INTRODUCTION

Health literacy is increasingly being recognized as an influence on health.[1,2] While many definitions of health literacy exist, a basic definition of 'functional' health literacy is, 'the degree to which individuals can obtain, process, understand, and communicate about health-related information and services to make informed health decisions'.[3] According to a national assessment of adult literacy, 10-13% of American adults aged 16-64 and 29% aged ≥65 have 'below basic' health literacy and are often unable to properly self-manage their health.[4–8] Improvement of the health literacy of the population is therefore a goal of the Healthy People 2020 initiative.[9] Of particular concern are older adults, who are vulnerable to low health literacy due to the negative effects of cognitive aging on health literacy skills.[10–12] At the same time, health literacy is important for health in older age, a period in life when physical, social, and material limitations often increasingly affect one's capacity for health self-management.[13] Indeed, low health literacy has independently been associated with increased risk of all-cause mortality in older adults in several contexts.[14–17]

Health-promoting lifestyle behaviors, such as engagement in moderate-to-vigorous physical activity (MPVA) may be mediators on the pathway from low health literacy to greater risk of all-cause mortality.[17,18] Low MVPA is robustly associated with increased risk of all-cause mortality in older adults.[19–22] Health literacy may positively affect knowledge, motivation, and self-efficacy for physical activity, which are important factors in the initiation and maintenance of MVPA.[18,23-27] However, evidence on the relationship between health literacy and MVPA is sparse. An American study of Medicare enrollees and a UK general population survey both found no association between health literacy and weekly physical activity.[28,29] In contrast, an

American study of hypertensive patients from federally qualified health centers and a Dutch study of community dwelling adults found that health literacy explained a modest proportion of variance in physical activity, with self-efficacy acting as a mediator.[23,30] Health literacy was also positively associated with physical activity in the Rush Memory and Aging Project.[31] These studies were cross-sectional and did not adjust for physical or cognitive health, which are major limitations in behavioral studies of health literacy. The potential contribution of cognitive function is salient to consider, given its association with health literacy and emerging relationship with physical function and activity in later life.[11,32,33]

This study aimed to prospectively investigate the association between health literacy and weekly participation in MVPA among older English adults from 2004 to 2013, while accounting for sociodemographic factors, physical health, and cognitive function.

METHODS

Study sample

The English Longitudinal Study of Ageing (ELSA) is a cohort of English adults aged ≥50 years.[34] The ELSA was approved by the London Multicentre Research Ethics Committee (MREC/01/2/91) and informed consent was obtained from all participants. The cohort was established in 2002 based on a random stratified sample of households in England. Data are collected in biennial waves. The present analysis was conducted in 2015 using data from waves 2 (2004/05) through 6 (2012/13). Eligible participants were non-cognitively impaired 'core' ELSA participants aged 52-79 years at wave 2, who completed data collection at all waves with non-proxy interviews (proxy interviews were conducted for institutionalized or physically or

cognitively impaired participants). Wave 2 was the baseline for this analysis, as health literacy was first measured in this wave. Hence, the lower limit of the eligible age range was 52 years, rather than 50 years. Of the 11392 core participants recruited in wave 1, 8780 were present in wave 2 (77%). Of these, 7659 were aged 52-79 at wave 2. Of these, 4470 remained in the study and completed data collection at all waves through wave 6 (58%). Of these, 116 (3%) had proxy interviews in at least one wave and were ineligible. In total, 4354 participants were eligible for this analysis.

Measures

Health literacy

Functional health literacy (referred to hereafter as 'health literacy') was assessed in the in-person study interview at wave 2 (2004/05) using a validated four-item measure from the OECD International Adult Literacy Survey.[35] Participants were presented with a fictitious medicine label and were asked four reading comprehension questions (Appendix). Health literacy was scored as 'high' (4/4 correct), 'medium' (3/4 correct), or 'low' (≤2/4 correct).[17] Of the 4354 eligible participants, n=6 refused the assessment and were excluded and n=70 were unable to complete the assessment due to sight, health, or reading problems. The latter individuals were included and coded as having low health literacy, as they would likely perform with low health literacy in real-life settings.[7]

Cognitive function

Aspects of cognitive function that are essential for everyday functioning and sensitive to decline during aging were assessed in the study interview at wave 2 (2004/05).[36] Aspects of cognitive

function that would be minimally affected by literacy skills were included: time orientation (continuous, out of four for the ability to state the correct day, week, month, and year), immediate recall (continuous, out of 10 aurally presented words), delayed recall (continuous, out of the same 10 aurally presented words), and verbal fluency (continuous; the number of animal names listed in one minute). The former three variables were grouped together to create a memory index, with possible scores ranging from 0 to 24.[37] The latter variable was coded as '0', '1-7', '8-12', '13-15', '16-17', '18-19', '20-21', '22-24', '25-29', and '≥30' animals and scored from 0 to 9.[37] A measure of mental processing speed was not included as it required literacy skills by assessing the number of Ps and Ws crossed out in a grid of random alphabet letters.

Moderate-to-vigorous physical activity

Physical activity was assessed in the study interview at each wave, where participants were asked about their typical frequency of participation in mild, moderate, and vigorous sports and activities, with examples given on show cards (Appendix). Response options were 'hardly ever or never', 'one to three times a month', 'once a week', and 'more than once a week'. At each wave, physical activity was coded dichotomously as engagement in MVPA once per week or more vs. less than once per week.[22,38] The outcome variable was consistent weekly participation in MVPA at every wave from 2004/05 to 2012/13 (yes vs. no).

Covariates

Sociodemographic covariates were assessed in the wave 2 (2004/05) interview: age (continuous), sex (male; female), marital status (married or living as married; single, divorced, or widowed), net non-pension wealth (calculated in quintiles stratified at age 65 to account for the effect of

retirement on wealth), education (degree-level; up to degree-level; no qualifications), and ethnicity (white; non-white). Other covariates were those known to be associated with health literacy or with MVPA in the ELSA: working status (yes vs. no), access to a car when needed (yes vs. no), self-rated health (excellent/very good/good vs. fair/poor), having a limitation in one or more instrumental activity of daily living (IADL; yes vs. no) having a limiting long-standing illness (yes vs. no), presence of depressive symptoms, defined as scoring >4 on the 8-item Centre for Epidemiological Studies Depression Scale (yes vs. no).[39,40]

Statistical analysis

The final sample was 4345/4354, as six participants declined the health literacy assessment and a further three were missing physical activity data. All other variables were missing on a case-by-case basis. Weekly MVPA over eight years was examined bivariately against participant characteristics using frequency counts for categorical variables and means for continuous variables, and unadjusted logistic regression to generate odds ratios (ORs) and 95% confidence intervals (CIs). All covariates were then included in a multivariable-adjusted logistic regression model to predict the relationship between health literacy ('medium' vs. 'low' and 'high' vs. 'low') and weekly MVPA over eight years. With the exception of age, sex, and education, which were forced into the model, all covariates that were not significantly associated with weekly MVPA with $p<0.05$ in the model were removed, as long as their removal did not alter the ORs between health literacy and long-term MVPA by ≥10%.[41] The final model is shown both with and without the cognitive function variables, to examine the degree to which poor cognitive functioning might explain any relationship between health literacy and weekly MVPA. All regression modeling was performed with population weights applied to account for study non-

response and attrition.[42] The ELSA User Guide provides in-depth technical information on the population weights, but, briefly, they were calculated as the inverse of the estimated probability of responding for a given participant based on demographic, health-related, social, and geographic factors associated with non-response and attrition.[42] All statistical analyses were performed using StataSE 13.1 (College Station, Texas)

RESULTS

Table 1 shows the baseline characteristics of the study participants. Participation in weekly MVPA declined over time in the study population, but decline was more pronounced in adults with low and medium than in those with high health literacy (Figure 1). Overall, 54% (2350/4345) consistently reported participating in MVPA at least once per week at all waves (Table 2). This proportion was 59% (1840/3128) in those with high health literacy, 47% (372/797) in those with medium health literacy, and 33% (138/420) in those with low health literacy. The unadjusted OR for eight-year participation in weekly MVPA associated with high vs. low health literacy was 2.83 (95% CI: 2.25-3.87). Mean baseline memory and verbal fluency scores were higher among those with consistent weekly participation in MVPA, with unadjusted OR=1.13 (95% CI: 1.11-1.15) per one point memory increase and unadjusted OR=1.21 (95% CI: 1.17-1.25) per one point verbal fluency increase. The other predictors of weekly MVPA in unadjusted models are also shown in Table 2.

The final adjusted, population weighted logistic regression models are shown in Table 3. Without memory and verbal fluency in the model, the adjusted OR for eight-year participation in weekly MVPA with medium vs. low health literacy was 1.29 (95% CI: 0.95-1.75) and high vs.

low was 1.53 (95% CI: 1.16-2.01). With cognitive function in the model, these associations were attenuated by about one-third, to 1.21 (95% CI: 0.89-1.64) for medium vs. low and 1.37 (95% CI: 1.04-1.81) for high vs. low. The borderline statistically significant OR for memory was 1.03 (95% CI: 1.00-1.05 per point increase) and for verbal fluency was 1.05 (95% CI: 1.01-1.09 per point increase). The other independent predictors of weekly MVPA were: being male (OR=1.42; 95% CI: 1.23-1.66), having degree-level education (OR=1.64; 95% CI: 1.33-2.02), having higher net non-pension wealth (OR=3.02; 95% CI: 2.35-3.88 for the richest vs. poorest quintiles), having good self-rated health (OR=1.76; 95% CI: 1.42-2.18), having no limiting long-standing illness (OR=2.13; 95% CI: 1.77-2.56), having no functional limitations (OR=1.78; 95% CI: 1.46-2.17).

DISCUSSION

In this longitudinal study of older English adults, health literacy was prospectively associated with weekly participation in MVPA over an eight-year follow-up period. These results are consistent with evidence that health behaviors, such as MVPA, may contribute to the link between low health literacy and increased risk of all-cause mortality.[17] Memory and verbal fluency were weakly positively associated with long-term MVPA, in addition to indicators of social advantage including being male, having degree-level education, being wealthier, and being healthier. Disparities in the long-term participation in MVPA may lead to inequalities in the health outcomes associated with physical inactivity, such as cardiovascular disease, cancer, and all-cause mortality.[22,43] Research is needed on the development of health inequalities during the aging process and how they may be prevented. Low health literacy may represent a target point

for interventions, and may be a way of identifying adults who need more support to optimize MVPA throughout their lifespan.[44]

These results indicate a graded, rather than a threshold effect of health literacy on MVPA, consistent with previous research showing a linearly graded relationship between health literacy and physical functioning in older adults.[45] However, the odds ratio for medium health literacy and MVPA was somewhat imprecise and crossed the null. The present results are also consistent with two American studies and a Dutch study of health literacy and physical activity,[23,30,31] but they conflict with an American study of new Medicare enrollees finding null associations between health literacy and several behaviors[28] and a UK study of adults in a younger and wider age range.[29] The present results may differ due to the longitudinal nature of this study, the differing assessment methods for health literacy and MVPA, and the older age range of the participants. The results are longitudinal, population-weighted, and were adjusted for important aspects of cognitive function that are independent of literacy skills, improving upon previous research.

The findings that memory and verbal fluency were weakly positively associated with long-term MVPA are consistent with a recent study of older American adults finding that the cognitive functions of task coordination and inhibition of habitual response were associated with physical exercise through self-efficacy.[46] The reverse association, where physical activity improves cognitive health in older adults, has been well-characterized in prospective cohort studies and randomized controlled trials.[47–50] In a *post-hoc* analysis, the reverse association between weekly MVPA at baseline (yes vs. no) and change in memory, verbal fluency, or health literacy over the

184 follow-up was not observed (Appendix Table 1). In a second *post-hoc* analysis with mental
185 processing speed (an aspect of executive function) included in the final model, it was not
186 associated with long-term MVPA (OR=1.01; 95% CI: 0.97-1.05).
187
188 More broadly, results of this study are consistent with another study using data from the English
189 Longitudinal Study of Ageing to examine the predictors of sustained physical activity over 10
190 years,[39] and other cross-sectional and short-term longitudinal studies on the predictors of MVPA
191 in older adults.[51,52] Although physical activity levels are accepted to often decline during aging,
192 few studies have examined the sociodemographic and health-related predictors of MVPA during
193 aging over a long follow-up. This study underscores the role of the ability to regularly engage in
194 MVPA over a long time period as a potential mechanism leading to later-life health inequalities.
195 MVPA is associated with reduced risk for several health outcomes,[43] but it is increasingly
196 difficult to maintain in later life due to increased physical, social, and material limitations.[47]
197 Health literacy may represent a modifiable target for intervention, whereby the maintenance of
198 literacy skills may aid in maintenance of the self-efficacy and level of physical function required
199 to engage in MVPA.[53]
200
201 **Limitations**
202 MVPA was assessed at multiple time points by self-report and is subject to recall error.[54,55] If
203 recall error in reporting MVPA is non-differential by health literacy, then the odds ratios will
204 underestimate the true associations. If the high health literacy group is relatively accurate in
205 reporting MVPA and low health literacy group systematically under-reports (over-reports)
206 MVPA, then the odds ratios will overestimate (underestimate) the true association. There has not

been any validation study of self-reported physical activity according to the health literacy of study participants. Overall, the frequency of self-reported MVPA in this sample was slightly higher than that assessed in the population-representative Health Survey for England (HSE), possibly because the longitudinal ELSA sample is slightly healthier and wealthier than the general population of England due to study attrition.[34]

The self-report physical activity assessment used in the ELSA has been validated in a sub-sample of 116 study participants using objective accelerometer data, showing a modest correlation (Spearman's r=0.21; p=0.02).[38] Physical activity was not measured with reference to a specific time frame (e.g. the past 12 months), which may have limited participants' abilities to accurately respond. Because of the way the physical activity data were collected in the ELSA, a variable that mapped onto the WHO recommendation of 150 minutes/week of moderate intensity or 75 minutes/week of vigorous intensity, or an equivalent combination of the two could not be defined.[56] However, the weekly physical activity variables in the ELSA have been associated with a range of health outcomes including all-cause mortality, demonstrating their biological and clinical relevance.[22,38]

The health literacy measure used in this study was validated,[35] but displayed a ceiling effect that is common to other standard measures of functional health literacy.[57,58] However, the measure has predictive ability for health outcomes including the uptake of preventive health services and risk of all-cause mortality in older adults.[7,17] Another limitation is that attrition was differential by baseline wealth, as 15% of participants who remained in the study through wave 6 were in quintile 1 (poorest) and 24% were in quintile 5 (richest); if no attrition occurred these

proportions would be 20%. The association between net non-pension wealth and weekly MVPA is therefore likely to be an underestimate. Participants with medium or low health literacy at baseline and with no educational qualifications were also more likely to drop out of the study. Attrition was 30.6% in the 'high', 37.6% in the 'medium', and 48.6% in the 'low' health literacy groups, and was 34.3% in the 'degree-level', 36.5% in the 'up to degree-level', and 52.1% in the 'no qualifications' educational groups. The observed associations between these variables and weekly MVPA may therefore underestimate the true associations.

Despite these limitations, this study provides important evidence on the simultaneous roles of health literacy and cognitive function in contributing to long-term participation in MVPA during aging. Strengths of this study include its large sample size and its longitudinal nature. Health literacy measurements with follow-up data are rare, especially for an eight-year period. The ELSA is one of the first available data sources that can investigate the behavioral outcomes of health literacy, especially jointly with other sociodemographic and health-related factors. Population-representative weights were applied to the regression models to account for differential degrees of non-response and attrition across population subgroups.[42]

Conclusions

Health literacy and cognitive function had independent positive associations with long-term participation in weekly MVPA in this prospective cohort of older English adults. These factors may be useful markers of capacity for engagement in this health-promoting lifestyle behavior in older adults. However, there were marked inequalities in weekly MVPA during aging. Adults who were male, highly educated, wealthier, and healthier were the most likely to participate in

weekly MVPA over the eight-year follow-up period. These long-term patterns of MVPA may translate to inequalities in health outcomes. Further research is needed on how the trajectories of health behaviors during aging may contribute to health inequalities among older adults.

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REFERENCES

1. Nutbeam D. Health literacy as a public health goal: a challenge for contemporary health education and communication strategies into the 21st century. *Health Promot Int*. 2000;15(3):259–268. http://dx.doi.org/ 10.1093/heapro/15.3.259

2. Kickbusch I, Pelikan JM, Apfel F, Tsouros AD. Health literacy: The solid facts. http://www.euro.who.int/__data/assets/pdf_file/0008/190655/e96854.pdf. Published 2013. Accessed October 2, 2015.

3. Berkman ND, Davis TC, McCormack L. Health literacy? What is it? *J Health Commun*. 2010;15(S2):9–19. http://dx.doi.org/10.1080/10810730.2010.499985

4. Kutner M, Greenberg E, Jin Y, Paulsen C. The Health Literacy of America's Adults: Results From the 2003 National Assessment of Adult Literacy (NCES 2006-483). https://nces.ed.gov/pubs2006/2006483.pdf. Published September 2006. Accessed October 2, 2015.

5. Berkman ND, Sheridan SL, Donahue KE, Halpern DJ, Crotty K. Low health literacy and health outcomes: an updated systematic review. *Ann Intern Med*. 2011;155:97–107. http://dx.doi.org/ 10.7326/0003-4819-155-2-201107190-00005

6. Davis TC, Wolf MS, Bass III PF, et al. Literacy and misunderstanding prescription drug labels. *Ann Intern Med*. 2006;145:887–894. http://dx.doi.org/ 10.7326/0003-4819-145-12-200612190-00144

7. Kobayashi LC, Wardle J, von Wagner C. Limited health literacy is a barrier to colorectal cancer screening in England: Evidence from the English Longitudinal Study of Ageing. *Prev Med*. 2014;61:100–105. http://dx.doi.org/ 10.1016/j.ypmed.2013.11.012.

8. Morris NS, Field TS, Wagner JL, et al. The association between health literacy and cancer-related attitudes, behaviors, and knowledge. *J Health Commun*. 2013;18(S1):223–241. http://dx.doi.org/ 10.1080/10810730.2013.825667.

9. Office of Disease Prevention and Health Promotion. Health Communication and Health Information Technology. Available at: https://www.healthypeople.gov/2020/topics-objectives/topic/health-communication-and-health-information-technology/objectives. Published October 2015. Accessed October 2, 2015.

10. Federman AD, Sano M, Wolf MS, Siu AL, Halm EA. Health literacy and cognitive performance in older adults. *J Am Geriatr Soc*. 2009;57(8):1475–1480. http://dx.doi.org/ 10.1111/j.1532-5415.2009.02347.x.

11. Kobayashi LC, Wardle J, Wolf MS, von Wagner C. Cognitive function and health literacy decline in a cohort of aging English adults. *J Gen Intern Med*. 2015. http://dx.doi.org/ 10.1007/s11606-015-3206-9

12. Kobayashi LC, Smith SG, O'Conor R, et al. The role of cognitive function in the relationship between age and health literacy: a cross-sectional analysis of older adults in Chicago, USA. *BMJ Open*. 2015;5:e007222. http://dx.doi.org/ 10.1136/bmjopen-2014-007222

13. Thomas PA. Trajectories of social engagement and limitations in late life. *J Healthh Soc Behav*. 2011;52(4):430–443. http://dx.doi.org/ 10.1177/0022146511411922.

14. Baker DW, Wolf MS, Feinglass J, Thompson JA. Health literacy, cognitive abilities, and mortality among elderly persons. *J Gen Intern Med*. 2008;23(6):723–726. http://dx.doi.org/10.1007/s11606-008-0566-4.

15. Sudore RL, Yaffe K, Satterfield S, et al. Limited literacy and mortality in the elderly: the health, aging, and body composition study. *J Gen Intern Med*. 2006;21(8):806–812. http://dx.doi.org/10.1111/j.1525-1497.2006.00539.x.

16. Cavanaugh KL, Wingard RL, Hakim RM, et al. Low health literacy associates with increased mortality in ESRD. *J Am Soc Nephrol*. 2010;21:1979–1985. http://dx.doi.org/10.1681/ASN.2009111163.

17. Bostock S, Steptoe A. Association between low functional health literacy and mortality in older adults: longitudinal cohort study. *BMJ*. 2012;344:e1602. http://dx.doi.org/10.1136/bmj.e1602.

18. von Wagner C, Steptoe A, Wolf MS, Wardle J. Health literacy and health actions: a review and a framework from health psychology. *Health Educ Behav*. 2009;36(5):860–877. http://dx.doi.org/10.1177/1090198108322819.

19. Samitz G, Egger M, Zwahlen M. Domains of physical activity and all-cause mortality: systematic review and dose-response meta-analysis of cohort studies. *Int J Epidemiol*. 2011;40(5):1382–1400. http://dx.doi.org/10.1093/ije/dyr112.

20. Kvaavik E, Batty D, Ursin G, Huxley R, Gale C. Influence of individual and combined health behaviors on total and cause-specific mortality in men and women: the United Kingdom Health and Lifestyle Survey. *Arch Intern Med*. 2011;170(8):711–719. http://dx.doi.org/10.1001/archinternmed.2010.76

21. Leitzmann MF, Park Y, Blair A, et al. Physical activity recommendations and decreased risk of mortality. *Arch Intern Med*. 2007;167(22):2453–2460. http://dx.doi.org/10.1001/archinte.167.22.2453.

22. Hamer M, de Oliveira C, Demakakos P. Non-exercise physical activity and survival: English Longitudinal Study of Ageing. *Am J Prev Med*. 2014;47(4):452–460. http://dx.doi.org/10.1016/j.amepre.2014.05.044.

23. Geboers B, Winter AF De, Luten KA, Jansen CJM, Reijneveld SA. The association of health literacy with physical activity and nutritional behavior in older adults, and its social cognitive mediators. *J Health Commun*. 2014;sup2(19):37–41. http://dx.doi.org/10.1080/10810730.2014.934933.

24. McAuley E. Self-efficacy and the maintenance of exercise participation in older adults. *J Behav Med*. 1993;16(1):103–113.

25. Stiggelbout M, Hopman-Rock M, Crone M, Lechner L, van Mechelen W. Predicting older adults' maintenance in exercise participation using an integrated social psychological model. *Health Educ Res*. 2006;21(1):1–14. http://dx/doi.org/10.1093/her/cyh037

26. Buckley J, Cohen JD, Kramer AF, McAuley E, Mullen SP. Cognitive control in the self-regularion of physical activity and sedentary behavior. *Front Hum Neurosci*. 2014;8:1–15. http://dx/doi.org/10.3389/fnhum.2014.00747

27. McAuley E, Mullen SP, Szabo AN, et al. Self-regulatory processes and exercise adherence in older adults: executive function and self-efficacy effects. *Am J Prev Med*. 2011;41(3):284–290. http://dx.doi.org/10.1016/j.amepre.2011.04.014

28. Wolf MS, Gazmararian JA, Baker DW. Health literacy and health risk behaviors among older adults. *Am J Prev Med*. 2007;32(1):19–24. http://dx.doi.org/10.1016/j.amepre.2006.08.024.

29. von Wagner C, Knight K, Steptoe A, Wardle J. Functional health literacy and health-promoting behaviour in a national sample of British adults. *J Epidemiol Community Health*. 2007;61(12):1086–90. http://dx.doi.org/10.1136/jech.2006.053967.

30. Osborn CY, Paasche-Orlow MK, Bailey SC, Wolf MS. The mechanisms linking health literacy to behaviour and health status. *Am J Health Behav*. 2011;35(1):118–128. http://dx.doi.org/10.5993/AJHB.35.1.11

31. Bennett JS, Boyle PA, James BD, Bennett DA. Correlates of health and financial literacy in older adults without dementia. *BMC Geriatr*. 2012;12:30. http://dx.doi.org/10.1186/1471-2318-12-30.

32. Buckley J, Cohen JD, Kramer AF, McAuley E, Mullen SP. Cognitive control in the self-regulation of physical activity and sedentary behavior. *Front Hum Neurosci*. 2014;8:1–15. http://dx.doi.org/10.3389/fnhum.2014.00747.

33. Clouston SAP, Brewster P, Kuh D, et al. The dynamic relationship between physical function and cognition in longitudinal aging cohorts. *Epidemiol Rev*. 2013;35:33–50. http://dx.doi.org/10.1093/epirev/mxs004.

34. Steptoe A, Breeze E, Banks J, Nazroo J. Cohort profile: The English Longitudinal Study of Ageing. *Int J Epidemiol*. 2013;42(6):1640–1648. http://dx.doi.org/10.1093/ije/dys168.

35. Thorn W. *International Adult Literacy and Basic Skills Surveys in the OECD Region*.; 2009.

36. Banks J, Breeze E, Cheshire H, et al. Cognitive function. In: Banks J, Breeze E, Lessof C, Nazroo J, eds. *Retirement, health and relationships of the older population in England: The 2004 English Longitudinal Study of Ageing (Wave 2)*. London: The Institute for Fiscal Studies; 2006:217–42.

37. Steptoe A, Demakakos P, de Oliveira C. The psychological well-being, health and functioning of older people in England. In: Banks J, Nazroo J, Steptoe A, eds. *The Dynamics of Ageing: Evidence from the English Longitudinal Study of Ageing 2002-10 (Wave 5)*. London: Institute for Fiscal Studies; 2012:98–182.

38. Hamer M, Lavoie KL, Bacon SL. Taking up physical activity in later life and healthy ageing: the English longitudinal study of ageing. *Br J Sport Med*. 2014;48(3):239–243. http://dx.doi.org/10.1136/bjsports-2013-092993.

39. Smith L, Gardner B, Fisher A, Hamer M. Patterns and correlates of physical activity behaviour over 10 years in older adults: prospective analyses from the English Longitudinal Study of Ageing. *BMJ Open*. 2015;5(4):e007423. http://dx.doi.org/10.1136/bmjopen-2014-007423.

40. Matthews K, Demakakos P, Nazroo J, Shankar A. The evolution of lifestyles in older age in England. In: Banks J, Nazroo J, Steptoe A, eds. *Wave 6: The Dynamics of Ageing: Evidence from the English Longitudinal Study of Ageing 2002-2012*. London: The Institute for Fiscal Studies; 2014:51–93.

41. Rothman K, Greenland S, editors. *Modern Epidemiology*. 3rd ed. Philadelphia: Lippincott-Raven; 2008.

42. NatCen Social Research. *English Longitudinal Study of Ageing (ELSA): Wave 1 to Wave 6: User Guide to the core datasets*. London; 2014.

43. Warburton DE, Nicol CW, Bredin SSD. Health benefits of physical activity: the evidence. *CMAJ*. 2006;174(6):801–809. http://dx.doi.org/10.1503/cmaj.051351.

44. Kobayashi LC, Wardle J, von Wagner C. Internet use, social engagement and health literacy decline during ageing in a longitudinal cohort of older English adults. *J Epidemol Community Health*. 2015;69:278–283. http://dx.doi.org/10.1136/jech-2014-204733.

45. Wolf MS, Feinglass J, Thompson J, Baker DW. In search of "low health literacy": threshold vs. gradient effect of literacy on health status and mortality. *Soc Sci Med*. 2010;70(9):1335–1341. http://dx.doi.org/10.1016/j.socscimed.2009.12.013.

46. McAuley E, Mullen SP, Szabo AN, et al. Self-regulatory processes and exercise adherence in older adults: executive function and self-efficacy effects. *Am J Prev Med*. 2011;41(3):284–290. http://dx.doi.org/10.1016/j.amepre.2011.04.014.

47. Weuve J, Kang JH, Manson JE, Breteler MMB, Ware JH, Grodstein F. Physical activity, including walking, and cognitive function in older women. *JAMA*. 2006;292(12):1454–1461. http://dx.doi.org/10.1016/S0084-3970(08)70261-5.

48. Hillman CH, Erickson KI, Kramer AF. Be smart, exercise your heart: exercise effects on brain and cognition. *Nat Rev Neurosci*. 2008;9:58–65. http://dx.doi.org/10.1038/nrn2298

49. Geda YE, Roberts RO, Knopman DS, et al. Physical Exercise, Aging, and Mild Cognitive Impairment. *Arch Neurol*. 2010;67(1):80–86. http://dx.doi.org/10.1001/archneurol.2009.297

50. Colcombe S, Kramer AF. Fitness effects on the cognitive function of older adults: a meta-analytic study. *Psychol Sci*. 2003;14(2):125–130. http://dx.doi.org/10.1111/1467-9280.t01-1-01430.

51. Van Stralen MM, De Vries H, Mudde AN, Bolman C, Lechner L. Determinants of initiation and maintenance of physical activity among older adults: a literature review. *Heal Psychol Rev*. 2009;3(2):147–207. http://dx.doi.org/10.1080/17437190903229462.

52. Bauman AE, Reis RS, Sallis JF, Wells JC, Loos RJF, Martin BW. Correlates of physical activity: why are some people physically active and others not? *Lancet*. 2012;380(9838):258–271. http://dx.doi.org/10.1016/S0140-6736(12)60735-1.

53. Smith SG, O'Conor R, Curtis LM, et al. Low health literacy predicts decline in physical function among older adults: findings from the LitCog cohort study. *J Epidemiol Community Health*. 2015;69(5):474-480. http://dx.doi.org/10.1136/jech-2014-204915.

54. Newell SA, Girgis A, Sanson-Fisher RW, Savolainen NJ. The accuracy of self-reported health behaviors and risk factors relating to cancer and cardiovascular disease in the general population: A critical review. *Am J Prev Med*. 1999;17(3):211–229. http://dx.doi.org/10.1016/S0749-3797(99)00069-0.

55. Prince SA, Adamo KB, Hamel ME, Hardt J, Gorber SC, Tremblay M. A comparison of direct versus self-report measures for assessing physical activity in adults: a systematic review. *Int J Behav Nutr Phys Act*. 2008;5:56. http://dx.doi.org/10.1186/1479-5868-5-56.

56. World Health Organization. *Global Recommendations on Physical Activity for Health*. Geneva; 2010.

57. Parker R, Baker D, Williams M, Nurss J. The test of functional health literacy in adults: a new instrument for measuring patients' literacy skills. *J Gen Intern Med*. 1995;10(10):537–41.

58. Davis T, Crouch M, Long S, et al. Rapid assessment of literacy levels of adult primary care patients. *Fam Med*. 1991;23(6):433–5.

List of figure titles:

Figure 1. Participation in weekly MVPA at each time point (%), according to baseline health literacy

APPENDIX

Health Literacy Assessment

MEDCO TABLET
INDICATIONS: Headaches, muscle pains, rheumatic pains, toothaches, earaches.

RELIEVES COMMON COLD SYMPTOMS

DOSAGE: ORAL. 1 or 2 tablets every 6 hours, preferably accompanied by food, for not longer than 7 days. Store in a cool, dry place.

CAUTION: Do not use for gastritis or peptic ulcer. Do not use if taking anticoagulant drugs. Do not use for serious liver illness or bronchial asthma. If taken in large doses and for an extended period, may cause harm to kidneys. Before using this medication for chicken pox or influenza in children, consult with a doctor about Reyes Syndrome, a rare but serious illness. During lactation and pregnancy, consult with a doctor before using this product, especially in the last trimester of pregnancy. If symptoms persist, or in the case of an accidental overdose, consult a doctor. Keep out of reach of children.

INGREDIENTS: Each tablet contains
500 mg acetylsalicylic acid.
Excipent c.b.p 1 tablet
Reg. No. 88246

Made in Canada by STERLING PRODUCTS. INC
1600 Industrial Blvd. Montreal, Quebec H9J 3P1

Instructions Read Out by the Interviewer

The final task in this section is about comprehension. This is a made-up medicine label and does not refer to a real medicine. It is often difficult to read and understand instructions on medicine labels. In a moment, I will ask you to read the card quietly to yourself. I will then ask you some questions about what it says. You do not have to memorise the card, as you will be able to look at it while answering the questions.

1. What is the maximum number of days you may take this medicine?
   (Correct answer 7. If responds with 'one week', interviewer may probe for number of days. Other answers incorrect.)

2. List three situations for which you should consult a doctor.
   (Respondent should mention at least three of the following: (Before giving medication to children with) chicken pox; (Before giving medication to children with) influenza, Reyes syndrome, (During) lactation, (During) pregnancy, If symptoms persist, (Accidental) overdose. Incorrect answer: any other response.)

3. List one condition for which you might take the Medco tablet.
   (Correct if answered one of: Headaches, Muscle Pains, Rheumatic pains, Toothache, Earache, Common cold. Other answers incorrect.)

4. List one condition for which you should not take the Medco tablet.
   (Correct if respondent mentions at least one of the following as conditions for which you should not take the tablet: Gastritis, Peptic ulcer, Serious liver illness, Bronchial asthma. Incorrect answer: any other response.)

Scoring: 1 point per complete correct response.

Physical Activity Example Show Card

P3096 HEACTA/HEACTB/HEACTC

CARD C25

Vigorous	Moderate	Mild
For example:	*For example:*	*For example:*
Running or jogging	Gardening	Vacuuming
Swimming	Cleaning the car	Laundry
Cycling	Walking at a moderate pace	Home repairs
Aerobics or gym workout	Dancing	
Tennis	Floor or stretching exercises	
Digging with a spade or shovel		

Appendix Table. Reverse associations between baseline MVPA and change in memory, verbal fluency, and health literacy over the follow-up, England, 2004-13, n=4345

MVPA	Health literacy decline of ≥1 point (Yes vs. No)	Memory decline of >1 point (Yes vs. No)	Verbal fluency decline of >1 point (Yes vs. No)
	OR (95% CI)	OR (95% CI)	OR (95% CI)
Weekly MVPA at baseline			
No	1.00 (ref)	1.00 (ref)	1.00 (ref)
Yes	0.93 (0.73, 1.17)	0.93 (0.76, 1.13)	0.99 (0.82, 1.20)

Note: All ORs adjusted for age, sex, ethnicity, education, net non-pension wealth, self-rated health, limiting long-standing illness, and IADL limitations, and are population-weighted