Preventive Medicine 129 (2019) 105872

Contents lists available at ScienceDirect

Preventive Medicine

journal homepage: www.elsevier.com/locate/ypmed

Association between numeracy and self-rated poor health in 33 high- and upper middle- income countries

Justin Rodgers[a,b,1], Sujay Kakarmath[c,1], Vanessa Denis[d], Marta Encinas-Martin[d], S.V. Subramanian[a,b,*]

[a] Harvard Center for Population and Development Studies, Harvard University, Cambridge, MA 02138, USA
[b] Department of Social and Behavioral Sciences, Harvard T.H. Chan School of Public Health, Boston, MA 02115, USA
[c] Department of Global Health and Population, Harvard T.H. Chan School of Public Health, Boston, MA 02115, USA
[d] Directorate for Education and Skills, Organisation for Economic Co-operation and Development, 2 Rue André Pascal, 75116 Paris, France

ARTICLE INFO

Keywords:
Numeracy
Health literacy
Literacy
Self report
Health status
Socioeconomic factors
Organisation for economic co-operation and development
Programme for the international assessment of adult competencies

ABSTRACT

The association between numeracy proficiency and health outcomes has been the subject of several studies. However, it is not known if this association is independent of educational attainment and literacy proficiency. In this study, we used logistic regression to model numeracy proficiency as a predictor of self-rated poor health after accounting for educational attainment and literacy proficiency. The prevalence of self-rated poor health among 166,863 adults aged 16–65 years from 33 high- and upper middle-income countries was 24%. Compared to those with the highest numeracy proficiency (level 4), the odds ratio of self-rated poor health for those with the lowest numeracy proficiency (level 1) was 2.2 (95% CI 1.9–2.7) and attenuated to 1.8 (95% CI 1.5–2.1) and 1.5 (95% CI 1.1, 2.0), respectively, after sequential addition of self-education and literacy proficiency. For those who were assessed to have low levels of both numeracy and literacy proficiency, the odds ratio of self-rated poor health was 1.4 (95% CI 1.3 to 1.5), relative to those who had high levels of both numeracy and literacy proficiencies. Numeracy and literacy proficiencies show both independent and interdependent correlations with poor self-rated health. Further, these associations varied by sociodemographic characteristics and across countries. Policies aimed at improving numeracy and literacy may be beneficial in preventing adverse health outcomes.

1. Introduction

Health literacy, the degree to which individuals have the capacity to obtain, process, understand, and act on basic health information, is an important determinant of population health and health inequalities (Berkman et al., 2011; Chinn, 2011; Hibbard et al., 2007; Peters et al., 2007). Those with lower levels of health literacy may face challenges accurately comprehending and acting on health-related information, obtaining preventive health services, and following treatment protocols (Berkman et al., 2011; Chinn, 2011; Hibbard et al., 2007; Osborn et al., 2013; Peters et al., 2007). A recent systematic review by Berkman et al. found consistent evidence of associations between low health literacy and increased hospitalizations, greater use of emergency departments, lower utilization of preventive care (e.g., cancer screenings and vaccinations), worse health outcomes, and a higher risk of mortality (Berkman et al., 2011). Further, the role of health literacy in patient lives may be of increasing import as policymakers, health providers, and insurers aim to place a greater share of health-related decision-making onto consumers, with the hope of achieving gains in efficiency and reducing overall healthcare costs (Hibbard et al., 2007). At the same time, healthcare systems, insurance policies, and evidence of provider quality and treatment efficacy are all becoming more complex (Hibbard et al., 2007). Thus, consumers are being simultaneously confronted with an increasingly complex healthcare ecosystem and infosphere, with a growing necessity to effectively navigate it. Unfortunately, nationally representative surveys have found that many individuals struggle with basic literacy questions (Berkman et al., 2011; Hibbard et al., 2007). Upwards of a quarter of the U.S. population is estimated to have limited health literacy and rates may be even higher among the elderly, minorities, individuals of lower socioeconomic status, and in other countries (Berkman et al., 2011). Thus, low health literacy may also be a conduit for the production of social inequalities

* Corresponding author at: 9 Bow Street, Cambridge, MA 02138, USA.
E-mail address: svsubram@hsph.harvard.edu (S.V. Subramanian).
[1] Co-first-authors.

https://doi.org/10.1016/j.ypmed.2019.105872
Received 25 September 2018; Received in revised form 15 October 2019; Accepted 17 October 2019
Available online 20 October 2019
0091-7435/

in health. Yet, the distinct components of literacy and their unique effects on health are still poorly understood.

While health literacy has been traditionally conceptualized as one's ability to understand health information through the reading of print materials, there is an increasing recognition that literacy may be composed of facets other than reading comprehension, such as oral communication, electronic literacy, and numeracy (Herndon et al., 2011; Rothman et al., 2008; Rudd, 2017). Health numeracy, a related but distinct component of health literacy, focuses on an individual's capacity to understand and act on numeric information (Golbeck et al., 2005). Health numeracy may play an important role in patients' abilities to interpret quantitative information, appropriately weigh risks and benefits of treatment options, and properly adhere to treatment protocols (Herndon et al., 2011). As with health literacy in general, health numeracy in particular may be of increasing importance as a health input due to the ever-increasing magnitude and complexity of numeric information within the healthcare ecosystem and society as a whole. Further, as noted by Herndon et al., assessing numeracy skills separately from reading comprehension may be important for identifying appropriate targets for interventions (Herndon et al., 2011). However, the joint and independent effects of health numeracy on health outcomes are unclear.

While the relationship between general health literacy and health has been extensively researched, the role of health numeracy as a unique contributor to specific health outcomes is less well understood (Berkman et al., 2011; Herndon et al., 2011). The aforementioned systematic review by Berkman et al. located far fewer numeracy studies (22 studies of numeracy compared to 98 on literacy), and was unable to come to a conclusion regarding the relationship between numeracy and health outcomes due to the limited number of studies and inconsistencies in their results (Berkman et al., 2011). Likewise, a systematic review of health literacy among Emergency Department (ED) patients was only able to locate a single study that looked specifically at health numeracy (Herndon et al., 2011). Of note, this study by Ginde et al., reported shockingly low measures of health numeracy among ED patients; e.g., one-third of patients were unable to understand how many pills of a prescription should be taken (Ginde et al., 2008). In their systematic review of health literacy and diabetes, Al Sayah et al. located many studies on numeracy and intermediary outcomes (e.g., self-efficacy, self-care, and ability to use computers), but few including objectives measures of health (Al Sayah et al., 2013). Of the four studies including objective health outcomes (i.e., A1c measures), only one identified a significant association with health numeracy (Al Sayah et al., 2013). The authors also noted considerable heterogeneity in confounding control – of these four studies; only two included any adjustment for confounding (Al Sayah et al., 2013). We also conducted our own review of the literature, uncovering 48 original research studies on numeracy and health, which we have summarized in the supplementary materials (Appendix A). As with previous reviews, we observed copious variation across studies in terms of methods and findings. We also found that the majority of studies were conducted in the U.S., primarily on non-representative samples, especially clinical populations, thereby greatly limiting generalizability and precluding the application of findings to countries with differing social, cultural, and macroeconomic conditions.

Therefore, we estimated the relationship between health numeracy and self-rated health among adults from 33 high and upper-middle-income countries, utilizing nationally representative survey data from the Programme for the International Assessment of Adult Competencies (PIAAC). Additionally, in order to address ambiguity in the precise role of numeracy as a correlate of health – vis-à-vis general health literacy – we further estimated both the independent and synergistic effects of numeracy and literacy in relation to poor self-rated health. It is our hope that understanding the relative contributions to health of these distinct components of health literacy may aid in the design of interventions to optimize the translation of health information into improved population health, reduced inequalities in health, and reductions in healthcare costs.

2. Methods

2.1. Sample

Data for this study derive from the Programme for the International Assessment of Adult Competencies (PIAAC) (OECD, 2013). PIAAC is an international survey of approximately 250,000 adults (aged 16–65 years) conducted by the Organization for Economic Cooperation and Development (OECD), with the aim of collecting cross-national data on adult proficiencies and utilization of key information-processing skills, including literacy, numeracy, and problem-solving (OECD, 2013). After removing individuals with missing responses on key study variables, we were left with a final analytic sample of 166,863 participants. Data was collected over the period 2011–2015 from the following 33 countries or national sub-regions: Australia, Austria, Belgium (Flanders), Canada, Chile, the Czech Republic, Cyprus, Denmark, Estonia, Finland, France, Germany, Greece, Ireland, Israel, Italy, Japan, Korea, Lithuania, the Netherlands, New Zealand, Norway, Poland, the Russian Federation (excluding the Moscow region), Singapore, the Slovak Republic, Slovenia, Spain, Sweden, Turkey, the United Kingdom (England and Northern Ireland), and the United States. Further details regarding survey design, timeline, and implementation in each participating region are published in a separate technical report (OECD, 2013).

2.2. Outcome: poor self-rated health

PIAAC surveys included a question to assess self-rated health, which was asked as follows: “In general, would you say your health is: ‘excellent’, ‘very good’, ‘good’, ‘fair’, or ‘poor’?” (OECD, 2013). We collapsed these responses in order to construct a binary ‘self-rated poor health’ outcome variable. In accordance with prior research, and based on the distribution of responses, we defined ‘poor’ self-rated health to include both ‘fair’ and ‘poor’ health (Kakarmath et al., 2018). Correspondingly, the ‘healthy’ reference category was defined as those who responded ‘excellent’, ‘very good’, or ‘good’. Self-rated health has been demonstrated to be a valid and reliable predictor of objective health, including mortality (Farmer and Ferraro, 1997; Idler and Benyamini, 1997; Subramanian and Ertel, 2009). The association between self-rated health and mortality is consistent across socioeconomic status, but may vary by gender and ethnicity (Franks et al., 2003; Van Doorslaer and Gerdtham, 2003).

2.3. Primary independent variable: numeracy proficiency

The PIAAC defines numeracy as: “the ability to access, use, interpret and communicate mathematical information and ideas, in order to engage in and manage the mathematical demands of a range of situations in adult life” (OECD, 2013). According to the PIAAC's conceptual framework, numerate behavior is founded on the activation of several enabling factors, which may include dispositional elements, such as: a) numeracy-related beliefs and attitudes, b) practices and experiences, and c) context/world knowledge – in addition to prototypical quantitative aptitudes such as: d) mathematical knowledge and conceptual understanding, e) adaptive reasoning, and f) mathematical problem-solving and literacy skills (PIAAC Numeracy Expert Group, 2009). Further, numerate behavior relies on the ability to leverage mathematical information depicted in numerous ways to solve problems or manage situations in a real context. Thus, the construct of numeracy was operationalized and assessed through an index of 100 test items of varying difficulty, covering four areas of mathematical content (“data and chance”, “dimension and shape”, “pattern, relationships and change”, and “quantity and number”), three response types (“identify,

locate, access", "act upon, use", and "interpret, evaluate/analyze"), and four contexts (work, school, community, and personal) (PIAAC Numeracy Expert Group, 2009). Each participant responded to a subset of items from the total pool of 100 items, following a computer-based adaptive testing process (OECD, 2013) (OECD, 2013). This design allowed for the efficient administration of a large number of tasks at all proficiency levels. Evaluations of scoring systems found robust reliability both within and between countries (PIAAC Numeracy Expert Group, 2009).

Continuous Proficiency Scores represented on a 500-point scale were calculated using Item Response Theory models based on probabilities of correctly answering items of varying difficulties (PIAAC Numeracy Expert Group, 2009). PIAAC categorized continuous proficiency scores into a six-level categorical Proficiency Levels variable (Table B.2 in Appendix B) (PIAAC Numeracy Expert Group, 2009). For the purposes of this study, we re-coded the Proficiency Levels variable from six to four categories according to the following criteria: 'Below Level 1' and 'Level 1' = 1 (Score < 226 points); 'Level 2' = 2 (Score 226–276); 'Level 3' = 3 (Score 276–326); and 'Level 4' and 'Level 5' = 4 (Score > 326). This approach was taken in order to be consistent with prior analyses published by OECD personnel, and based on low cell counts in the extreme categories (Kakarmath et al., 2018). More comprehensive descriptions of the PIAAC's conceptualization and operationalization of the construct of numeracy (and literacy) are described elsewhere (Kakarmath et al., 2018; OECD, 2013; PIAAC Numeracy Expert Group, 2009).

2.4. Secondary independent variable: general literacy

General literacy was defined by the PIAAC as: "understanding, evaluating, using and engaging with written texts to participate in society, to achieve one's goals, and to develop one's knowledge and potential" (OECD, 2013). This concept of literacy was assessed through 100 test items of varying difficulty, consisting of two mediums (print and digital), four contexts (work, school, community, and personal), and three cognitive strategies ("access and identify", "integrate and interpret", and "evaluate and reflect") (OECD, 2013). As with the assessment of numeracy, each participant only responded to a subset of the 100 literacy questions, and was scored on a 500-point scale (OECD, 2013). Continuous Proficiency Scores were categorized into a four-level categorical variable based on the same criteria and rationale described above for numeracy.

2.5. Combination of numeracy and literacy proficiencies

We also created a categorical variable reflecting the combination of numeracy and literacy proficiency scores, which will hereafter be referred to as 'numeracy-literacy combination'. The numeracy-literacy combination variable was defined as follows: a proficiency level of 3 or higher in both numeracy and literacy proficiency was coded as '0' (high in both); proficiency level of 3 or higher in literacy, but level 2 or below in numeracy was coded as '1' (low in numeracy); proficiency level of 2 or below in literacy, but level 3 or higher in numeracy was coded as '2' (low in literacy); and proficiency level of 2 or below in both numeracy and literacy proficiency was coded as '3' (low in both). This variable was constructed in order to approximate the additive interaction of literacy and numeracy within a single variable. The specific coding scheme was based on distributions of the numeracy and literacy variables, study objectives, and theoretical considerations.

2.6. Covariates

The PIAAC survey included a background interview that asked respondents a series of sociodemographic questions. From this section of the survey we acquired a number of key variables to adjust for the possibility of confounding, including age, gender, country of birth, education, parents' education, employment status, and absolute income. For this analysis, we re-coded employment status and country of birth into dichotomous variables (employed at the time of survey: yes/no; born in country where survey was administered: yes/no). Income was divided into quintiles based on the distribution of sample data. Participant and parental education variables were mapped onto the International Standard Classification of Education (ISCED) levels by PIAAC to allow for cross-country comparability (Schneider, 2013).

2.7. Statistical analysis

Distributions of poor self-rated health, numeracy and literacy proficiencies, and sociodemographic characteristics were summarized numerically (descriptive statistics) and graphically (box plots). Bivariate correlations of poor self-rated health by numeracy and literacy proficiencies were calculated and presented via cross-tabulations and box plots.

The independent and combined effects of numeracy (and literacy) on poor self-rated health, adjusted for sociodemographic covariates, were estimated using logistic regression. First, we modeled numeracy proficiency alone as a predictor of self-rated poor health (Model 1). Then, we sequentially adjusted for parental education (Model 2) and participant education (Model 3) to assess the relative importance of numeracy proficiency beyond educational attainment. Next, in Model 4, we assessed the robustness of the effect of numeracy proficiency on poor self-rated health, after additional adjustment for literacy. To further understand the interplay between numeracy and literacy proficiencies, we used the numeracy-literacy combination variable as a predictor of self-rated poor health, with high levels of both numeracy and literacy set as the reference group. Lastly, we evaluated the possibility of variation in the association between the numeracy-literacy combination variable and self-rated poor health by education and gender via stratified models. All models adjusted for age, gender, employment, income, and country of birth. All models were estimated using a SAS macro enabling computation of design based standard errors, which take into account the complex sampling of persons within countries and psychometric items within respondents using a jackknife procedure (Denis, 2014).

3. Results

3.1. Sample characteristics

The prevalence of self-rated poor health across all 33 countries and national sub-regions was 24% (Median 19%; Interquartile range (IQR) 16 to 23%), ranging from 12% in Canada to 45% in the Russian Federation and South Korea. Overall, only 11% (IQR: 8–14%) of participants were assessed to be at the highest numeracy proficiency level (level 4/5), ranging from under 2% in Turkey and Chile to approximately 20% in Finland, Japan and Sweden. (Fig. B.3 in Appendix B). Numeracy and literacy proficiency scores were highly correlated with one another, yielding an overall correlation coefficient of $r = 0.86$, which ranged from $r = 0.80$ for the Czech Republic and the Russian Federation to $r = 0.93$ in Singapore (Table B.5 in Appendix B). For the numeracy-literacy combined variable, the overall proportion of participants in each category were as follows: 47% low in numeracy and literacy, 9% low in numeracy but high in literacy, 7% high in numeracy but low in literacy, and 35% high in both numeracy and literacy (Table B.5 in Appendix B).

3.2. Numeracy and self-rated poor health: bivariate associations

Results from bivariate comparisons showed inverse relationships, such that higher numeracy/literacy proficiency levels correlated with lower prevalence of poor self-rated health. The prevalence of self-rated poor health was highest at numeracy proficiency level 1 for all

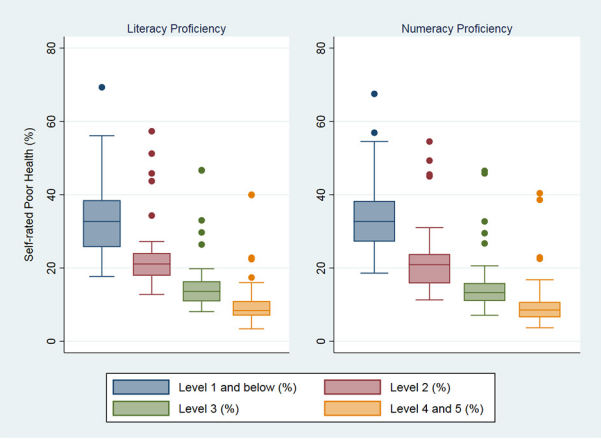

Fig. 1. Prevalence of self-rated poor health by literacy and numeracy proficiency levels in the Programme for the International Assessment of Adult Competencies survey data from 33 high and upper middle income countries and national sub-regions (2011–2015).

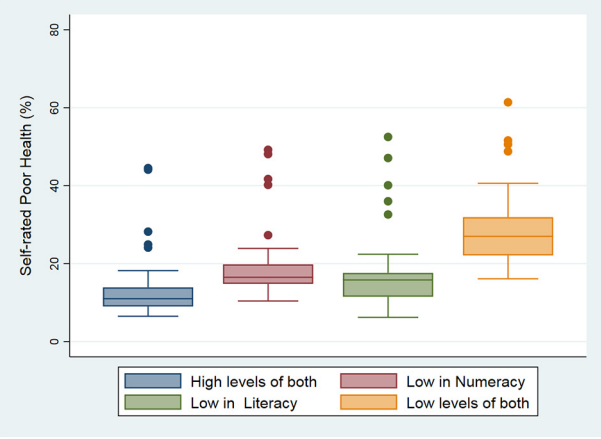

Fig. 2. Prevalence of self-rated poor health by levels of numeracy-literacy combination in the Programme for the International Assessment of Adult Competencies survey data from 33 high and upper middle income countries and national sub-regions (2011–2015).

countries with an overall median (M) of 33% (IQR: 27–38%), ranging from a low of 20% in Canada and Greece to a maximum of 68% in South Korea (Fig. 1). On the other hand, for those with numeracy proficiency level 4/5, the prevalence of poor-self rated health was only 10% (IQR: 12–15%). Bivariate correlations between self-rated poor health and literacy showed a similar pattern, and have been described in detail elsewhere (Kakarmath et al., 2017). As such, correlations between poor SRH and the numeracy-literacy combination variable also followed an inverse relationship, albeit with some variation across countries (Fig. 2).

3.3. Numeracy and self-rated poor health: multiple-adjusted associations

Estimates from logistic regression models showed that, after adjustment for age, gender, employment, income and country fixed effects (Model 1), those with the lowest numeracy proficiency (level 1) had a 2.4 times greater odds [OR = 2.4 (95% CI 2.0 to 2.8)] of self-rated poor health compared to those with the highest numeracy proficiency (level 4) (Table B.6 in Appendix B). Further, a graded pattern was observed, such that those in Level 2 had an odds ratio of 1.5 (95% CI 1.2 to 1.8) and those in level 3 had an odds ratio of 1.2 (95% CI 1.0 to 1.4). After additional adjustment for parental education (Model 2) and participant education (Model 3), the odds ratio (for lowest vs. highest numeracy) decreased sequentially to 2.2 (95% CI 1.9 to 2.7) and 1.8 (95% CI 1.5 to 2.1), respectively (Table B.6 in Appendix B). Upon further adjustment for literacy proficiency (Model 4), the odds ratio further attenuated to 1.5 (95% CI 1.1, 2.0), but remained statistically significant at the 5% level (Table 1). Further examination of this relationship via the numeracy-literacy combination variable showed that, for individuals with low levels in either numeracy or literacy, but moderate levels in the other construct, the odds ratio was not significantly different from unity (1.00) (Table 2). However, for those with low levels in *both* numeracy and literacy proficiencies, the odds ratio of self-rated poor health was statistically significant ($p = .05$) with an adjusted OR = 1.4 (95% CI 1.3 to 1.5) (Table 2).

Table 1
Association between numeracy, literacy and self-rated poor health in pooled data from 33 high- and upper middle-income countries and national sub-regions from the Programme for the International Assessment of Adult Competencies survey (2011–2015).

	Model 3 Odds ratio (95% confidence interval)	Model 3* Odds ratio (95% confidence interval)	Model 4 Odds ratio (95% confidence interval)
Numeracy proficiency			
Level 0/1, lowest	1.8 (1.5, 2.1)		1.5 (1.1, 2.0)
Level 2	1.3 (1.0, 1.5)		1.2 (0.9, 1.5)
Level 3	1.1 (0.9, 1.3)		1.1 (0.9, 1.3)
Level 4/5, highest	Reference		Reference
Literacy proficiency			
Level 0/1, lowest		1.9 (1.6, 2.2)	1.5 (1.2, 2.0)
Level 2		1.3 (1.1, 1.6)	1.2 (0.97, 1.5)
Level 3		1.2 (1.0, 1.4)	1.1 (0.9, 1.4)
Level 4/5, highest		Reference	Reference

All models adjusted for age, gender, education, parental education, employment status, income, country of birth, and country fixed effects.

3.4. Variation in numeracy-self-rated poor health associations

The relationship between the numeracy-literacy combination variable and poor self-rated health showed some slight variation by education and gender, with odds ratios ranging from 1.6 (95% CI 1.2 to 2.0) for those in the lowest education category to 1.3 (95% CI 1.1 to 1.5) for those in the highest education level (Table B.7 in Appendix B), and from 1.5 (95% CI 1.3 to 1.7), for males and 1.3 3 (95% CI 1.1 to 1.5) for females (Table B.8 in Appendix B). Fully adjusted odds ratios also displayed some variation across countries, with country-specific ORs ranging from 1.3 in Estonia and Flanders (Belgium) to 1.8 in Austria, Germany and United States, and 1.9 in Israel. The association

Table 2
Effect of numeracy-literacy combination on self-rated poor health in pooled data from 33 high- and upper middle-income countries and national sub-regions from the Programme for the International Assessment of Adult Competencies survey (2011–2015).

	Model 6[a] Odds ratio (95% confidence interval)	Model 7[b] Odds ratio (95% confidence interval)
Numeracy-literacy combination		
High levels of both	Reference	Reference
Low in numeracy	1.2 (0.99, 1.4)	1.1 (0.9, 1.3)
Low in literacy	1.2 (0.93, 1.5)	1.1 (0.9, 1.4)
Low levels of both	1.6 (1.5, 1.8)	1.4 (1.3, 1.5)

[a] Model adjusted for age, gender, parental education, employment status, income, country of birth, and country fixed effects.
[b] Model adjusts for education in addition to all covariates from Model 6.

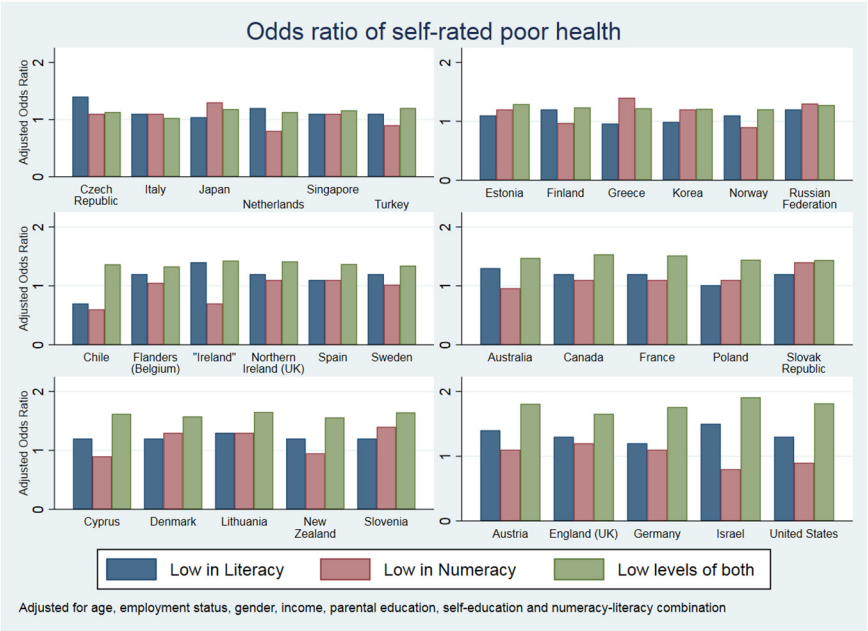

Fig. 3. Association between numeracy, literacy and self-rated poor health in 33 high and upper middle income countries and national sub-regions from the Programme for the International Assessment of Adult Competencies survey (2011–15).

between numeracy-literacy combination and self-rated poor health was significant for those low in both numeracy and literacy proficiency in 19 out of 33 countries (Fig. 3; Table B.10 in Appendix B).

4. Discussion

4.1. Summary of findings and relation to current research

Our study advances the literature on literacy and health in three important ways. First, we examined a particular component of literacy known as numeracy, the extent to which individuals can comprehend and act upon quantitative information, and its relationship to self-rated health in a representative sample of adults from 33 upper- and upper-middle- income countries. We observed that numeracy had an independent association with poor self-rated health, such that those with the lowest level of numeracy had 50% greater odds of reporting poor self-rated health compared to those with the highest numeracy level, even after adjustment for education, parental education, and traditional notions of literacy (related to reading comprehension). Further, there was some evidence of a synergistic relationship between numeracy and literacy in relation to poor SRH. In particular, a numeracy-literacy combination variable showed the greatest correlation with poor SRH for those with low levels of both numeracy and literacy, compared to those with lower levels on just one of these constructs. Lastly, we illustrated that there may be important heterogeneities in the numeracy-SRH relationship – both by gender and education, as well as across countries.

Given the varied nature of the literature on numeracy and health, our findings of a significant, inverse relationship are in accordance with some prior studies, but in discord with others. A majority of studies find significant correlations with subjective measures of general health (e.g., SRH), however variation exists in the persistence of these associations after adjustment for covariates (Berkman et al., 2011). For example, inline with results from the present study, Yamashita and Kunkel found that higher numeracy was positively associated with self-rated good health, after adjusting for general literacy and education in an analysis of the Adult Literacy and Life skills (ALL) survey data from 5 high-income countries (Yamashita and Kunkel, 2015). On the other hand, a study by Prins and Monnat found that numeracy was associated with better self-rated health in the United States after adjusting for demographic and health background characteristics, but this association was not significant after additional adjustment for socioeconomic status (Prins and Monnat, 2015). It is possible that our findings from 33 upper- and upper-middle- income countries more closely align with the study by Yamashita and Kunkel because they included five additional high-income countries, as opposed to just the U.S. If this is the case, it would indicate a divergence in the role of numeracy as a determinant of health, or in the way in which it is related to health, between the U.S. and other developed countries. We did not find any prior studies examining an interaction between numeracy and literacy, however a study by Szrek et al. demonstrated effect modification of numeracy and enrollment in prescription drug insurance by characteristics of the insurance plan (e.g., size) (Szrek and Bundorf, 2014). These results, as ours do, suggest an ability of the numeracy-health relationship to be modified by external factors – and hence, a more nuanced relationship that needs to be understood via further inquiry.

4.2. Strengths and limitations

Our study has several important strengths. First, few studies have examined the independent and interdependent associations between numeracy and health, especially in large general populations outside of the U.S. clinical setting. The PIAAC sample is representative of the general population of 33 upper- and upper-middle- income countries and national sub-regions. Our study presents the first nationally generalizable analysis of the numeracy-health relationship for many of these countries. Second, the PIAAC used a comprehensive and standardized assessment of numeracy that was shown to be both valid and reliable across all countries allowing for cross-country comparisons. In addition to estimating the relationship between numeracy and self-rated health, our study also included a comprehensive presentation of the distributions of numeracy and literacy proficiency levels for all 33 countries. Third, the large sample size allowed us to adjust for several important confounders, investigate the possible additive effects of numeracy and literacy, and examine variation in these relationships by sociodemographic characteristics and across countries.

Nonetheless, the present study is not without limitations. First and foremost, inferring a causal association between numeracy and self-

rated poor health is not possible due to the cross-sectional nature of our study design. We attempted to address the issue of confounding by adjusting for important variables related to both numeracy and health, however it is still possible that we omitted an important confounder(s), either measured or unmeasured. There is also the potential for reverse causation – i.e., that poor health, either real or perceived, is influencing (lowering) numeracy proficiency levels. We think it is less likely that self-rated poor health causes lower numeracy in the age groups included in this study, but it is still a possibility. Secondly, the outcome measure, self-rated health, is a subjective and general measure of perceived health. Self-rated health may be partially confounded by negative thoughts and perceptions, although prior studies have found SRH to be a rigorous marker of physical health. Still, the all-encompassing nature of SRH presents a limitation in our ability to interpret results and identify possible mechanisms. Third, while our measure of numeracy (and literacy) was derived from a robust assessment, we were unable to examine different facets of numeracy and whether their relationships to health were similar or disparate from our overall numeracy measure. Finally, the degree of correlation (~80%) between literacy and numeracy may add a level of ambiguity to our findings depending on the source of this correlation. It is possible that numeracy and literacy are measuring a shared underlying construct(s), such as general ability, knowledge, or intelligence. However, we posit that the majority of this correlation is due to the identical format of numeracy/literacy assessments (i.e., short, computer-based textual questions with machine scorable response formats) and their practical limitations (PIAAC Numeracy Expert Group, 2009). While both scenarios are plausible, prior studies have shown that even though there may be a correlation, numeracy is getting at something distinct from literacy (Rothman et al., 2008). Indeed, models adjusted for literacy still showed a significant association between numeracy and health, suggesting at least some independent effect due to the concept of numeracy. Nonetheless, additional research teasing out this issue is needed.

Future studies should also examine the independent and interdependent relationships between overall and sub domains of numeracy and various, objective measures of health. They should utilize more rigorous study designs (e.g., longitudinal data) whenever possible. Additionally, future research may benefit from further examination of mediation and moderation of the numeracy-health relationship. Results from our study indicate that education and literacy might operate as either or both mediators and moderators. However, a more formal analysis of the role of these (and other) variables is needed. Further, more applied research is needed in order to develop numeracy and literacy interventions, and to evaluate their efficacy and cost-effectiveness. Emphasis should be placed on improving numeracy and literacy proficiencies in countries with below-average proficiency levels, and to examining whether differential effectiveness exists based on countries with different cultures and economies.

4.3. Implications for health policy and practice

The findings from our study offer important insights from a policy perspective. There is a noticeable shift across countries towards greater patient involvement in health-related decision-making (Hibbard et al., 2007). Given the ubiquity of quantitative information within the healthcare system, and its increasing scale and complexity, it is essential that patients have the capability to successfully navigate this information so that they may make appropriate decisions regarding their health. Likewise, it is imperative for health professionals to understand the relationships between numeracy and health in order to facilitate patients' abilities to use health information. Indeed, our analyses showed substantial variation in numeracy proficiency levels across countries, and considerable room for improvement among all countries. Thus, interventions aimed at improving population levels of numeracy may be successful in improving population health and reducing inequalities in health. Interventions may operate at multiple levels to address discrepancies in numeracy proficiencies, for example, national or local policies, hospital or health organizations, or among providers themselves (Batterham et al., 2016). Further research is needed to develop and evaluate the precise form of such interventions, but our current findings may offer some direction for their development.

For example, findings from our analyses suggest that numeracy has both independent and interdependent correlations with health. That is, numeracy was significantly associated with poor self-rated health, over and above adjustments for education, literacy, and other covariates. At the same time, numeracy-health associations were marginally attenuated upon adjustment for education and literacy. Further, results from the numeracy-literacy combination variable showed that numeracy's association with health might be amplified by literacy. Taken together, these findings indicate that national and local polices aimed at improving general education may help to reduce inequities in health mediated by numeracy proficiency. Likewise, interventions by healthcare organizations and providers that aim to specifically enhance patients' abilities to navigate textual health information (e.g., online training programs) may prevent poor health outcomes through literacy's effect on numeracy. Nonetheless, given our findings as a whole, we recommend that interventions should ideally address both literacy *and* numeracy for the greatest potential to prevent poor health outcomes.

4.4. Conclusions

Our study found evidence for an inverse, graded association between numeracy and self-rated health, such that lower levels of numeracy correlated with greater odds of poor self-rated health. This association was robust to adjustment for sociodemographic factors, notwithstanding marginal attenuation upon controlling for education and literacy. Further examination showed evidence of a positive synergistic relationship between numeracy, literacy, and poor SRH. Thus, lower levels of numeracy may adversely affect self-rated health – both independently and interdependently along with literacy. These associations may be partially mediated or moderated by education and literacy. Future studies are needed to make causal inference and to assess the influence of numeracy on specific health outcomes. Lastly, there was considerable variation across countries in numeracy and literacy proficiencies and their correlations with SRH. Thus, despite the need for further investigation with more rigorous study designs, our findings indicate that investments into improving numeracy and literacy proficiencies are needed, and that policies and interventions aimed at doing so may have great potential to improve population health and minimize health inequalities.

Ethical approval

The study was approved by the Institutional Review Board of the Harvard T.H. Chan School of Public Health.

Informed consent

Informed consent was obtained from all survey participants.

Declaration of competing interest

The authors declare there is no conflict of interest.

Acknowledgments

We would like to acknowledge the contributions of all participants of the Programme for the International Assessment of Adult Competencies (PIAAC) survey, researchers from the Organisation for Economic Cooperation and Development involved in the planning, design and implementation of the surveys and field staff in participant countries without whom this study would not have been possible.

Funding

The Organization for Economic Cooperation and Development, France

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ypmed.2019.105872.

References

Al Sayah, F., Majumdar, S.R., Williams, B., Robertson, S., Johnson, J.A., 2013. Health literacy and health outcomes in diabetes: a systematic review. J. Gen. Intern. Med. 28, 444–452. https://doi.org/10.1007/s11606-012-2241-z.

Batterham, R.W., Hawkins, M., Collins, P.A., Buchbinder, R., Osborne, R.H., 2016. Health literacy: applying current concepts to improve health services and reduce health inequalities. Public Health 132, 3–12. https://doi.org/10.1016/j.puhe.2016.01.001.

Berkman, N.D., Sheridan, S.L., Donahue, K.E., Halpern, D.J., Crotty, K., 2011. Low health literacy and health outcomes: an updated systematic review. Ann. Intern. Med. 155, 97–107. https://doi.org/10.7326/0003-4819-155-2-201107190-00005.

Chinn, D., 2011. Critical health literacy: a review and critical analysis. Soc. Sci. Med. 73, 60–67. https://doi.org/10.1016/j.socscimed.2011.04.004.

Denis, V., 2014. User's Guide for a SAS Macro Enabling the Computation of Design Based Standard Errors in the Survey of Adult Skills (PIAAC).

Farmer, M.M., Ferraro, K.F., 1997. Distress and perceived health: mechanisms of health decline. J. Health Soc. Behav. 38, 298–311. https://doi.org/10.2307/2955372.

Franks, P., Gold, M.R., Fiscella, K., 2003. Sociodemographics, self-rated health, and mortality in the US. Soc. Sci. Med. 56, 2505–2514. https://doi.org/10.1016/S0277-9536(02)00281-2.

Ginde, A.A., Weiner, S.G., Pallin, D.J., Camargo, C.A., 2008. Multicenter study of limited health literacy in emergency department patients. Acad. Emerg. Med. 15, 577–580. https://doi.org/10.1111/j.1553-2712.2008.00116.x.

Golbeck, A.L., Ahlers-Schmidt, C.R., Paschal, A.M., Dismuke, S.E., 2005. A definition and operational framework for health numeracy. Am. J. Prev. Med. 29, 375–376. https://doi.org/10.1016/j.amepre.2005.06.012.

Herndon, J.B., Chaney, M., Carden, D., 2011. Health literacy and emergency department outcomes: a systematic review. Ann. Emerg. Med. 57, 334–345. https://doi.org/10.1016/j.annemergmed.2010.08.035.

Hibbard, J., Peters, E., Dixon, A., Tusler, M., 2007. Consumer competencies and the use of comparative quality information - it Isnt just about literacy.Pdf. Med. Care Res. Rev. 64, 379–394.

Idler, E.L., Benyamini, Y., 1997. Self-rated health and mortality: a review of twenty-seven community studies. J. Health Soc. Behav. 38, 21–37. https://doi.org/10.2307/2955359.

Kakarmath, S., Denis, V., Encinas-Martin, M., Borgonovi, F., Subramanian, S.V., 2018. Association between literacy and self-rated poor health in 33 high- and upper middle-income countries. Int. J. Public Health 63, 213–222. https://doi.org/10.1007/s00038-017-1037-7.

OECD, 2013. Technical Report of the Survey of Adult Skills (PIAAC).

Osborn, C.Y., Wallston, K.A., Shpigel, A., Cavanaugh, K., Kripalani, S., Rothman, R.L., 2013. Development and validation of the general health numeracy test (GHNT). Patient Educ. Couns. 91, 350–356. https://doi.org/10.1016/j.pec.2013.01.001.

Peters, E., Hibbard, J., Slovic, P., Dieckmann, N., 2007. Numeracy skill and the communication, comprehension, and use of risk-benefit information. Health Aff. 26, 741–748.

PIAAC Numeracy Expert Group, 2009. PIAAC Numeracy: A Conceptual Framework (No. 35), OECD Education Working Papers. https://doi.org/10.1787/220337421165.

Prins, E., Monnat, S., 2015. Examining associations between self-rated health and proficiency in literacy and numeracy among immigrants and U.S.-born adults: evidence from the program for the international assessment of adult competencies (PIAAC). PLoS One 10, e0130257. https://doi.org/10.1371/journal.pone.0130257.

Rothman, R.L., Montori, V.M., Cherrington, A., Pignone, M.P., 2008. Perspective: the role of numeracy in health care. J. Health Commun. https://doi.org/10.1080/10810730802281791.

Rudd, R.E., 2017. Health literacy: insights and issues. Stud. Health Technol. Inform. 240, 60–78. https://doi.org/10.3233/978-1-61499-790-0-60.

Schneider, S.L., 2013. The International Standard Classification of Education 2011. pp. 365–379. https://doi.org/10.1108/S0195-6310(2013)0000030017.

Subramanian, S.V., Ertel, K., 2009. Author's response: self-rated health may be adequate for broad assessments of social inequalities in health. Int. J. Epidemiol. 38, 319–320. https://doi.org/10.1093/ije/dyn241.

Szrek, H., Bundorf, M.K., 2014. Enrollment in prescription drug insurance: the interaction of numeracy and choice set size. Health Psychol. 33, 340–348. https://doi.org/10.1037/a0032738.

Van Doorslaer, E., Gerdtham, U.G., 2003. Does inequality in self-assessed health predict inequality in survival by income? Evidence from Swedish data. Soc. Sci. Med. 57, 1621–1629. https://doi.org/10.1016/S0277-9536(02)00559-2.

Yamashita, T., Kunkel, S.R., 2015. An international comparison of the association among literacy, education, and health across the United States, Canada, Switzerland, Italy, Norway, and Bermuda: implications for health disparities. J. Health Commun. 20, 406–415. https://doi.org/10.1080/10810730.2014.977469.