The Roles of Education, Literacy, and Numeracy in Need for Health Information during the Second Half of Adulthood: A Moderated Mediation Analysis

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Conflict of Interest

The authors report no conflict of interest in this research.

Ethical Approval

This research utilized the publicly available data and therefore, the ethical approval was not required.

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Abstract

We examine complex pathways that link health information seeking behavior with education and health literacy (decomposed into general literacy and numeracy), and how these pathways differ by perceived health status (need) among a nationally representative sample of Americans age 50 and older (n = 2,750). Data come from the Program for International Assessment of Adult Competencies (PIAAC). Multi-group structural equation models were used to examine the use of eight health information sources (newspapers, magazines, internet, radio, TV, books, friends/family, and health professionals). Findings partially support the long-standing notion that health seeking behaviors are directly linked to educational attainment, and provide some of the first nationally representative evidence for how education functions through distinct health literacy components to shape health information seeking behaviors by health status. Findings from this moderated mediation analysis point to the importance of examining, and addressing, health literacy disparities in access to and use of health information.

Keywords: health literacy; behavioral model; information seeking; health disparities; older adults

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Health information plays a critical role in health decision making and health behaviors, which are important factors in determining health outcomes (Bass, 2003; Feinberg et al., 2016). Health information seeking behaviors are understood to be shaped by educational attainment, abilities to obtain and process health information (i.e., health literacy), and need for such information (e.g., perceived health status) (Tu & Cohen, 2008). Links between health information use and education are often examined in isolation of one's ability to obtain and understand relevant information (Kutner et al., 2007; Prins & Monnat, 2015; Tu & Cohen, 2008). Furthermore, when health literacy is examined, the fundamental components that compose this gross measure (i.e., general literacy and numeracy) are rarely disentangled (Berkman et al., 2011; Jensen et al., 2010; Malone et al., 2017). Thus, the present study decomposes health literacy to examine how the association between health seeking behaviors and education is mediated by both literacy and numeracy, and whether these mediated relationships are moderated by perceived health status.

Background

The use of health information involves a process that first requires one to locate, then understand, and next evaluate the quality of information to draw a conclusion on whether (and how) to use the information (Gaglio, Glasgow, & Bull, 2012). Health information seeking is a highly individualized activity that is commonly triggered by one's health needs (Taha, Sharit, & Czaja, 2009). Effective health information seeking requires sufficient health literacy, which reflects "the degree to which individuals have the capacity to obtain, process, and understand

basic health information and services needed to make appropriate health decisions" (U.S. Department of Health and Human Services, 2010, p. 1).

Health literacy consists of two fundamental skill sets, general literacy and numeracy, which respectively reflect one's ability to read/write and understand and work with numbers (Squiers, Peinado, Berkman, Boudewyns, & McCormack, 2012). Only about one in ten Americans have proficient literacy skills (U.S. Department of Health and Human Services, 2008), which is indicative of a mismatch between existing skills and the complexity of available health information (Feinberg et al., 2016; Isaac M. Lipkus, Johnson, Amarasekara, Pan, & Updegraff, 2018). However, in terms of numeracy, there is a dearth of knowledge in the context of health information use (Yamashita, Bardo, & Liu, 2018). Nonetheless, individuals commonly face uncertainty about the effectiveness of their health information seeking efforts (Malone, Jo, & Clifton, 2017).

Traditionally, educational attainment is considered to be one of the most important determinants of health behaviors (e.g., health information seeking) (Link & Phelan, 1995), but the underlying mechanisms are not yet well understood (Phelan, Link, & Tehranifar, 2010). Indeed, one's health literacy is closely associated with her or his educational attainment (Kutner et al., 2007; Prins & Monnat, 2015). However, given relatively low levels of general literacy and numeracy among Americans (U.S. Department of Health and Human Services, 2008), there is a need to better undertand the underlying mechansims that link educational attainment with health information seeking beahviors. Here, we focus on the second half of adulthood, as health information seeking behaviors are often uniquely triggered by health-related needs during this stage of life (Jensen, King, Davis, & Guntzviller, 2010; Tu & Cohen, 2008).

Conceptual framework

The present study was guided by two conceptual frameworks: (a) the behavioral model for vulnerable populations (Gelberg, Andersen, & Leake, 2000) and (b) the health literacy casual model (Paasche-Orlow & Wolf, 2007). The behavioral model holds that health behaviors, such as health information seeking, are a function of one's predisposing (e.g., sociodemographic characteristics), enabling (e.g., personal resources such as income and self-help skills), and need (e.g., health status) factors. While the behavioral model has been widely employed (Babitsch, Gohl, & von Lengerke, 2012), the role that health literacy plays in this context remains unclear. Thus, we draw on the health literacy causal model to identify potential pathways that jointly and sequentially influence health information seeking behaviors.

Health behaviors are partially determined by health literacy, which is closely tied to sociodemographic characteristics (e.g., age, education) (Paasche-Orlow & Wolf, 2007). For example, the health literacy causal model shows that an individual's ability and knowledge in health care settings (e.g., navigating health care systems), and everyday settings (e.g., disease prevention and self-care), represent key pathways between health literacy and health outcomes (Paasche-Orlow & Wolf, 2007). Thus, in conjunction with the behavioral model (Gelberg et al., 2000), we considered health literacy to be an enabling factor and its sociodemographic determinants are classified as predisposing factors.

Figure 1 shows that health information seeking behaviors are linked both directly and indirectly to educational attainment. Direct pathways reflect such aspects as one's previous exposure to, and foundational understanding of, health information, which is stratified by level of educational attainment (Feinberg et al., 2016; Tu & Cohen, 2008). Indirect pathways are shown to be mediated by both general literacy and numeracy, which collectively reflect the fundamental competencies that compose health literacy. Educational attainment is linked to enhanced ability

to read, write and understand and work with numbers (OECD, 2013). These underlying competencies are shown to shape health information seeking behaviors through unique pathways.

Individuals with poor literacy skills often feel overwhelmed and embarrassed when faced with health information they are unable to understand (Saab et al., 2018). Additionally, health information often includes complex numeric information, and adequate numeracy skills are required to fully understand such information (Peters, Hibbard, Slovic, & Dieckmann, 2007). Additionally, individuals with poor numeracy skills may simply feel demoralized because they are uncomfortable with numeric information (Chen & Feeley, 2014).

Finally, the pathways that link education, literacy, and numeracy with health information seeking behaviors are shown to be moderated by need factors. Specifically, those in greater need of health information tend not only to have poorer health but also to have lower levels of education and lower health literacy skills (Kelley, Su, & Britigan, 2016). This study also considered relevant contextual factors, including age, gender, race, social network, English as a native language, income, and health insurance (Kelley et al., 2016; Koch-Weser, Bradshaw, Gualtieri, & Gallagher, 2010; Pew Internet & American Life Project, 2005; Saab et al., 2018; Taha et al., 2009; Yoon & Jang, 2015).

[Figure 1 About Here]

Educational attainment

Arguably, educational attainment is the most important determinant of both health literacy and health behaviors (Kutner et al., 2007; Prins & Monnat, 2015), and this should be considered when examining pathways between health literacy and health information seeking behaviors. Individuals with relatively lower levels of education often struggle to comprehend

complex health and medical information (Rothman et al., 2006). Moreover, education provides opportunities to practice basic literacy skills and establish continuous learning behaviors (Nutbeam, 2008). Given that education is a predisposing factor that is closely linked to both health literacy (an enabling factor) and health behaviors, health literacy skills likely mediate the relationship between education and health-related behaviors. Specifically, education and health literacy reflect related, but distinct, pathways that influence one's health information seeking behavior.

Health literacy components

It has been suggested that literacy and numeracy should be separately examined to advance health literacy research (Berkman, Sheridan, Donahue, Halpern, & Crotty, 2011; Jensen et al., 2010; Malone et al., 2017), in large part because extant knowledge is almost exclusively based on measures that reflect an overall assessment of relevant skills (DeWalt & Pignone, 2005). Simply put, knowledge gained surrounding underlying mechanisms linking health behaviors to gross measures of health literacy is relatively limited. Decomposing these two central components (i.e., literacy and numeracy) is ideal for examining health information seeking behaviors because health information sources are diverse and health information seeking is a highly individualized behavior (Taha et al., 2009). Moreover, this measurement approach that accounts for specific health literacy components aligns with recently developed national and international guidelines (Rampey et al., 2016). The present study employed literacy and numeracy measures as indicators of health literacy and health numeracy proficiency, respectively, given that they collectively reflect the foundation for health literacy (Berkman et al., 2011).

Health information sources

Researchers have classified health information seeking into active and passive categories. Active information seeking facilitates the purposeful search for specific health information (Niederdeppe et al., 2007), whereas passive information seeking relies on unintentional encounters with relevant health information (e.g., family, health care providers) (Saab et al., 2018). Others have classified health information into text-based (e.g., internet, books, newspapers) and oral-based (e.g., TV, radio, healthcare providers) categories (Feinberg et al., 2016), among other classifications (see Kelly, Su and Britigan, 2016). An appropriate classification should be evaluated according to the purpose of research and available data. In this regard, we focus on specific information sources, with the intent to identify underlying patterns in the classification of health information sources.

While education and health literacy are both positively associated with health information use (Feinberg et al., 2016), little is known about how these two factors influence the type of sources from which health information is sought and obtained. Common health information sources include the internet, health care providers, print media, broadcast media, and personal social networks (Kelley et al., 2016). Higher education is associated with greater use of text versus oral-based health information (Feinberg et al., 2016), whereas health literacy is associated with the ability to obtain sufficient health information from multiple sources (Gaglio et al., 2012; Jensen et al., 2010; Neter & Brainin, 2012). Regardless of educational attainment and health literacy, the most preferred health information source is health care providers (Gaglio et al., 2012; Gutierrez, Kindratt, Pagels, Foster, & Gimpel, 2014).

Health status

One of the unique aspects of health information seeking behaviors is that they are driven by need, as individuals typically look for health information only when they face health

problems (Gaglio et al., 2012; Lagoe & Atkin, 2015), and not vice versa (Gelberg et al., 2000). Thus, perceived health status likely moderates the relationship between health literacy and health information seeking behaviors (Kim, Lim, & Park, 2015). Simply put, people do not typically search for health information unless they encounter some health problem. Moreover, inadequate health information use may result in poor health, which likely triggers additional health information seeking behaviors (Manierre, 2015).

Research questions and hypotheses

Taken together, little is known about complex interactions between education, health literacy, and health information seeking behaviors among older adults. The objective of the current research is to identify the moderated mediation relationships among education, health literacy, and health information seeking behaviors, by health status among older adults in the U.S. Two research questions were addressed: (1) Are there mediation relationships among education, literacy, numeracy, and the use of specific health information sources? (2) Are the mediation relationships among education, literacy, numeracy, and health information moderated by health status? In line with our proposed conceptual model, it is hypothesized that literacy and numeracy mediate the relationships between education and health information seeking behaviors, and the mediation relationships are moderated by health status.

Methods

Data

Data come from the Program for International Assessment of Adult Competencies (PIAAC) 2012/2014 public use file (PUF), which was provided by the U.S. Department of Education's Institute of Education Sciences (National Center for Education Statistics, 2017). The U.S. employed a four-stage stratified probability sampling strategy, and respondents were

interviewed in their place of residence by trained interviewers and completed either computer-based or paper-based (roughly one in five respondents) literacy assessments according to their computer skills (see Hogan et al., 2016 for more detail). These data are nationally representative of Americans age 16 to 74-years old, and they include some of the best available measures for both literacy and numeracy (AIR PIAAC Team, n.d.). The PIAAC PUF also provides detailed demographic, socioeconomic, and behavioral information, as well as sampling weights and replicate weights. The analytic sample was limited to those age 50-years and older. We selected age 50 to reflect a turning point at which the second half of adult life begins. While this age cut-point is somewhat arbitrary, we selected age 50 because it is a standard cut-point used in public health research focused on older adults (e.g., Johnson & Schoeni, 2011). Moreover, age 50 is often socially recognized as the starting point of later adulthood (e.g., AARP membership eligibility). The final analytic sample size was 2,570 after excluding 11 respondents with missing information.

Measures

Outcome variables. ***Health information sources:*** Eight health information sources including newspapers, magazines, internet, radio, TV, books, friends/family (e.g., social networks), and health professionals were assessed. For each respective source respondents were asked "how much information about health issues do you get from…?" The original response categories included "none, a little, some, or a lot." Due to skewed distributions and comparability issues across the information sources, responses were dichotomized to reflect (none & little) vs. (some & a lot).

Mediator. ***Literacy and numeracy:*** Health information broadly consists of both text and numbers, so it is critical to examine both literacy and numeracy (Jensen et al., 2010; Peters et al.,

2007). Simply put, literacy and numeracy collectively reflect the main components of health literacy (Berkman et al., 2011). The PIAAC includes a set of 10 plausible values (i.e. the statistical means of estimated score distributions; possible range 0 – 500) based on respondents' performance on literacy and numeracy tasks (see National Center for Education Statistics, n.d for specific examples). The greater the value, the more proficient. Literacy and numeracy are considered as enabling factors, and they were used as mediators and modeled as a function of predisposing factors.

Predictor variable. ***Educational attainment.*** Education was dichotomized to indicate whether respondents had a college degree or higher (i.e., associate, bachelor's and graduate degree) versus less than a college degree (i.e., high school diploma and less than high school).

Moderator/need factor. ***Perceived health status.*** Self-rated health was measured on a 5-point scale that ranged from excellent to poor. This measure was dichotomized to compare those with good (i.e., excellent, very good, and good) versus fair or poor health due to skewed distributions (e.g., approximately 7% reported poor health). Combining the self-rated health categories (i.e., good vs. others) is a reasonable approach to meaningfully reflect health status as shown in previous research (e.g., Jylhä, 2009). Self-rated health was classified as a need factor and used as a moderator.

Covariates were selected based on previous studies (e.g., Kelley et al., 2016; Koch-Weser et al., 2010; Pew Internet & American Life Project, 2005; Saab et al., 2018; Taha et al., 2009; Yoon & Jang, 2015) and their availability in the PIAAC. Covariates in this study include predisposing and enabling factors, and they are detailed below.

Covariates: Predisposing factors. Age groups were recorded by 5-year increments (a continuous measure for age was not available in the PUF). Gender included options for female or

male. Race was dichotomized to reflect white vs. non-white, as there was not enough diversity in the sample to decompose race/ethnicity into multiple racial/ethnic groups. Number of household members was used as a proxy for social network. We also included a self-reported indicator for whether a respondent was a native English speaker (Kelley et al., 2016).

C**ovariates: Enabling factors.** Income in the PIAAC was based on income from current employment, and it was recorded in quintiles. Thus, to include those not employed (i.e., unemployed, out of labor force), respondents with no reported income from current employment were classified into the lowest income quintile. Finally, we included an indicator for whether a respondent had health insurance.

Statistical analysis

An unweighted descriptive summary by health status was computed for all variables of interest. Multi-group structural equation models (SEM) with indirect effect estimation were employed to assess the proposed moderated mediation relationships (Wang & Wang, 2012). Multi-group SEM was adopted because of its capability to simultaneously model multiple health information sources. The multi-group analysis allows for the test of moderation effects, and the indirect estimation allows for the test of mediation effects (B. O. Muthén, Muthén, & Asparouhov, 2016; Ryu & Cheong, 2017). A probit link function with a mean and variance adjusted weighted least squares (WLSMV) estimator was used given the dichotomous outcome variables. The sampling weight and 80 replicate weights were applied in all analyses (AIR PIAAC Team, n.d.). Mediation analysis typically includes a bootstrapping approach for robust standard error estimation (Hayes, 2013), but here the replicate weights were used for the same purpose—and to also incorporate the measurement of literacy and numeracy based on sets of 10

plausible values. Statistical analyses were conducted using Mplus version 8 (L. K. Muthén & Muthén, 1998-2017).

The basic mediation model equation has been published elsewhere (e.g., Hayes, 2013; B. O. Muthén et al., 2016). Thus, we simply highlight selected parts of the equation. Covariates are not shown for simplicity (see Figure 2 for the overall model specifications, correlations and corresponding coefficients are expressed with Greek letters in the equations).

$$y_{vig} = \kappa_{0g} + \kappa_{ig} Education_i + \kappa_{2g} Literacy_i + \kappa_{3g} Numeracy_i + \epsilon_{1gi} \text{ (Equation 1)}$$

$$Literacy_i = \pi_{01g} + \pi_{1g} Education_i + \epsilon_{2gi} \text{ (Equation 2)}$$

$$Numeracy = \pi_{02g} + \pi_{2g} Education_i + \epsilon_{3gi} \text{ (Equation 3)}$$

Let Y_v represent one (v = 1-8) of eight health information sources and κ be the coefficient of the variable for individual (i) in health status group (g) (i.e., fair/poor vs. good or better health). Use of health information sources is modeled as a function of education, literacy, and numeracy. The mediation or indirect effects of education on the use of health information sources (Y_v) through literacy and numeracy are estimated as follows:

$$Indirect\ effect\ (Literacy)_g = \pi_{1g} * \kappa_{2g} \text{ (Equation 4)}$$

$$Indirect\ effect\ (Numeracy)_g = \pi_{2g} * \kappa_{3g} \text{ (Equation 5)}$$

Finally, the moderation of the indirect effects by health status (g) is evaluated by computing the difference between the indirect effect of the fair/poor health group and that of the good or better health group.

[Figure 2 About Here]

A total of 162 parameters were estimated in the final model, which included 18 variables. Given the off-diagonal elements (n = 172) of the variance-covariance matrix and no error message in the Mplus output, we assumed the identification of the final model (Wang & Wang,

2012). Model fit was evaluated using standard indices and guidelines, including the model chi-square statistic, comparative fit index (CFI > 0.90), Tucker-Lewis index (TLL > 0.90), and root mean square error of approximation (RMSEA < 0.10) (Kline, 2016). However, it was not possible to compute the recommended model fit indices with the plausible values and replicate weights. As such, models with each of the 10 plausible value sets and without the replicate weights were constructed to compute model fit indices. Considering all 10 sets of model fit indices, the range was reported and was used for model evaluation. Although this model evaluation may not precisely reflect the final model, the indices from the models with individual plausible values should provide approximate model fit information because the model specifications were identical. In the preliminary analysis, we examined the bivariate summary statistics (e.g., correlation matrix; available upon request) of all variables, checked for possible collinearity, and conducted a series of sensitivity analysis (e.g., alternative models, nested or reduced models). The final model was selected according to the model fit indices, theoretical propositions, model assumptions, and parsimony. Statistical significance was determined at the *p*-value of 0.05.

Results

Table 1 shows the unweighted descriptive summary of key variables by health status. Approximately 25% of respondents reported that their health was fair or poor. More than half of the fair/poor health group used health professionals (85%), TV (69%) and social networks (59%), whereas more than half of the good health group used health professionals (84%), TV (70%), internet (69%), social networks (68%), books (61%), and magazines (51%) as health information sources. The fair/poor health group had relatively lower literacy and numeracy. Also,

the fair/poor health group was more likely to be non-white, have lower educational attainment, no health insurance, and non-native English speakers compared to the good health group.

[Table 1 About Here]

[Table 2 About Here]

The estimated coefficients from unconditional models are presented in Table 2 to document baseline associations between education and health information sources. The estimated coefficients of the fully conditional model are summarized in Table 3a and 3b, and the coefficients of covariates on literacy and numeracy are shown in Table 4. The model fit indices [Model x^2 = 222.282 – 230.489 (all $p < 0.05$); CFI = 0.968 – 0.971; TLI = 0.930 – 0.935; RMSEA = 0.028 – 0.029] collectively suggested good fit in the final model. Education was a strong predictor of literacy and numeracy among both health groups. The significance of education effects on the use of specific health information sources differed by health status. For example, education was associated only with the use of internet and books among the fair/poor health group. Whereas education was a significant predictor for the use of 6 health information sources among the good health group (i.e., newspapers, internet, radio, TV (negative effect), books, and health professionals).

The significance of literacy and numeracy effects on the use of health information sources also differed by health status. For example, literacy was only associated with the use of magazines, books, and health professionals among the fair/poor health group, but literacy was predictive of newspapers, magazines, internet, books, social network, and health professionals among the good health group. Furthermore, numeracy was negatively associated with the use of 4 health information sources among the fair/poor health group (i.e., magazines, TV, books, and health professionals). However, numeracy was negatively associated with the use of all but one

source (i.e., radio) among the good health group. With respect to the covariates, older age, race (non-white), less than a college education and non-native English speaker were statistically significantly associated with lower literacy and numeracy (all $p < 0.05$; see Table 4).

Literacy and numeracy were shown to partially mediate the effects of education on the use of specific health information sources. For example, literacy mediated the effects of education on the use of magazines, books, and health professionals among the fair/poor health group, and all sources but radio and TV among the good health group. Mediation effects through numeracy were observed for magazines, TV, books and health professionals in the fair/poor health group, and all sources but radio in the good health group. Furthermore, the comparison of estimated indirect effects between the fair/poor and good health groups showed significant differences in the indirect effects through literacy as well as numeracy on health professionals. That is, the mediation effects of literacy and numeracy on health professionals as a health information source were moderated by health status.

Taken together, in terms of both literacy and numeracy, moderated mediation effects were observed for health professionals. Specifically, the mediation effect through literacy was significantly greater among the fair/poor health group compared to the good health group. Given that the effect of education on the use of health professionals among the poor/fair health group is non-significant, literacy mainly promotes the use of health professionals as a health information source. Even among the good health group, literacy still promotes the use of health professionals as a health information source above and beyond education. Also, the mediation effect through numeracy was significantly greater among the fair/poor health group than the good health group. However, in this case, the effect was negative. In other words, when health status is optimal,

greater numeracy is linked to relatively less frequent use of health professionals as a health information source.

[Table 3a, 3b, and 4 About Here]

Discussion

We addressed whether fundamental health literacy components (i.e., literacy and numeracy) mediate the relationship between educational attainment and health information use, and whether these mediated relationships were moderated by health status. Education is a widely recognized determinant of health information seeking behaviors (Kutner et al., 2007; Prins & Monnat, 2015; Tu & Cohen, 2008), and our findings partially supported the importance of considering health information needs. Also, one's educational attainment is directly linked to her or his health literacy (Kutner et al., 2007). The present study provided some of the first nationally representative empirical evidence for how education functions through health literacy (in terms of literacy and numeracy) to determine health information seeking behavior. Finally, health status substantially moderates the relationship between both literacy and numeracy with the use of health professionals as a health information source.

Direct effect: education

Given that education is a well-established predictor of health information seeking behaviors (Kutner et al., 2007; Prins & Monnat, 2015; Tu & Cohen, 2008), it was somewhat surprising that education was not a consistent predictor of health information use. For example, while education was directly linked to 6 of 8 health information sources among those with good health, it was only predictive of two sources (i.e., internet and books) among those with fair/poor health. Education might have resulted in proactive health information seeking among those with good health, which would reflect a preventative health strategy (Taha et al., 2009). Alternatively,

people tend to look for health information regardless of their educational attainment when there is an urgent need (i.e., poor health) (Manierre, 2015), and this may explain why education did not largely differentiate health information seeking behavior among the fair/poor health group. However, it should be noted that there is no statistically significant difference in the coefficients between the good and fair/poor health groups. As shown in Tables 3a and 3b with the † symbol, results only suggest that education is a predictor of some health information sources in one group but not in the other group.

Mediation and direct effect: literacy and numeracy

Present findings are among the first to show how health literacy (in terms of literacy and numeracy) actually mediates the association between health information seeking behaviors and education. The mediation effects of literacy and numeracy were evident for some, but not all, health information sources. When trying to identify patterns in these mediation effects we thought it may be useful to consider common classifications of health information sources, such as active and passive, and text- and oral-based classifications (Feinberg et al., 2016; Malone et al., 2017; Niederdeppe et al., 2007). Yet, there were no clear patterns for predicting the use of specific types of health information sources. However, it is important to consider that education was not a particularly strong predictor of health information seeking behaviors among those with poor health. Thus, future research should focus on identifying indirect pathways that link educational attainment with health information seeking among those with good health.

While the direct effects of literacy differed across health information sources and by health status, all of the statistically significant effects were in a positive direction. Some possible explanations for this finding include: Greater literacy skills have been consistently associated with the use of multiple health information sources (Feinberg et al., 2016; Kim et al., 2015).

Those with lower literacy skills may feel uncomfortable seeking health information (Hibbard, Peters, Dixon, & Tusler, 2007). Effective health information seeking requires one to know specific health topics, locate possible sources of information and evaluate their accuracy (Gaglio et al., 2012). Often, patients use an alternative information source as a "second opinion" to verify information provided by their physicians (Sciamanna, Clark, Diaz, & Newton, 2003). At the same time, even when health is optimal, adults with greater literacy skills were shown to seek health information from a variety of sources. Similar to the findings of education and information seeking among those with good health, literacy skills are presumed to promote proactive health information seeking (Saab et al., 2018).

Somewhat conversely, all of the statistically significant effects of numeracy on health information seeking behaviors were in a negative direction. Our explanation of this finding is two-fold: First, given that numeracy is associated with the comprehension of complex numeric health information (Hibbard et al., 2007; Isaac M Lipkus & Peters, 2009; Peters et al., 2007), those with greater numeracy potentially avoid specific sources that typically have a reputation for "low quality" health information (e.g., magazines, TV, and newspapers) (Len-Ríos & Hinnant, 2014). Second, these findings may imply existing health-related knowledge (Gaglio et al., 2012; Isaac M Lipkus & Peters, 2009). In other words, mature adults with greater numeracy may have already acquired necessary health information, and therefore, they require relatively less information.

Moderated mediation: literacy and numeracy

A major finding from this study is that health status was shown to moderate the mediated relationships between education and both literacy and numeracy with the use of health professionals as a health information source. Previous research has established that, regardless of

health literacy, health professionals are the most common and preferred health information source (Gaglio et al., 2012; Kelley et al., 2016). With greater literacy, adults are more likely to use health professionals to obtain health information presumably due to their enhanced ability to ask appropriate questions and carry out effective communication (Neter & Brainin, 2012). Less use of health professionals as an information source among those with greater numeracy may be a reflection of successful communication (e.g., effective information seeking experience; comprehension of information obtained) (Chen & Feeley, 2014; Hibbard et al., 2007). For example, poor numeracy distorts the risk and benefits of preventive health behaviors and lack thereof (Reyna, Nelson, Han, & Dieckmann, 2009). As such, adults with poor numeracy skills are likely to rely on health care providers for health information, but they tend to be relatively less successful in acting on the health information, thus, resulting in repeated visits (McNaughton et al., 2013).

In view of the behavioral model (Gelberg et al., 2000), when need is greater (i.e., poor versus good health status), the difference in numeracy skills as an enabling factor that leads to health information seeking arguably becomes more apparent. These moderated mediation findings point to the importance of examining, and addressing, health literacy disparities in access to and use of health information (Jensen et al., 2010). Thus, health professionals should be attentive to patients' health literacy, and recognize that in some cases they may be the sole source of health information (Feinberg et al., 2016).

Limitations

Some limitations include those that most other studies based on secondary data analysis face. Omitted variable bias cannot be ruled out. Other relevant information such as conventional sociodemographic indicators (e.g., marital status and wealth), existing health knowledge, and

previous information seeking experience (not available for use in the PIAAC PUF) would strengthen the validity of findings. An examination of potentially important factors such as the purpose and timing of health information seeking is useful. Also, additional data collection would be useful to verify findings in sub-populations such as racial/ethnic groups.

It was not feasible to generate commonly accepted model fit indices. Although we provided the range of fit indices based on all 10 sets of literacy and numeracy plausible values, uncertainty about their validity is warranted. Furthermore, due to scant research on numeracy and health information seeking at the population-level, our discussion of the moderated mediation effects drew on insights from relevant research with different literacy and numeracy measurements and non-representative samples. Thus, caution in the interpretation of results is warranted. Given the unique nature of our study, further development of our proposed conceptual model is needed. Also, as more detailed data become available, research should focus on other health information seeking behaviors (e.g., time spent, outcome, satisfaction, self-efficacy),

Conclusions

Findings from this study provided the evidence of the mediation relationships between education, literacy, numeracy and health, and moderation effect of self-rated health among adults aged 50 years and older. Poor health was found to alter both the effect of education on health information seeking as well as the mediation effects through literacy and numeracy. Given the identified moderated mediation effects, researchers, educators, and health practitioners should be aware of the complex interactions and distinctive roles of literacy and numeracy in the context of health information seeking. In later life, literacy and numeracy skills are critical to take advantage of existing and emerging health information over and above one's educational

background. Addressing health information disparities by education and health literacy may reflect a key step toward improving population health.

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Table 1: Unweighted Descriptive Summary by the Health Status

	Fair and poor health (n = 634)	Good or better health (n = 1,947)
	Percentage or mean (standard deviation)	Percentage or mean (standard deviation)
Health information sources		
Newspapers (some & a lot)	30.44%*	44.38%
Magazines (some & a lot)	39.12%*	50.95%
Internet (some & a lot)	42.59%*	68.72%
Radio (some & a lot)	30.12%*	38.16%
TV (some & a lot)	69.24%*	70.47%
Books (some & a lot)	47.95%*	60.55%
Social network (some & a lot)	59.30%*	68.31%
Health professionals (some & a lot)	85.18%*	83.93%
Literacy (1-500) [a]	210.74*	239.81
Numeracy (1-500) [a]	225.22*	254.13
Age group		
50-54 years old	24.76%	25.53%
55-59 years old	23.50%	21.88%
60-65 years old	23.66%	24.50%
66-70 years old	16.72%	18.95%
71 years and older	11.36%	9.14%
Gender (female)	56.62%	53.72%
Race (white)	67.30%*	76.02%
Education (college and higher)	19.72%*	44.55%
Income level [b]	*	
1 – lowest	83.91%	62.40%
2	5.99%	6.06%
3	4.26%	8.27%
4	3.15%	10.73%
5 – highest	2.68%	12.53%
Insurance (insured)	84.23%*	87.56%
Number of household members	2.22 (1.26)	2.20 (1.10)
Native English speaker	86.28%*	89.68%

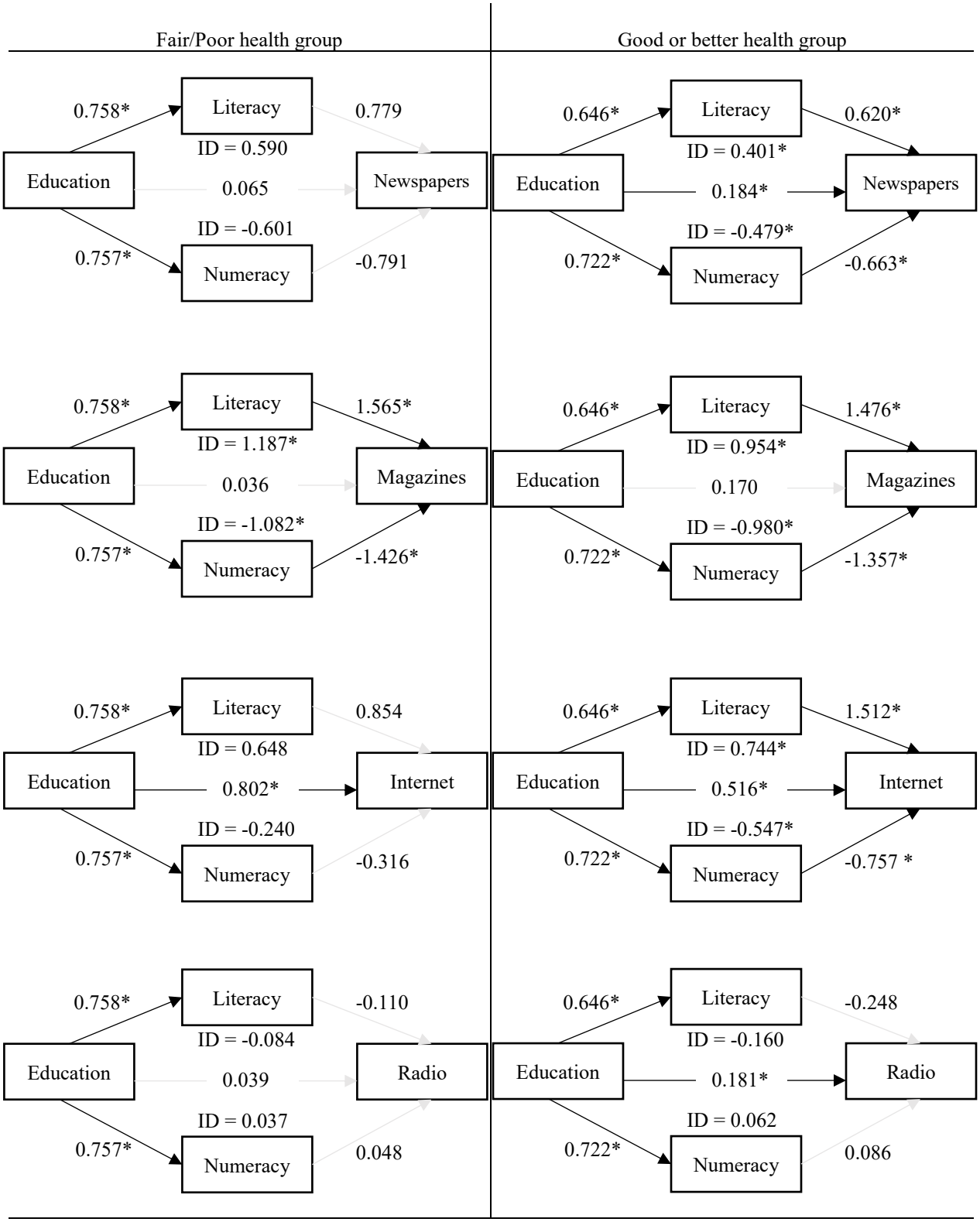
*$p < 0.05$; bivariate test between the fair/poor and good/very good or better health groups
a. Weighted average of 10 plausible values (See the methods section for details)
b. Level was determined by quintiles and no income was classified as the lowest quintile

Table 2: Estimated Coefficients of Education on Health Information Sources by Health Status from Unconditional Path Analysis with a Probit Link Function

	Fair and poor health (n = 634)	Good or better health (n = 1,947)
	Coefficient of education	Coefficient of Education
	Estimated coefficient (SE)	Estimated coefficient (SE)
Newspapers (some & a lot)	0.082 (0.132)	0.106 (0.059)
Magazines (some & a lot)	0.228 (0.158)	0.132 (0.066)*
Internet (some & a lot)	1.070 (0.133)*	0.700 (0.080)*
Radio (some & a lot)	-0.007 (0.108)	0.041 (0.067)*
TV (some & a lot)	-0.247 (0.125)*	-0.404 (0.069)*
Books (some & a lot)	0.587 (0.143)*	0.279 (0.061)*
Social network (some & a lot)	-0.052 (0.157)	0.067 (0.065)
Health professionals (some & a lot)	0.466 (0.192)*	0.355 (0.060)*

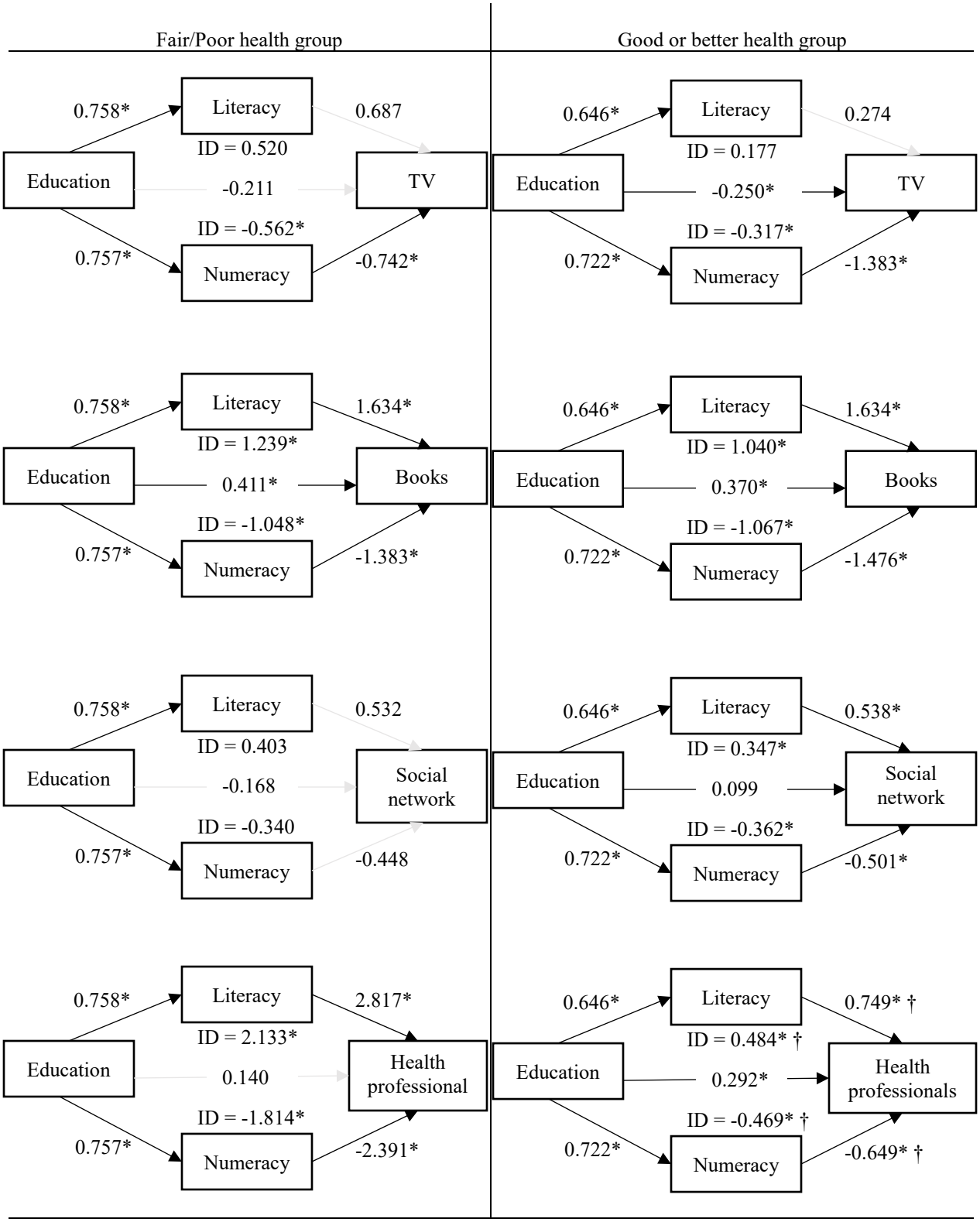
*$p < 0.05$; SE = Standard Error; Education = college and higher vs. less than college
Note: Sampling weights and replicates weights were applied. The models were not adjusted for covariates for the purpose of describing baseline associations.

Table 3a: Estimated Coefficients from Path Models with a Probit Link Function



*$p < 0.05$; ID = indirect/mediation effect; solid line indicates statistical significance; gray line indicates non-significance; all models were adjusted for covariates, and correlations between literacy and numeracy

Table 3b: Estimated Coefficients from Path Models with a Probit Link Function



*$p < 0.05$; † = $p < 0.05$ (significant moderation effect by health status); ID = indirect/mediation effect; solid line indicates statistical significance; gray line indicates non-significance; all models were adjusted for covariates, and correlations between literacy and numeracy

Table 4: Estimated Coefficients for the Covariates on Literacy and Numeracy from Path Analysis with a Probit Link Function

	Poor/fair health		Good or better health	
Outcome	Literacy	Numeracy	Literacy	Numeracy
Covariates				
Age group	-0.120*	-0.142*	-0.087*	-0.105*
Gender (female)	-0.040	-0.241*	0.039	-0.315*
Race (white)	0.668*	0.816*	0.587*	0.844*
Education (college and higher)	0.758*	0.757*	0.646*	0.722*
Income level	0.114*	0.088	0.064*	0.055*
Insurance (insured)	0.079	-0.166	0.292*	0.183*
Number of household members	-0.060	-0.049	-0.015	-0.008
Native English speaker	0.535*	0.385*	0.371*	0.295*

*$p < 0.05$

Note: Sampling weights and replicates weights were applied.

Figure 1: Operationalized Conceptual Model of Educational Attainment, Literacy, Numeracy, and Health Information Seeking

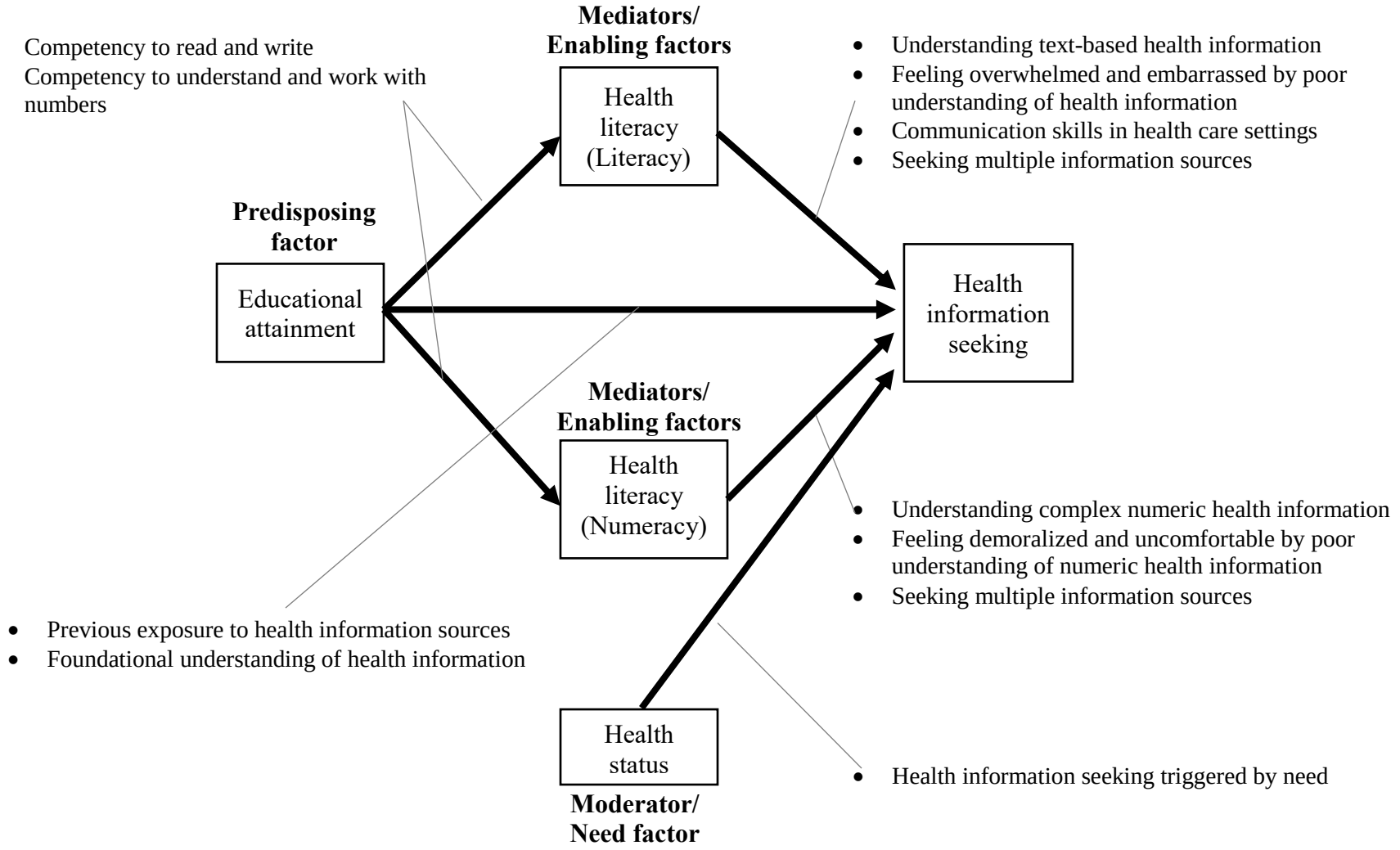
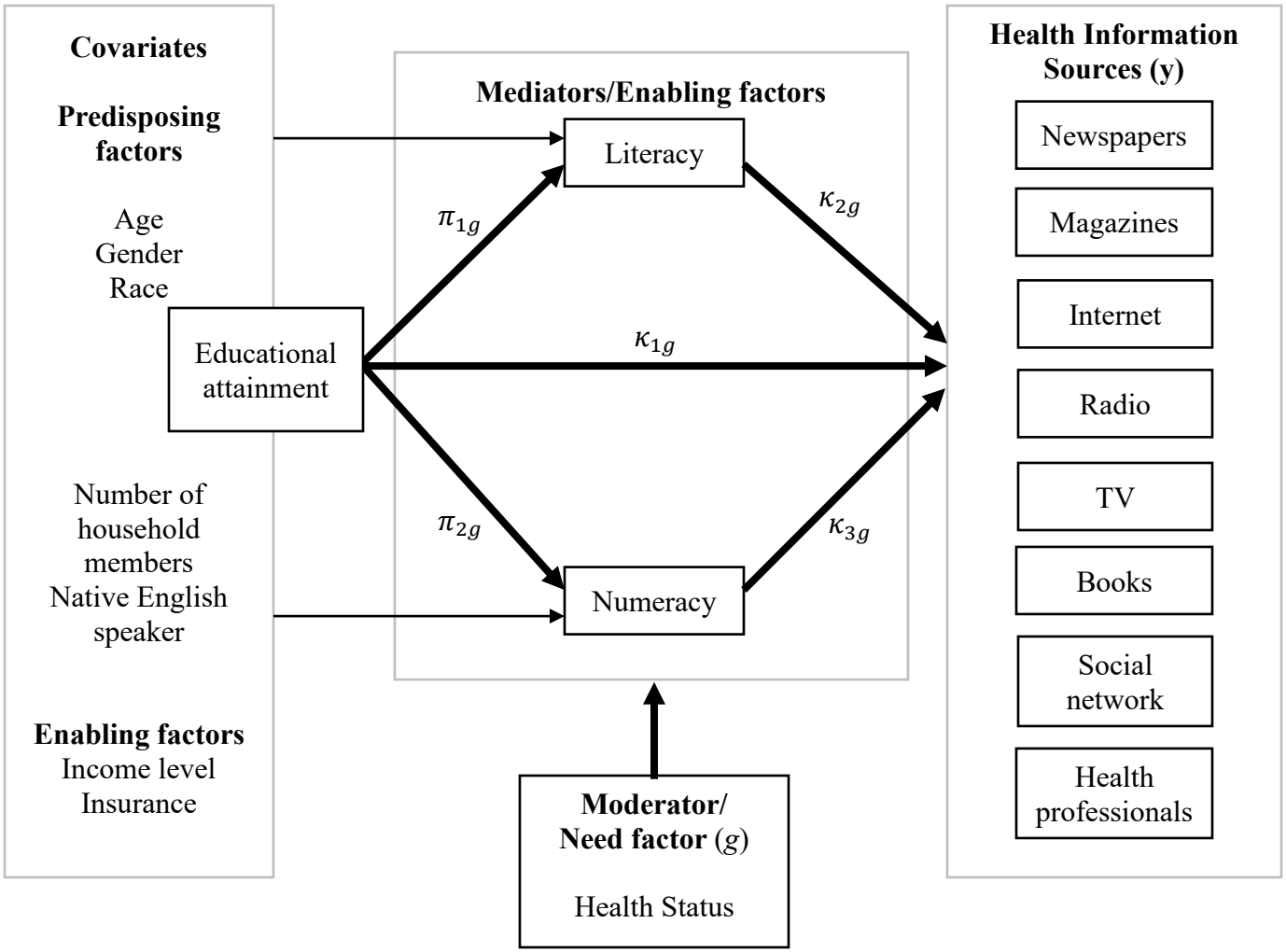


Figure 2: Simplified Path Diagram of the Final Model



Note: Straight line = regression paths; bold lines indicate research questions; all variables in each box with gray lines were allowed to be correlated. For the notation (i.e., Greek letters), see the methods section; (g) groups indicator (fair/poor health vs. good or better health)