Health literacy in relation to web-based measurement of cognitive function in the home: UK Women's Cohort Study

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Abstract

OBJECTIVE

Older adults may require additional support to comprehend written information due to inadequate health literacy, which involves components of cognitive function including reaction time. This study tested the acceptability of web-based reaction time testing in the UK Women's Cohort Study and possible sources of bias. Additionally, it assessed the association between health literacy and reaction time.

DESIGN

A cross-sectional analysis was conducted using data from the UK Women's Cohort Study, a prospective cohort study.

PARTICIPANTS

The study involved women aged 48 to 85 without cancer registration who participated in the 2010/11 follow-up (n = 768)..

SETTING

Postal questionnaires and web-based cognitive function tests were administered in participants' homes.

METHODS AND ANALYSIS

Logistic regression identified predictors of volunteering for reaction time testing, used to calculate inverse probability weights for the primary analysis. Associations between health literacy and reaction time were estimated with linear regression models, adjusting for volunteer effects. Poisson regression models assessed associations between health literacy and choice reaction time errors.

PRIMARY AND SECONDARY OUTCOME MEASURES

The primary outcome was acceptability of web-based testing (response rate, task distress, task difficulty). Secondary outcomes were sources of volunteer bias, and the association between health literacy and reaction time.

RESULTS

Web-based testing of cognitive function was attempted by 67% of women (maximum age 80), with little distress or difficulty reported. There was substantive volunteer bias. Women providing data on cognitive function were younger, had higher health literacy, higher educational attainment and were higher in self-rated intelligence. Inadequate health literacy was associated with making fewer choice reaction time errors among those providing valid data, but was also associated with not providing valid data. Health literacy was not associated with other aspects of reaction time (speed, variability). Additionally, selection bias may have restricted range on study variables, given that 2010/11 volunteers were younger and more educated compared to those at recruitment in 1995/98.

CONCLUSION

Brief web-based measures of cognitive function in the home are acceptable to women aged 48 to 80, but there are substantive selection effects and volunteer biases. Additionally, there are potentially vulnerable subgroups who provide poorer quality data.

STRENGTHS AND LIMITATIONS

- Web-based reaction time testing introduced via postal questionnaires offers a viable method for measuring cognitive function at home, enhancing reach and convenience, for those with internet access
- The use of inverse probability weights helps address volunteer bias, given the strong volunteer effects we observed
- Combining postal questionnaires with web-based tests allows for multi-modal data collection, potentially increasing response rates but possibly excluding those who do not use the internet regularly
- Logistic regression models show inadequate health literacy is associated with providing poor quality data
- Among those providing valid reaction time data, health literacy was not associated with reaction time in linear regression models adjusted for volunteer bias, although inadequate health literacy was associated with fewer choice reaction time errors (suggesting accuracy or caution was prioritised over speed)

Conflicts of interest

Dr. Gareth Hagger-Johnson has been employed by University of Leeds, University of Edinburgh, University College London (UCL), UCL Consultants, Kantar Worldpanel, C. Hoare & Co. and held an honorary contract with the National Health Service (NHS) Health and Social Care Information Centre (longer than 36 months ago). He has been employed by PCF Bank and the Nottingham Building Society (within the last 36 months). He currently has an honorary contract with Norwich Medical School at University of East Anglia and an Affiliate Academic position at University College London (UCL). He receives author royalties from Pearson Education and Routledge. None had involvement in the study design, collection, analysis, interpretation of data, writing of the paper and/or decision to submit for publication. No conflicts of interest are perceived.

Prof. Stian Reimers has undertaken paid consultancy for various government departments and commercial clients. He has also undertaken various paid teaching, media engagements and public speaking. No conflicts of interest are perceived.

Prof. Janet Cade is director of Dietary Assessment Ltd, unrelated to UK Women's Cohort Study or this manuscript. No conflicts of interest are perceived.

All other authors have no completing interest to declare.

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Introduction

Provision of written information is fundamental in patient healthcare – it is involved in obtaining informed consent, treatment plans, patient safety, communication efficacy, appointments for follow-up care, and connecting patients with additional resources such as educational materials, support groups and community services. Reading skills are part of the wider adequate functional 'health literacy' skills needed to manage the complex tasks frequently needed for self-care. Health literacy is defined as 'the degree to which individuals have the capacity to obtain, process, and understand basic health information and services needed to make appropriate health decisions'[1]. Inadequate health literacy levels can contribute to an accumulation of risks and exposures that ultimately elevate the risk of earlier mortality[2]. Clinicians and healthcare providers may need to know if their patients require additional support for this reason.

Health literacy can be measured in clinical and other supervised settings with the Single Item Literacy Screener (SILS)[3], the Rapid Estimate of Adult Literacy in Medicine (REALM)[4], Newest Vital Sign (NVS)[5] and the Test of Functional Health Literacy in Adults (TOFHLA)[6] among other instruments. Health literacy tests correlate with cognitive abilities, leading some to argue they are measuring similar things[7–10], or at least that cognitive abilities are a proximal determinant of health literacy skills[11]. When viewed through a longitudinal lens, cognitive abilities separate into fluid abilities that decline with age (e.g. adaptability, reasoning, processing speed, reaction time) and crystallised abilities (e.g. knowledge, vocabulary, expertise) that are more resistant to age-related decline. Reaction time declines from age 30[12] and perhaps as early as age 24[13]. The TOFHLA and NVS tend to correlate more strongly with fluid abilities, and the REALM with crystallised abilities (health related vocabulary)[14]. The association between SILS and fluid cognitive abilities such as reaction time has not been tested. It is important to consider various confounding factors or covariates that might be associated both with health literacy and reaction time, including age[12,15], educational attainment[9,15], physical health[15], physical activities[16], personality traits[17], health behaviours[15] and adiposity[18].

Reaction times are often positioned as simple measures of the brain's information processing efficiency[19,20]. Reaction time takes a few minutes to measure, whereas comprehensive cognitive testing is relatively time consuming[21]. Reaction time tests have been shown to predict mortality independently of established risk factors[22]. They are relatively inexpensive and can be administered in person[20], online[23] and via smartphone apps[24] if they are validated as new psychometric tests[20,21,23]. Unsupervised reaction time testing may also be less impacted by cheating or non-adherence to protocol[25] than cognitive tests requiring close supervision to ensure engagement with the task[26]. Being able to measure reaction time without the need for home visits, or asking participants to travel, is appealing for these reasons[27]. There is still the potential for accidental presses, distractions, internet connectivity and other problems which can produce outliers from the observed distributions[23]. We also have to consider the acceptability of web-based testing in the home, particularly to older adults, which should be demonstrated rather than assumed[26].

Reaction times decline with age, and slower and more variable times are established risk factors for both cognitive decline and dementia[22]. For example, more variable reaction times are associated with subsequent amyloid beta pathology, even at ages when dementia prevalence is very low[28]. Among non-demented adults aged 70 to 90, simple reaction time tests were found to have comparable performance with a wider and more detailed set of cognitive tests in predicting dementia four years later[29]. In another study, reaction time predicted dementia just 3 to 8 years later[30]. It may therefore be necessary to administer tests of cognitive function or reaction time more frequently[31] than has been traditionally done in longitudinal studies that involve home visits or asking participants to travel.

The primary aim of this study was to determine acceptability of online reaction time testing to women enrolled in the UK Women's Cohort Study[32]. We also sought to identity characteristics that differed between those providing compared to not providing reaction time data, among those responding to a follow-up questionnaire. The secondary aim of the study was to determine the cross-sectional association between reaction time and the SILS, which has not been evaluated before.

Methods

The UK Women's Cohort Study has been described previously[32]. Briefly, the cohort was created mainly to study associations between nutritional exposures and health outcomes. It covers England, Scotland and Wales and comprised roughly equal proportions of meat eaters, vegetarians and pescatarians at recruitment in 1995/98 (age 35 to 69). The cohort were re-contacted in 1999/02 with a follow-up questionnaire which included measures of self-reported physical activity, sitting time, sleep time and fidgeting. In 2010, National Health Service (NHS) multi-region ethical approval (IRAS ref 55443) was obtained to invite 2,000 women (age 48 to 85, not cancer registered) who had taken part at 1995/98 and 1999/02 to complete a short follow-up postal questionnaire including a personality trait assessment and an invitation to complete a web-based reaction time test. The questionnaire included instructions on how to provide waist and hip measurements using a paper tape measure provided. Returning the questionnaire or providing reaction time data were considered to represent informed consent.

Reaction Time. Based on the Deary-Liewald reaction time test[20], which was based on the Health and Lifestyle Study (HALS) reaction time test, the web-based version[23] of the simple reaction time (SRT) task involved responding to the appearance of the letter ‘Y’ on the screen by pressing the ‘Y’ key on the keyboard within a time limit. This task comprised 20 trials. The choice reaction time (CRT) task required participants to promptly respond to randomly presented numbers (5, 6, 7, or 8) on the screen by pressing the corresponding number on the keyboard. The number of CRT errors made was recorded if the wrong number was selected. The CRT task consisted of 40 trials. Reaction time scores were scrambled using random letters into a code to ensure data integrity and prevent cheating, which participants transcribed onto the questionnaire.

Health literacy. Health literacy was measured using the Single Item Literacy Screener (SILS)[3]. This asks, ‘How often do you need to have someone help you when you read instructions, pamphlets, or other written material from your doctor or pharmacy?’ Response options are 1 (never), 2 (rarely), 3 (sometimes), 4 (often), 5 (always). Responses greater than 2 indicate possible inadequate health literacy.

Educational attainment. The highest level of educational attainment reported, ranging from none (1) to higher University degree (6), was categorised using qualifications reported in 1995/98 and 2010/11.

Self-rated health. Participants were asked 'Overall, how would you rate your health during the past 4 weeks?' Response options were Excellent (5), Very good (4), Good (3), Fair (2), Poor (1), Very poor (0).

Self-rated intelligence. Five items were selected from a lexical trait inventory[33] which describe self-rated intelligence ('intelligent', 'knowledgeable', 'perceptive', 'cultured', 'analytical'; Cronbach's alpha = 0.82). A total score was converted to z-score (mean = 0, standard deviation =1) prior to analysis.

Smoking. Participants were asked 'Which of the following best describes you?' I have never smoked (0), I used to smoke every day, but do not smoke at all now (1), I smoke occasionally, but not every day (2), I smoke every day (3). These data were used to create three groups (current regular smokers, former smokers, never smokers).

Frequency of alcohol consumption. Participants were asked, 'How often, if ever, do you drink alcohol?' Response options were Never (0), Less than once a week (1), Once a week (2), More than once a week (3), 4 or more times a week (4).

Dietary quality. Participants were asked, 'In an average week, how many servings of the following do you eat? Response options were vegetables or dishes containing vegetables (excluding potatoes), fruit or dishes containing fruit, red meat or dishes containing red meat (e.g. beef, lamb, pork), white meat or dishes containing white meat (e.g. chicken, turkey, and other poultry), fish or dishes containing fish, nuts or dishes containing nuts, beans or pulses or dishes containing beans or pulses.

Physical activity, sitting time and sleeping time. In 1999/02, participants were asked, ‘On an average weekday how is your day spent?’ and ‘On an average weekend day how is your day spent?’ They were asked to provide the number of hours and/or minutes in a 24-hour day spent doing nine activities: (Sleeping, Sitting, Light activities, Standing, Household chores, Lifting heavy objects, Light exercise, Moderate exercise, Strenuous exercise). High physical activity level was defined as 150 minutes moderate or 75 minutes moderate activity per week[34]. Low physical activity level was defined as less than 2 hours moderate and less than 1 hour vigorous activity per week. Medium physical activity level was defined as falling between low and vigorous thresholds.

Fidgeting behaviour. In 1999/02, participants were asked, ‘On a scale from 1-10 please indicate how much of your time you spend fidgeting. 1 would represent ‘no fidgeting at all’ and 10 would represent ‘Constant fidgeting’’. Low fidgeting combined with longer sitting times were previously shown to predict all-cause mortality in this cohort[35].

Adiposity. In 2010/11, participants were shown three pictures indicating the correct positioning for waist and hip measurements. They were asked to take two tape measurements for each, which were averaged. Participants were also asked to report their current weight (pounds and ounces, or kilograms) and height (feet and inches, or cm).

Personality traits. Lexical personality items[33] were used to measure personality traits: neuroticism (worrying, nervous, high-strung, emotionally unstable, temperamental, insecure, self-pitying, impatient), extraversion (sociable, fun-loving, affectionate, friendly, spontaneous, talkative, active), openness to experience (original, imaginative, creative, broad, complex, curious, daring), agreeableness (good, soft, courteous, selfless, helpful, sympathetic), conscientiousness (conscientious, careful, reliable, hard-working, organized, scrupulous, self-disciplined, neat, punctual, practical, deliberate, ambitious, emotionally stable). Cronbach's alpha scores indicated good internal consistency reliability (0.87, 0.89, 0.77, 0.89, 0.92 respectively).

Psychological distress in relation to reaction time testing. Reaction time volunteers were asked 'What was it like completing the reaction time task?' Response options ranged from 1 ('not at all distressing') to 5 ('extremely distressing').

Ease of reaction time testing. Reaction time volunteers were asked 'How easy was it to complete the reaction time task?' Response options ranged from 1 (very easy) to 6 (very difficult).

Statistical analysis

Variables associated with completing the reaction time task (indicating volunteer bias) were identified using logistic regression, regressing completion (coded 1) with non-completion (coded 0) on all predictor variables. One participant attempted the task but made transcription errors in their reaction time score. They were coded as not having completed the task. Predicted probabilities of volunteering were used to create inverse probability weights for analyses involving reaction time data[36]. By upweighting individuals who are similar to women not providing reaction time data, inverse probability weighting would mitigate volunteer bias and make the web-based reaction time volunteers more representative of the wider 2010/11 questionnaire sample.

To study the association between simple and choice reaction time (means and variability) and health literacy, we used linear regression models. To study the association between health literacy and the number of choice reaction time errors, we used Poisson regression models. All analyses were conducted using R version 4.3.2. Data preparation and descriptive statistics were computed using the ‘tidyverse’ packages. Linear, Poisson and logistic regression analyses were conducted using the ‘stats’ package. Removing data from women with missing data on covariates could introduce bias and reduce statistical power. Therefore, analyses were performed using multiple imputation[37] of covariates across 100 datasets with models pooled into a single set of estimates, using the ‘mice’ package.

Results

There were 892 questionnaires returned (45% response rate). There were 128 without data on age, six without data on the Single Item Literacy Screener (SILS) and four missing both. These 128 were excluded from our analytic sample (n = 768). Compared to the study population at recruitment in 1995/98, the 2010/11 analytic sample comprised a higher proportion of women with degree level education (67% vs 27%) and was slightly younger (mean 63.9 vs 52.3 years), suggesting substantive selection effects. In the analytic sample, there were missing data on education (n = 54), health (n = 25), waist/hip ratio (n = 26), smoking (n = 10), alcohol (n = 11), diet (n = 3 to n = 37), fish oil supplement usage (n = 67), personality or intelligence (n = 12), physical activities (n = 25), and fidgeting (n = 4). Because 108 women did not report their weight, we calculated waist/hip ratio (n = 26 missing) to estimate adiposity rather than Body Mass Index (BMI). The overall percentage of missing data was 4.9%.

Of the analytic sample providing questionnaire data (n = 768), 515 (67%) transcribed a reaction time score, of which 436 (57%) could be verified against anonymised data recorded by the web-based application. We next removed six participants who made more than four errors in the CRT task[12]. For the remaining 430 participants we calculated mean and SDs for SRT and CRT as follows: We excluded the first to fourth trial for both tasks[38], which showed the steepest change in

RT as the task was acquired; we also removed all responses in which RTs were <150ms (n=16; 0.2% of trials) or >1500ms (n=19; 0.3% of trials) for SRT or <250ms (n=1; 0.01% of trials) or >2500ms (n=14; 0.1% of trials) for CRT. For CRT we only included correct responses in RT mean and SD calculations[12].

Descriptive statistics for study variables are shown in Supplementary Table 1 for the 430 women with valid reaction time data (age 48 to 80). Older women had significantly slower and more variable choice reaction time means and reaction time variabilities (simple and choice) compared to younger women. Those with inadequate health literacy had more variable simple reaction time variability. Supplementary Table 2 compares study variables for women with adequate vs. inadequate health literacy. Women with adequate health literacy tended to be younger, more highly educated, reported better self-rated health, reported higher self-rated intelligence, and comprised more vegetarians. They reported higher levels of extraversion and openness to experience. Table 1 demonstrates reaction time volunteer effects. Women were more likely to attempt the reaction time task if they were younger, had adequate health literacy, were more educated, were higher in self-rated intelligence, higher in self-rated health, reported higher vegetable and fish consumption, reported less white meat consumption, drank alcohol less than weekly, had longer sitting times, less sleep time, less physical activity and higher levels of fidgeting.

Table 1: Predictors of attempting the reaction time task for the analytic sample (n = 768)

Predictor variable	Odds Ratio (95% Confidence Interval)
Age	0.89 (0.88, 0.90)
Inadequate health literacy	0.94 (0.82, 1.09)
Educational attainment	1.07 (1.03, 1.12)
Adiposity (waist/hip ratio 0.85 or higher)	0.86 (0.73, 1.02)
Self-rated intelligence	1.19 (1.08, 1.32)
Self-rated health	1.31 (1.21, 1.42)
Current/former smoker (vs. never smoker)	1.09 (0.94, 1.26)
Alcohol consumption at least weekly (vs. less than weekly)	0.66 (0.56, 0.79)
Vegetarian (vs. meat eater)	1.31 (0.91, 1.87)
Pescatarian (vs. meat eater)	0.75 (0.52, 1.07)
Vegetables / week	1.02 (1.01, 1.04)
Fruit / week	1.00 (0.99, 1.01)
Nuts / week	1.01 (0.98, 1.04)
Beans / week	0.98 (0.94, 1.02)
Red meat / week	1.01 (0.96, 1.06)
White meat / week	0.91 (0.85, 0.96)
Fish / week	1.12 (1.05, 1.20)
1 SD neuroticism	1.02 (0.94, 1.11)
1 SD extraversion	1.07 (0.97, 1.17)

1 SD openness to experience	1.07 (0.98, 1.18)
1 SD conscientiousness	1.08 (0.99, 1.18)
1 SD agreeableness	0.88 (0.80, 0.97)
Fish oil supplement use (vs. no use)	0.97 (0.82, 1.15)
Sitting hours per day	1.10 (1.06, 1.15)
Sleep hours per day	0.87 (0.87, 0.95)
Physical activity level	0.86 (0.78, 0.94)
Fidgeting level	1.09 (1.05, 1.13)

We compared reaction time distributions to those from the Health and Lifestyle Survey (HALS, 1984/85; UK Data Archive). This is the only available set of UK population representative data on reaction times covering the same age range. UK Biobank contains reaction time data[30], but is not population representative[39]. UKWCS distributions were similar, but were slower and more variable in HALS, presumably owing to selection bias and volunteer effects in UKWCS (Supplementary Table 3).

Among women providing feedback about the test, acceptability was high. For distress the available ratings were: Not at all (n = 361), mildly (n = 74), moderately (n = 4), very (n = 1), extremely (n = 0). For difficulty, the ratings were: Very easy (n = 163), easy (n = 188), somewhat easy (n = 57), somewhat difficult (n = 22), difficult (n = 0), very difficult (n = 1). This suggests little substantive distress (1.1% of volunteers) or difficulty (5.1% of volunteers) reported in relation to the task. Written feedback about factors affecting task performance was provided by two women, one describing a cat circling the keyboard, and one describing poor internet connectivity.

Associations between health literacy and reaction time are shown in Table 2. Inadequate health literacy was not associated with simple or choice reaction time mean, or choice reaction time mean or variability, adjusting for age and other covariates. As shown in Table 3, inadequate health literacy was associated with making *fewer* choice reaction time errors adjusting for age (Incident Rate Ratio = 0.78, 95% CI 0.69, 0.89), which did not change materially after further adjustment for the other covariates (Incident Rate Ratio = 0.71, 95% CI 0.61, 0.81). Compared to those with adequate health literacy, women with inadequate health literacy made 29% *fewer* choice reaction time errors.

Table 2. Estimated difference (in milliseconds) between women with inadequate (vs. adequate) health literacy and reaction time (mean and variability) from multivariable linear regression models (n = 430)

	Simple reaction time mean	Choice reaction time mean	Simple reaction time variability	Choice reaction time variability
Minimally adjusted for age	4.42 (-15.21, 24.05)	4.48 (-19.51, 28.47)	8.67 (-2.47, 19.81)	2.61 (-10.42, 15.64)
Additionally adjusted for:				
Educational attainment	7.24 (-12.28, 26.76)	2.01 (-21.98, 26.00)	9.79 (-1.35, 20.93)	1.83 (-11.25, 14.91)
Self-rated health	6.55 (-13.22, 26.32)	2.99 (-21.22, 27.2)	8.75 (-2.5, 20.00)	1.89 (-11.26, 15.04)
Self-rated intelligence	6.13 (-13.78, 26.04)	6.17 (-18.16, 30.5)	7.63 (-3.67, 18.93)	2.85 (-10.38, 16.08)
Diet and fish oil supplement use	3.04 (-17.14, 23.22)	0.12 (-24.67, 24.91)	9.20 (-2.23, 20.63)	2.31 (-11.04, 15.66)
Smoking and alcohol use	4.45 (-15.24, 24.14)	4.88 (-19.09, 28.85)	8.61 (-2.54, 19.76)	2.91 (-10.14, 15.96)
Physical activity, sitting time, fidgeting, sleep	7.41 (-12.32, 27.14)	5.76 (-18.32, 29.84)	9.07 (-2.15, 20.29)	1.61 (-11.46, 14.68)

time				
Adiposity	2.36	4.11	7.87	2.60
(waist/hip ratio)	(-17.73, 22.45)	(-20.28, 28.50)	(-3.57, 19.31)	(-10.75, 15.95)
Personality traits	5.01	7.30	8.81	2.39
	(-14.75, 24.77)	(-16.83, 31.43)	(-2.46, 20.08)	(-10.84, 15.62)
Fully adjusted for	8.25	1.83	8.09	1.51
variables above	(-12.97, 29.47)	(-24.04, 27.7)	(-4.07, 20.25)	(-12.76, 15.78)

Table 3. Association between inadequate health literacy and choice reaction time errors (n = 430)

Inadequate health literacy (vs. adequate)	Incident Rate Ratio (95% Confidence Interval)
Minimally adjusted for age	0.78 (0.69, 0.89)
Additionally adjusted for:	
Educational attainment	0.80 (0.71, 0.91)
Self-rated health	0.77 (0.68, 0.87)
Self-rated intelligence	0.78 (0.69, 0.88)
Smoking and alcohol use	0.80 (0.70, 0.90)
Waist/hip ratio 0.85 or higher	0.78 (0.69, 0.88)
Personality traits	0.76 (0.67, 0.86)
Sitting time, physical activity, fidgeting	0.73 (0.65, 0.83)
Diet and fish oil supplement use	0.82 (0.73, 0.93)
Fully adjusted for variables above	0.71 (0.61, 0.81)

In supplementary analysis (Supplementary Table 4), we considered the association between health literacy, other study variables and attempting the reaction time task but producing poor quality data (n = 85 poor quality vs. n = 430 sufficient quality data). Poor quality data was defined as statistical outliers, assumed accidental presses, transcription errors, or data capture problems. These data were considered to be separate from choice reaction time errors, which are assumed to be genuine errors occurring while engaged with the reaction time task. Women providing poor quality data were more likely to have inadequate health literacy, have higher adiposity, be current smokers, eat more fish, be vegetarian (vs. meat eater), and be more introverted.

Discussion

Administering brief measures of cognitive function using web-based technology in the home is acceptable to older women, but we found important volunteer biases. Reaction time volunteers were significantly younger, healthier and had higher levels of educational attainment compared to women who completed our questionnaire but declined the reaction time task. Bias associated with these volunteer effects was partially mitigated using inverse probability weighting to answer our second question about a possible association between reaction time and inadequate health literacy. Health literacy as measured by the SILS was not associated with reaction time mean or variability, even after considering volunteer bias. Women with inadequate health literacy made significantly fewer errors on the choice reaction time task, but were more likely to provide poor quality data.

Strengths and limitations

Strengths of the study are that we found web-based testing of cognitive function is acceptable to women aged 48 to 80 in unsupervised conditions in the home, while highlighting the potential for volunteer biases and presence of subgroups providing poor quality data. The web-based method produces distributions similar to established population norms from supervised testing, after removing poor quality data, which is a strength[12]. Additionally, we were able to remove outliers at the intra-individual trial level in most cases, enhancing data quality. Limitations include the lack of evaluation for vision or hearing, which may influence reaction time, particularly in relation to age-related sensory decline[40]. The English-only administration of the questionnaire and task potentially disadvantaged non-native speakers. Restriction of range on health literacy may have led to underestimation of an association with reaction time, biasing results towards the null. Data collection limitations included accidental presses, distracting pets, and internet connectivity issues. While interruptions from concurrent computer applications may occur, these likely introduce random rather than systematic errors[23]. The use of outdated technology (Flash) is noted, although many alternatives are now available, including smartphone applications[24]. The questionnaire response rate was 45% and comprised a higher proportion of women with degree level education, and younger women, compared to the original cohort. This may have introduced bias, but non-random attrition is commonly observed in longitudinal studies. Low response rates do not necessarily bias associations between study variables[42]. Although only 57% of those responding to the questionnaire had verifiable reaction time data, this is a relatively high participation rate, given the age range and period of the study. In 2010/11 internet access in the home was less common than today, particularly for older adults. The proportion of UK adults age 75+ who reported recently using the internet increased from 19.9% (2011) to 46.8% (2019), less than half still not regular internet users[41]. Another limitation is that owing to Flynn's cohort effect and its possible causes[43], reaction times might be expected to get slightly faster for each successive generation, limiting our comparisons between UKWCS 2010/11 or beyond, and HALS in 1984/85. The cross-sectional nature of the data prevents testing longitudinal associations or causal relationships.

Meaning of the study

Functional health literacy has been shown to capture aspects of fluid cognitive abilities including reaction time[44,45.] and so were expected to have resulted in an association between inadequate health literacy and slower reaction time. The NVS, REALM and TOFHLA are all positively correlated with speed of information processing[45]. Yet we found no association between the SILS and reaction time mean or variability. Either the SILS is not sensitive enough to detect aspects of health literacy involving cognitive speed, or by nature of being a single item, suffers from measurement error that attenuates a genuine association to null effects. Restriction of range on the

SILS and restriction of range on age in the analytic sample, will most likely have attenuated associations with reaction time towards null. No women saying they 'always' needed additional support to understand written instructions completed the web-based reaction time task, perhaps unsurprisingly.

It is not clear why inadequate health literacy was associated with making fewer choice reaction time errors, an unexpected finding. This could be due to differences in speed-accuracy trade-offs or individual differences in response strategies. Women lower in health literacy seemed to have adopted a more cautious approach, prioritising accuracy over speed, compared to those with higher health literacy. Previous research has shown that younger adults tend to aim for speed, risking inaccuracy, whereas older adults have been shown to prepare reactions for longer, improving accuracy[46,47]. This may extend to adults with less adequate health literacy, but this hypothesis would have to be tested in future research. The lack on association between health literacy and reaction time might be due confounding factors we did not consider beyond educational attainment, such as access to technology, income and occupation. Although we did not account for individual or wider household income, we adjusted for educational attainment and self-rated intelligence. It is not clear why vegetarians were more likely than meat eaters to provide invalid reaction time data, but we found no significant differences in reaction time scores.

Finally, given that less adequate health literacy was associated with outliers from the reaction time distributions and other data issues, it is important in future research to consider the possibility that there is more than one distribution from more than population or subgroup[48]. Researchers need to consider how to approach data that could be a mixture of healthy, intelligent, enthusiastic volunteers and vulnerable subgroups with impaired cognitive function or literacy problems that prevent full engagement throughout the task, resulting in poorer quality data.

Author statement

GHJ, JC and DG designed the sampling frame and administered postal questionnaires. SR designed and collected the reaction time data. GHJ, AG and SR contributed to data analysis and interpretation. DG provided statistical advice. All authors contributed to the literature review and writing the manuscript. GHJ is the guarantor of the manuscript.

Data statement

Technical appendix, statistical code and the anonymised dataset will be made available on application from the UK Data Service (https://ukdataservice.ac.uk/) to *bone fide* academic researchers for non-commercial research purposes.

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Patient and Public Involvement

It was not considered feasible to involve participants in the 2010/11 follow-up, given the nature of the cohort and the method of recruitment.

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