$$E(Y|X, C) = \lambda_0 + \lambda_1 X + \lambda_2 C \quad (4)$$

The coefficient for the years of schooling in the model with literacy (Eq. (3)) represents the direct effect. The coefficient for years of schooling in the model without literacy (Eq. (4)) represents the total effect, and the indirect effect is computed by the taking the difference in the coefficients for years of schooling from the two models.

We tested for the presence of interaction between education and literacy by including an education*literacy interaction term in the adjusted model for the outcome using Generalized Estimating Equations (GEEs) and specifying a compound symmetry working correlation structure to take account of the dependency of repeated measures of depressive symptoms. There was some evidence of an interaction, and we repeated the mediation analyses stratified by education level (≤ 12 vs ≥ 13 years of schooling).

Measurement error correction

Our main measure of literacy was a brief vocabulary test. We investigated the influence of measurement error in our literacy assessment in two ways. First, we implemented the inverse odds ratio weighting (IORW) and Baron and Kenny approaches using the Wide-Range Achievement Test (WRAT) Reading subtest, a widely used and validated measure of reading ability, available on a subsample of participants ($n = 350$) as our measure of literacy.

We next corrected for measurement error in our vocabulary assessment using the WRAT as validation data in implementing the measurement correction approach for IORW. Additional details and the mathematical proof for the measurement error correction has been published elsewhere (Nguyen et al., 2016). Briefly, we performed the following steps to implement the modified IORW approach.

First, we fit a regression of observed literacy scores (M*) on the WRAT scores measuring grade level reading ability (M), years of schooling (X), and covariates (C).

$$M^* = a_0 + a_1 M + a_2 X + a_3 C + d. \quad (5)$$

where d is mean zero independent error. We then fit a regression of years of schooling (X) on the WRAT scores and covariates:

$$X = \beta_0 + \beta_1 M + \beta_2 C + e \quad (6)$$

where e is N (0, σ^2). The inverse odds ratio weights are modified to account for measurement error correction and obtained by fitting the models above using the subsample of complete data on exposure, mediator, outcome, and covariates. The inverse odds ratio weights are calculated as follows:

$$W = \exp(-\beta_1 \times X \times M^*/(a_1 \times \sigma^2)].$$

The remaining steps to estimate the total, natural direct, and natural indirect effects are the same for measurement error corrected and uncorrected estimates described above. For the mediation analyses, using the inverse odds ratio weights precluded estimating GEE models. We instead estimated linear regression models with an assumed independence correlation structure for repeated measures of depressive symptoms from the same person and obtained confidence intervals via the nonparametric bootstrap (1000 iterations) with the individual as the independent unit, thus appropriately accounting for correlation within a person. These models are estimating the effects of education and literacy on level of depressive symptoms. Confirmatory factor analysis was conducted using Mplus Version 7. All other analyses were conducted using R 2.15.2.

Table 1
Demographic characteristics of the sample.

	N	(%)
N	16,718	100
Male	6911	41
Birth year		
< 1914	994	6
1914–1921	2357	14
1922–1930	4002	24
1931–1941	6735	40
1942–1947	2630	16
Years of schooling		
< 9	2093	12
9–11	2591	15
12	5998	35
13–15	3297	19
16	1489	9
17+	1586	9
Non-Hispanic White	13,576	81
Non-Hispanic Black	2327	14
Hispanic	600	4
Other	214	1
Born in the Southern U.S.	6369	38
Rural residence during childhood	7258	47
Father's occupation: professional (vs manual)	3526	24
Mother's education		
≤ 8	6292	50
9–11	1608	13
12	3312	26
> 12	1367	11
Father's education		
≤ 8	6997	57
9–11	1335	11
12	2475	20
> 12	1365	11
CESD score (mean, SD)		
1998	1.55	1.89
2000	1.52	1.88
2002	1.48	1.92
2004	1.43	1.9
2006	1.43	1.9
2008	1.37	1.88
2010	1.28	1.81

Results

The majority of the participants were non-Hispanic White, and 62 percent had 12 or fewer years of schooling. Forty-one percent were male (Table 1). Depressive symptoms steadily declined through the follow-up period. Depressive symptoms decreased with increasing educational attainment and literacy scores (Table 2). There was a positive and statistically significant interaction between years of schooling and literacy ($\beta = 0.04$, 95% CI: 0.02, 0.06). The main effects of education and literacy were each negative while the interaction term was positive. These interaction results suggested that the protective effect of literacy on depressive symptoms attenuated by 0.04 for every unit increase in years of schooling and vice versa. These models included years of schooling, literacy, years of schooling-literacy interaction, and covariates age, sex, race/ethnicity, and early life SES.

Using the IORW approach, a one standard deviation increase in educational attainment (~3 years) was associated with a 0.35-point decrement in the CES-D score (95% CI: -0.38, -0.32). This decrease represents a 0.22 standard deviation difference in depressive symptoms. The estimated effect of education on depressive symptoms mediated through literacy was -0.10 (95% CI: -0.18, -0.01), which represents 28% of the total effect, leaving the remaining 0.25 decrease in CES-D score as the natural direct effect (95% CI: -0.35, -0.16) (Table 3). The results using the Baron and Kenny approach were similar and within the 95% CI of the IORW results. The natural direct effect was statistically

Table 2
Average depressive symptoms by educational attainment and literacy.

	Average depressive symptoms		
Education (years)	N	Mean	Standard deviation
< 9	1978	2.46	1.83
9–11	2523	2.09	1.76
12	5907	1.54	1.53
13–15	3266	1.34	1.44
16	1472	1.04	1.24
17+	1572	0.91	1.12
Literacy score			
0–2	1044	2.42	1.74
2.5–4	3355	1.89	1.7
4.5–6	6479	1.57	1.58
6.5–8	4838	1.33	1.46
8.5–10	1002	1.19	1.39

Repeated measures of depressive symptom averaged within individuals

Table 3
Total, natural direct and natural indirect effects for depressive symptoms using Baron and Kenny and Inverse Odds Ratio Weighting (IORW) estimators.

Treatment effects[a,b] (N = 16,718)	Baron and Kenny		IORW	
	β	95% CI[c]	β	95% CI[c]
Total[d]	-0.35 (-0.38, -0.32)			
Natural direct	-0.31	(-0.35, -0.28)	-0.25	(-0.35, -0.16)
Natural Indirect	-0.03	(-0.04, -0.02)	-0.10	(-0.18, -0.01)

[a] Exposure: z-scored years of schooling with 1 SD = 3 years, Mediator: z-scored literacy score with 1 SD = 2 on a 10-point scale.
[b] Covariates: age, sex, race/ethnicity, self-rated child health status, and five indicators of early life SES combined into a single scale including mother's and father's educational attainment, father's occupational status, birth in southern US, and rural residence during childhood.
[c] Obtained using a nonparametric bootstrap.
[d] Estimation of total effects is the same for Baron and Kenny and inverse odds ratio weighting.

significant, indicating partial mediation (Table 3). The Baron and Kenny results were less variable than the IORW results. In this setting, both approaches lead to the same substantive conclusion.

Education stratified analysis

Since there was evidence of exposure-mediator interactions (results above), we also conducted the mediation analyses stratifying by education level. The total effect of education was larger among participants with 12 or fewer years of education compared with more years of education (β = -0.42; 95% CI: -0.49, -0.38 vs β = -0.28; 95% CI: -0.35, -0.22) (Table 4). Among participants with 12 or fewer years of education, the natural indirect effect estimated using IORW was -0.22 (95% CI: -0.30, -0.02), representing 52% of the total effect. However, among participants with greater than 12 years of education, the natural indirect effect estimates suggested no mediated effect (BK indirect estimate: 0.00 (95% CI: -0.02, 0.01), IORW indirect estimate: 0.05 (95% CI: 0.01, 0.10)) (Table 4).

In supplemental analyses, we examined whether the associations between education and literacy or between literacy and depressive symptoms were attenuated among participants with greater than 12 years of education. In covariate adjusted models, while education similarly predicted literacy among those with lower and higher levels of education, the association between literacy and depressive symptoms was less strong among participants with more than 12 years of schooling (Online Supplementary Tables 1–2). We also conducted stratified analyses for more refined education subgroups (≤ 8, 9–12, 13–15, 16+). We see similar pattern as with the broader education groupings, where total effects and indirect effects are larger for participants with lower levels of education (Online Supplementary Table 3).

Table 4
Total, natural direct and natural indirect effects for depressive symptoms using Baron-Kenney and Inverse Odds Ratio Weighting (IORW) among participants with ≤ 12 years of schooling and 13+ years of schooling.

Treatment Effects[a,b]	Baron and Kenny		IORW	
	β	95% CI[c]	β	95% CI[c]
≤ 12 years of schooling (N = 10,682)				
Total	-0.42 (-0.49, -0.38)			
Natural direct	-0.38	(-0.44, -0.33)	-0.20	(-0.43, -0.13)
Natural indirect	-0.04	(-0.06, -0.03)	-0.22	(-0.30, -0.02)
13+ years of schooling (N = 6310)				
Total	-0.28 (-0.35, -0.22)			
Natural direct	-0.28	(-0.35, -0.28)	-0.33	(-0.41, -0.26)
Natural indirect	0.00	(-0.02, 0.01)	0.05	(0.01, 0.10)

[d]Estimation of total effects is the same for Baron and Kenny and inverse odds ratio weighting
Mediator: z-scored literacy score with one standard deviation = 2
[a] Education was z-scored based on the distribution in the full sample, so 1 unit higher value of education = 3 years of schooling.
[b] Covariates: age, sex, race/ethnicity, self-rated child health status, and five indicators of early life SES combined into a single scale including mother's and father's educational attainment, father's occupational status, birth in southern US, and rural residence during childhood.
[c] Obtained using a nonparametric bootstrap.

Measurement error correction

In re-estimating the mediation analyses using the WRAT score instead of the vocabulary test as our measure of literacy, the estimated IORW direct effect shifted towards the null (β = -0.13 vs -0.25), and the estimated corrected indirect effect indicated a larger mediated effect (-0.19 vs -0.10) (Table 5). The estimates were imprecise due to the small sample size with the WRAT measure (n = 350).

We then used the WRAT as validation data to correct for measurement error in IORW. Measurement error correction results using this approach followed a similar pattern as above. The corrected direct effect was attenuated, and the corrected indirect effect moved farther from the null. Since validation data was only available on a small subsample of participants, measurement error correction using the modified IORW approach resulted in wide confidence bounds (Table 6).

Discussion

Literacy was found to be a partial mediator of the relationship between education and depressive symptoms in a large cohort of older Americans. Stratified results indicated the education was a stronger

Table 5
Total, natural direct and indirect effects for depressive symptoms using Baron-Kenney and Inverse Odds Ratio Weighting (IORW) with WRAT subsample.

Treatment effects[a,b] (N = 350)	Baron and Kenny	95% CI[c]	IORW	95% CI[c]
Total	-0.33 (-0.48, -0.16)			
Natural Direct	-0.37	(-0.57, -0.18)	-0.13	(-0.45, 0.14)
Natural Indirect	-0.04	(-0.09, 0.18)	-0.19	(-0.47, 0.08)

Mediator: z-scored literacy score with 1 SD = 2 on a 10-point scale
[a] Exposure: z-scored years of schooling with 1 SD = 3 years,
[b] Covariates: age, sex, race/ethnicity, self-rated child health status, and five indicators of early life SES combined into a single scale including mother's and father's educational attainment, father's occupational status, birth in southern US, and rural residence during childhood.
[c] Obtained using nonparametric bootstrap

Table 6
Total, natural direct and indirect effects for depressive symptoms using Baron-Kenney and Inverse Odds Ratio Weighting (IORW) with measurement error correction (MEC).

Treatment effects[a,b] (N = 16,718)	IORW	95% CI	IORW + MEC	95% CI
Total	-0.35	(-0.38, -0.32)		
Natural Direct	-0.25	(-0.35, -0.16)	0.04	(-0.48, 0.11)
Natural Indirect	-0.10	(-0.18, -0.01)	-0.39	(-0.46, 0.13)

[c]Obtained using nonparametric bootstrap
Mediator: z-scored literacy score with 1 SD = 2 on a 10-point scale
[a] Exposure: z-scored years of schooling with 1 SD = 3 years,
[b] Covariates: age, sex, race/ethnicity, self-rated child health status, and five indicators of early life SES combined into a single scale including mother's and father's educational attainment, father's occupational status, birth in southern US, and rural residence during childhood.

predictor of depressive symptoms among those with 12 or fewer years of education, and literacy mediated the relationship between education and depressive symptoms predominantly among those with lower levels of education. Supplemental analyses showed literacy and depressive symptoms were less strongly associated among the more educated. It may be that among those with greater than 12 years of education, pathways other than those including literacy operate to influence depressive symptoms. Since educational attainment has increased over time in the U.S., low educational attainment is more concentrated in the older birth cohorts. Our study findings may be most applicable to older birth cohorts. This work contributes to the scarce body of research evaluating literacy as mediator of educational attainment and health. Future work can investigate and quantify the other pathways through which education may influence depressive symptoms.

Under classic nondifferential measurement error such that errors are unrelated to the exposure or outcome, estimates of the mediated effect (indirect effect) will be biased toward the null, and estimates of the direct effect will be biased away from the null (VanderWeele, Valeri, & Ogburn, 2012). Our measurement error corrected results are consistent with nondifferential measurement error and suggest the effect of education on depressive symptoms mediated through literacy may be even larger than evidenced in our primary analysis.

Education can impact depressive symptoms via several pathways. More education is associated with greater likelihood of engaging in health promoting behaviors, better health outcomes, and longer life expectancy (Egerter et al., 2009). Education is associated with decreased likelihood of smoking and greater likelihood of obtaining health care check-ups and screening, and engaging in regular physical activity (Egerter et al., 2009). Educational attainment influences occupational opportunities and earning potential. It facilitates access to information as well as resources (Adler & Newman, 2002). It can also influence health via psychological processes including increasing sense of control and social standing (Egerter et al., 2009). By affecting living and working conditions, health behaviors, and health outcomes, education can influence depression.

In the education literature, there is on-going debate about the mechanisms to explain the relationship between education and health. There are many theorized mechanisms to explain the relationship between education and health. Some argue the effect of education on health arises through credentialing or “sheepskin” effects. According to the credential model, education confers degrees, which are symbolic in nature. Education impacts health because employers use degrees to screen and hire their employees. Higher education has been associated with full-time employment, higher incomes, and less exposure to occupational hazards (Kawachi, Adler, & Dow, 2010). Using this model, each additional year of education has no added value unless it leads to a degree (Ross & Mirowsky, 1999; Ross & Wu, 1995). Another hypothesized mechanism described by the quantity model is that education confers skills and knowledge (Ross & Mirowsky, 1999). Under the quantity model, more years of schooling leads to more human capital acquisition. Education may help develop foundational analytic skills such as the ability to observe, experiment, synthesize, and classify. Education introduces people to the process of gathering and interpreting information and solving problems (Ross & Mirowsky, 1999), and these abilities can serve people well in their daily lives. Some research suggests both may be operating. In examining national education and adult mortality patterns, a linear decline in mortality risk was found from 0–11 years of schooling, followed by a step change in mortality risk once a high school diploma is achieved, and then a steeper linear reduction in mortality risk with increasing schooling after high-school (Montez, Hummer, & Hayward, 2012). In this paper, we focused on testing the quantity model and assessed the extent to which the effects of education depressive symptoms are mediated through one important skill acquired through schooling, viz., literacy.

In this paper, we investigated literacy as a potential mediator. Literacy can also be conceptualized as a confounder since it may impact higher educational attainment. There may be a feedback loop with education conferring literacy, and literacy increasing likelihood of greater educational attainment, and both education and literacy influencing depressive symptoms. We did not have multiple measures of educational attainment to empirically examine this potential feedback loop in our data.

This was an observational study, so residual and unmeasured confounding remained a reasonable threat. One potential confounder of this relationship is early life intelligence. A concern is that our literacy measure could reflect a combination of literacy (reading ability) and general intelligence. HRS does not have an early life measure of cognitive function or intelligence. Although cognitive function was measured later in life, this measure may be affected by the respondents' educational attainment and/or literacy level. As a result, late life cognitive function may partially mediate the relationship between education, literacy, and depressive symptoms. Lack of an early life measure of cognitive function is a limitation of our study. However, previous research indicate educational attainment influences cognitive function (Stevenson, Chen, & Booth, 1990) independent of intelligence (Herd, 2010; Link, Phelan, Miech, & Westin, 2008).

A related concern is whether our vocabulary measure is influenced by cognitive decline. In this study, we also used vocabulary assessments from the 1995/6 and 1998 interview waves and treated our mediator as a time-constant variable. Thus, any cognitive decline after baseline would not be influenced by our vocabulary measure. The literature has demonstrated that literacy is stable over time even in the presence of early dementia (Manly, Schupf, Tang, & Stern, 2005). The Pearson correlation between the vocabulary score and change in memory score (difference between 2000 and 1998) score is -0.06. The correlation between our vocabulary score and age is -0.09. In comparison, the correlation between memory function and age was -0.69. Thus, consistent with prior literature, age has a very weak influence on literacy, compared to a large and consistent impact of age on memory function.

Furthermore, reverse causation may be a potential threat. There is some evidence that depression can influence educational attainment (Fletcher, 2008, 2010). Milder forms of depression may have less of an impact on education. In addition, most previous research suggests the predominant direction is educational attainment influencing depressive symptoms (McFarland & Wagner, 2015; Mezuk, Myers, & Kendler, 2013). In this study, we assessed literacy using a brief test. While correlation between the validated WRAT and our measure of literacy was moderately high (r = 0.75), there persists the possibility of measurement error in our proposed mediator. This suggests we likely underestimated the role of literacy in mediating effects of education on mental health.

The IORW approach was more flexible and made fewer modeling assumptions because we did not need to specify a model for the mediator given exposure and covariates. The mediator never appeared in

the model for the outcome except indirectly in the creation of the weights, and exposure-mediation interactions never had to be directly specified. Greater flexibility and fewer assumptions may have come at a cost. In this example, the IORW estimates were more variable than those from the Baron and Kenny approach.

This research adds to the body of evidence showing the long-term health benefits of years of schooling. A recent review of the evidence on the impact of education on health finds health benefits arise from receiving high quality education (Cohen & Syme, 2013). Relating education and literacy, quality of educational experience was associated with the reading level of the pupils (Fryer & Levitt, 2004; Heck, 2007). Our study helped to elucidate a specific pathway through which education impacts depressive symptoms. Doing so is critical for targeting educational policies and programs to influence levers of change.

Results from the National Adult Literacy Survey (NALS) reveal there is substantial room for improvement in literacy skills of high school graduates. Close to 1 in 5 adults with high school diplomas perform at the lowest level of literacy (Level1). Respondents in the lowest level of literacy have difficulty locating more than a single piece of information from a short text, table, or graph or performing arithmetic operations (Kirsch et al., 2002). This study indicates promoting literacy may have long-term mental health benefits.

Ethical statement

The Health and Retirement Study was approved by the University of Michigan Health Sciences Human Subjects Committee, and the Harvard T. H. Chan School of Public Health Human Subjects Committee determined the current analyses were exempt.

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Conflicts of interests

None.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.ssmph.2017.07.002.

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