Psychological Medicine (2010), **40**, 837–845. © Cambridge University Press 2009
doi:10.1017/S0033291709991024

ORIGINAL ARTICLE

The association of cognitive performance with mental health and physical functioning strengthens with age: the Whitehall II cohort study

M. Jokela[1,2]*, A. Singh-Manoux[1,3], J. E. Ferrie[1], D. Gimeno[1,4], T. N. Akbaraly[1,5], M. J. Shipley[1], J. Head[1], M. Elovainio[1,6], M. G. Marmot[1] and M. Kivimäki[1,7]

[1] *Department of Epidemiology and Public Health, University College London, UK*
[2] *Department of Psychology, University of Helsinki, Finland*
[3] *INSERM U687, AP-HP, France*
[4] *Division of Environmental and Occupational Health Sciences, School of Public Health, The University of Texas Health Science Center at Houston, TX, USA*
[5] *INSERM U888, Montpellier, France*
[6] *National Research and Development Centre for Welfare and Health, Helsinki, Finland*
[7] *Finnish Institute of Occupational Health, Finland*

Background. Cognitive performance has been associated with mental and physical health, but it is unknown whether the strength of these associations changes with ageing and with age-related social transitions, such as retirement. We examined whether cognitive performance predicted mental and physical health from midlife to early old age.

Method. Participants were 5414 men and 2278 women from the Whitehall II cohort study followed for 15 years between 1991 and 2006. The age range included over the follow-up was from 40 to 75 years. Mental health and physical functioning were measured six times using SF-36 subscales. Cognitive performance was assessed three times using five cognitive tests assessing verbal and numerical reasoning, verbal memory, and phonemic and semantic fluency. Socio-economic status (SES) and retirement were included as covariates.

Results. High cognitive performance was associated with better mental health and physical functioning. Mental health differences associated with cognitive performance widened with age from 39 to 76 years of age, whereas physical functioning differences widened only between 39 and 60 years and not after 60 years of age. SES explained part of the widening differences in mental health and physical functioning before age 60. Cognitive performance was more strongly associated with mental health in retired than non-retired participants, which contributed to the widening differences after 60 years of age.

Conclusions. The strength of cognitive performance in predicting mental and physical health may increase from midlife to early old age, and these changes may be related to SES and age-related transitions, such as retirement.

Received 20 November 2008; Revised 26 June 2009; Accepted 16 July 2009; First published online 1 September 2009

Key words: Aging, cognitive epidemiology, intelligence, longitudinal studies.

Introduction

It is widely accepted that cognitive status in the elderly predicts mortality and functional status (Holland & Rabbitt, 1991). High cognitive performance has been associated with better mental health, for example lower risk of psychiatric disorders (Zammit *et al*. 2004; Hatch *et al*. 2007; Martin *et al*. 2007), and the emerging field of cognitive epidemiology has begun to explore the role of cognitive ability in physical health and disease outcomes (Gottfredson, 2004; Deary & Batty, 2007). Good performance on cognitive tests has been shown to be associated with lower mortality (Whalley & Deary, 2001; Hart *et al*. 2003; Singh-Manoux *et al*. 2005; Batty *et al*. 2007*a*; Jokela *et al*. 2009*a*; Sabia *et al*. 2008), better self-reported health, and lower prevalence of chronic diseases (Hart *et al*. 2004; Schnittker, 2005; Bosma *et al*. 2007).

Despite the increasing number of cognitive epidemiologic studies, there has been little, if any, research addressing whether the relationship between cognitive performance and health changes over the adult life course, that is whether this relationship remains stable, diminishes, or grows stronger with age. This

* Address for correspondence: Dr M. Jokela, Department of Psychology, University of Helsinki, PO Box 9, FIN-00014, Finland.
(Email: markus.jokela@helsinki.fi)

issue is particularly important in understanding the role of cognitive factors in successful ageing. Furthermore, it remains unknown whether age-related social transitions, such as retirement, modify associations between cognitive performance and health. Retirement is one of the most important social transitions in late adulthood, as it involves substantial changes in daily life and social environments, and retirement has been associated with health outcomes, and with mental health gains in particular (Kim & Moen, 2001; Drentea, 2002; Mein *et al*. 2003).

In the present study using the Whitehall II occupational cohort (Marmot *et al*. 1991; Marmot & Brunner, 2005), we examined whether cognitive performance predicted mental health and physical functioning differently at different times of the adult life course from midlife to early old age. Previous studies have shown that social inequalities in health increase with age (Sacker *et al*. 2005; Chandola *et al*. 2007). Given that cognitive abilities are known to be associated with socio-economic status (SES; Strenze, 2007), we assessed the role of SES in explaining the link between cognitive performance and health. In addition, we examined whether retirement modified the association between cognitive performance and health. Assuming that being retired is less cognitively demanding than work life, we hypothesized that cognitive performance would be less strongly related to health in retired than in non-retired participants.

Method

Participants

The ongoing longitudinal Whitehall II cohort study has followed a sample ($n=10\,308$) of male and female civil servants in London, UK, since 1985–1988 when the participants were 35–55 years of age (Marmot *et al*. 1991; Marmot & Brunner, 2005). We used data from six follow-up phases (phases 3–8, collected in 1991–1993, 1995–1996, 1997–1999, 2001, 2003–2004 and 2006 respectively). The participants were 39–64 years of age at baseline for the present study (phase 3) and 50–76 years of age at the most recent follow-up. Thus, different participants provided data across the whole age range (39–76 years) depending on their age at baseline and year of follow-up. Here we included all participants who provided data at least at one follow-up phase ($n=7692$; 5414 men, 2278 women). At phases 3, 4, 5, 6, 7 and 8, data were available for 3379, 2994, 5749, 5116, 6180 and 5799 participants respectively. Thus, the total number of observations used in the multilevel model was 29 217. Ethical approval for the Whitehall II study was obtained from the University College London Medical School committee on the ethics of human research.

Cognitive performance

Cognitive performance was measured as the first factor derived from principal component analysis of five standard tests: (1) verbal memory was assessed by a 20-word free recall test of short-term memory; (2) the Alice Heim 4 part I (AH 4-I) 32-item verbal reasoning test (Heim, 1970); (3) the AH 4-I 33-item mathematical reasoning test (Heim, 1970); (4) phonemic fluency was assessed using 'S' words; and (5) semantic fluency using 'animal' words (Borkowski *et al*. 1967). In the short-term memory test, participants were presented a list of 20 one- or two-syllable words at 2-s intervals and were then asked to recall in writing as many of the words in any order within 2 min. The AH 4-I is a test of inductive reasoning that measures the ability to identify patterns and infer principles and rules. Participants had 10 min to complete this section. In the phonemic and semantic fluency tests, subjects were asked to recall in writing as many words beginning with 'S' and as many animal names as they could. One minute was allowed for these tests. Factor analysis of these cognitive tests indicated that the first factor accounted for 59% of the variance in these tests, and this factor score was used as the indicator of cognitive performance in the analyses [mean = 0, standard deviation (S.D.) = 1]. The factor analysis was performed across phases so that the factor loadings were the same at each phase. Cognitive tests were administered to a subsample of the participants at phase 3 ($n=3489$) and to all participants at phases 5 ($n=5882$) and 7 ($n=6286$).

Mental and physical health

Mental and physical health was assessed using the SF-36 questionnaire (Ware *et al*. 1993; Ware, 2000) at all six follow-ups from phase 3 to phase 8. In the present study, we used two of the subscales (mental health and physical functioning), representing the main SF-36 subscales for mental and physical health respectively (Ware, 2000). The mental health scale includes five items assessing psychological well-being (e.g. feeling happy, feeling nervous) and the physical functioning scale includes 10 items assessing the ability to carry out daily activities (e.g. difficulties in carrying groceries, difficulties in walking long distances). Both scales were negatively skewed, so they were transformed by cubic transformations (i.e. $X_T = X^3/10\,000$). Following common practice for using the SF-36, the scales were then transformed into *t* scores so that the overall mean score across participants and

https://doi.org/10.1017/S0033291709991024 Published online by Cambridge University Press

follow-up phases was 50 (S.D. = 10). The scales were scored so that higher values indicated better health.

SES and retirement

SES was assessed on the basis of the participant's civil service employment grade (0 = low, 1 = middle, 2 = high) reported by the participants at each phase. For participants who did not have these data (e.g. participants who had retired or were no longer working in the civil service), SES was assigned to be the employment grade at the most recent follow-up in which data on grade were provided.

At each follow-up phase, the participants reported whether or not they were retired, and this was used as the indicator of retirement status (0 = not retired, 1 = retired). Although the statutory retirement age is 60 in the civil service, some participants retired earlier (e.g. voluntarily or due to illness) whereas others had not retired by age 60 (e.g. because they continued to work outside the civil service). Thus, even though retirement status was strongly associated with age, they were not completely collinear (correlations between retirement status and age $r = 0.53$ before age 60 and $r = 0.57$ after age 60; see details of modelling the effects of age below), which allowed us to examine the moderating role of retirement status in addition to the ageing effect.

Statistical analysis

We applied multilevel longitudinal modelling (Singer & Willett, 2003; Gelman & Hill, 2007) to evaluate whether cognitive performance predicted the shape of health trajectories over the adult life course. Data were structured so that measurement times (observations at each phase) were nested within individuals, and the standard error (S.E.) were calculated by taking into account the non-independence of the observations; that is, that the same individuals contributed more than one observation to the dataset. On average, participants provided data at four of the six possible follow-up phases. In the multilevel models, regression coefficients are interpreted in the same way as non-standardized coefficients in ordinary linear regression. All predictors, apart from sex, were entered as time-varying covariates. Models included a random term for intercept but we did not include random terms for age or other covariates (data on the random part of the model not shown).

Based on preliminary analysis of the mental health trajectory, we modelled the effect of age using a piecewise approach (Naumova *et al*. 2001), where the age range (from 39 to 76 years) was divided into two parts: before and after the age of 60. This was accomplished by creating one age variable for the age period of 39–59 (Age before 60 years, abbreviated to Age_b, and 0 otherwise) and another age variable for the age period 60–76 (Age after 60 years, abbreviated to Age_a, and 0 otherwise). Both of these variables were centred on age 60 (i.e. were equal to age minus 60). Although the average physical functioning trajectory had a different shape than the mental health trajectory, we applied the same piecewise approach in modelling physical functioning because it provided a flexible model to examine whether cognitive performance predicted health trajectories differently before and after the age of 60.

To test whether the association between cognitive performance and health trajectories increased or decreased with age, we assessed interaction effects between cognitive performance and age with each age term included in the model. These interactions were assessed by first testing interaction terms with linear indicators of age and then with quadratic indicators of age. Only significant interaction terms were retained in the models. The interaction effects between SES and health were assessed in the same way. To test whether cognitive performance predicted health differently in retired and in non-retired participants, we assessed interaction effects between cognitive performance and retirement. The results were illustrated by plotting predicted mental health and physical functioning trajectories by age for three selected scores of cognitive performance (1 S.D. below the mean, the mean value, and 1 S.D. above the mean).

All models were adjusted for sex and its statistically significant interaction effects with age, that is allowing the association between sex and the outcomes to change over time. As data on cognitive performance were not available at phases 4, 6 and 8, we assigned cognitive performance scores assessed at phase 3, 5 and 7 to phases 4, 6 and 8 respectively, in order to include all health outcome measures (assessed at each phase) in modelling the mental and physical health trajectories. Given that different participants were followed over different age periods, the study design allowed the role of period or cohort effects to be taken into account in addition to ageing effects. Following previous research from the Whitehall II cohort (Chandola *et al*. 2007), we decided to adjust for period effects. The multilevel models were fitted using the xtreg command in Stata 9.2 (StataCorp, USA) statistical program.

Results

Mental health

Preliminary analysis of mental health and age indicated that a model including linear and quadratic

https://doi.org/10.1017/S0033291709991024 Published online by Cambridge University Press

Table 1. *Predicting mental health trajectories from 40 to 75 years of age by cognitive performance, socio-economic status (SES) and retirement status. Beta coefficients (and standard errors) of nested multilevel models (n = 7692)*

	Model 1	Model 2	Model 3
Intercept	56.50* (0.37)	55.11* (0.48)	54.53* (0.48)
Age_b	0.63* (0.03)	0.53* (0.04)	0.43* (0.04)
Age_b^2	0.02* (0.00)	0.02* (0.00)	0.01* (0.00)
Age_a	0.33* (0.05)	0.34* (0.05)	0.24* (0.05)
Age_a^2	−0.01* (0.00)	−0.01* (0.00)	−0.01* (0.00)
Period			
Phase 3	(reference)	(reference)	(reference)
Phase 4	−1.57* (0.17)	−1.57* (0.17)	−1.59* (0.17)
Phase 5	−1.78* (0.19)	−1.79* (0.19)	−1.79* (0.19)
Phase 6	−2.25* (0.22)	−2.26* (0.22)	−2.26* (0.22)
Phase 7	−2.74* (0.24)	−2.80* (0.24)	−2.72* (0.24)
Phase 8	−2.47* (0.28)	−2.53* (0.28)	−2.46* (0.28)
Sex (0 = men, 1 = women)	−2.45* (0.21)	−2.15* (0.23)	−2.17* (0.23)
Cognitive performance	0.50* (0.12)	0.21 (0.13)	0.00 (0.14)
Cognitive performance × Age_b	0.05* (0.01)	0.02 (0.01)	0.00 (0.02)
Cognitive performance × Age_a	0.05* (0.02)	0.05* (0.02)	0.02 (0.02)
SES		0.35* (0.07)	0.35* (0.07)
SES × Age_b		0.03* (0.01)	0.03* (0.01)
Retirement (0 = not retired, 1 = retired)			0.55* (0.13)
Retirement × cognitive performance			0.55* (0.14)

Age_b, Age before 60 years; Age_a, age after 60 years.

The main effect of cognitive performance refers to 60-year-olds (model 1), low-SES (model 2) and non-retired (model 3) participants. Mental health is scored as a *t* score (mean = 50, standard deviation = 10).

* $p < 0.05$ level (minimum).

effects of age fitted the data well, describing an S-shaped trajectory. On average, mental health increased between 39 and 60 years of age, after which the increase began to level off. Women had lower mental health than men (Table 1).

Interaction effects between cognitive performance and age before and after 60 years (Table 1, model 1) indicated that the association between cognitive performance and mental health increased with age (Fig. 1). The predicted mental health scores in those with high (+1 S.D.) compared to low (−1 S.D.) cognitive performance levels was better by 0.5, 1.0 and 2.6 units at 50, 60 and 70 years of age respectively.

The association between cognitive performance and health was accounted for, in part, by SES (Table 1, model 2). In an analysis that included cognitive performance and other covariates in the model, there was a significant interaction effect between SES and age before 60 years but not between SES and age after 60 years ($B = 0.00$, S.E. = 0.03, $p = 0.99$; not included in the model), suggesting widening mental health differences associated with SES before age 60. Including SES and its interaction effect with age in the model attenuated the interaction between cognitive performance and age before 60 years (Table 1, model 2), indicating that SES accounted for the mental health differences associated with cognitive performance before but not after age 60.

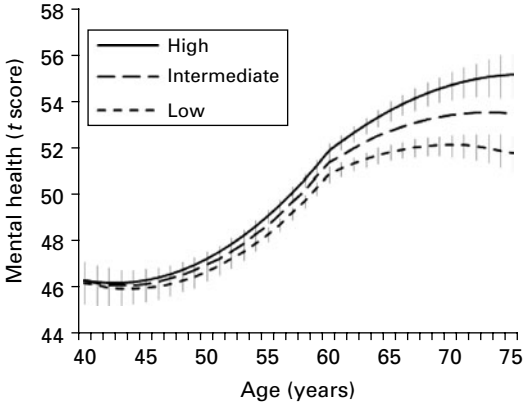

Fig. 1. Predicted mental health trajectories (and 95% confidence intervals) by levels of cognitive performance (low = 1 S.D. below the mean; intermediate = mean; high = 1 S.D. above the mean). For clarity, the 95% confidence intervals (vertical lines) are not shown for the intermediate group.

We found evidence to suggest that retirement modified the association between cognitive performance

https://doi.org/10.1017/S0033291709991024 Published online by Cambridge University Press

Table 2. *Predicting physical functioning trajectories from 40 to 75 years of age by cognitive performance, socio-economic status (SES) and retirement status. Beta coefficients (and standard errors) of nested multilevel models (n = 7692)*

	Model 1	Model 2	Model 3
Intercept	55.35* (0.36)	52.67* (0.46)	52.58* (0.46)
Age_b	−0.28* (0.02)	−0.37* (0.03)	−0.38* (0.03)
Age_a	−0.17* (0.04)	−0.18* (0.04)	−0.20* (0.04)
Age_a^2	−0.02* (0.00)	−0.02* (0.00)	−0.02* (0.00)
Period			
Phase 3	(reference)	(reference)	(reference)
Phase 4	−0.56* (0.16)	−0.56* (0.16)	−0.55* (0.16)
Phase 5	0.00 (0.17)	0.04 (0.17)	0.06 (0.17)
Phase 6	−0.62* (0.20)	−0.58* (0.20)	−0.57* (0.20)
Phase 7	−0.09 (0.23)	−0.17 (0.23)	−0.14 (0.23)
Phase 8	0.29 (0.26)	0.22 (0.26)	0.24 (0.26)
Sex (0 = men, 1 = women)	−4.55* (0.21)	−3.88* (0.22)	−3.89* (0.22)
Cognitive performance	1.63* (0.10)	1.14* (0.11)	1.15* (0.11)
Cognitive performance × Age_b	0.06* (0.01)	0.03* (0.01)	0.03* (0.01)
SES		0.64* (0.07)	0.64* (0.07)
SES × Age_b		0.03* (0.01)	0.03* (0.01)
Retirement (0 = not retired, 1 = retired)			0.24* (0.12)

Age_b, Age before 60 years; Age_a, age after 60 years.

The main effect of cognitive performance refers to 60-year-olds (model 1), low-SES (model 2), and non-retired (model 3) participants. Physical functioning is scored as a *t* score (mean = 50, standard deviation = 10).

* $p < 0.05$ level (minimum).

and mental health (Table 1, model 3). There was an interaction effect between cognitive performance and retirement indicating that cognitive performance was associated with mental health more strongly in retired than in non-retired participants. Inclusion of this interaction term in the model attenuated the interaction effect between cognitive performance and age after 60 years. In other words, the widening mental health differences associated with cognitive performance after the age of 60 were related to retirement becoming more common, as retirement strengthened the association between cognitive performance and mental health.

Physical functioning

We then repeated the above analysis with physical functioning as the dependent variable. Physical functioning scores declined with age and this decline accelerated after the age of 60, as indicated by the significant quadratic effect of age after 60 years (Table 2, model 1). Women had lower physical functioning than men. The effects of period on physical functioning were not consistent across the phases.

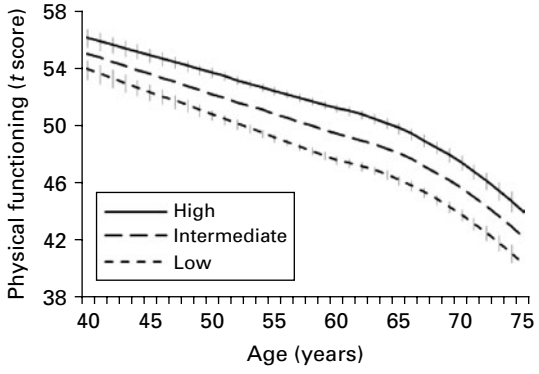

Fig. 2. Predicted physical functioning trajectories (and 95% confidence intervals) by levels of cognitive performance (low = 1 S.D. below the mean; intermediate = mean; high = 1 S.D. above the mean). The 95% confidence intervals (vertical lines) are shown only for the high and low groups.

There was a significant interaction effect between cognitive performance and age before 60 years but not with other age indicators (model 1), indicating that physical functioning differences associated with cognitive performance increased with age only before but not after the age of 60 (Fig. 2). The predicted difference

https://doi.org/10.1017/S0033291709991024 Published online by Cambridge University Press

between high and low cognitive performance groups was 2.2, 2.8, 3.6 and 3.6 units at ages 40, 50, 60 and 70 respectively.

Table 2 (model 2) shows that there was an interaction effect between SES and age before but not after 60 ($B=0.01$, S.E. $=0.02$, $p=0.82$; not included in the model), indicating that physical functioning differences associated with SES increased before but not after age 60. Inclusion of this interaction effect halved the magnitude of the interaction between cognitive performance and age before 60, suggesting that the widening differences in physical functioning between participants with high and low cognitive performance were partially explained by differences in SES. There was no interaction effect between cognitive performance and retirement (Table 2, model 3). Thus, retirement did not modify the association between cognitive performance and physical functioning (p value for interaction $=0.56$; not included in the model).

Attrition analysis

Attrition analysis suggests that our findings are not biased by selective attrition. For each phase, we created a dichotomous variable indicating whether or not the participant had data at the next phase. We then fitted a multilevel logistic model to predict this probability for cognitive performance, mental health and physical functioning, in analysis adjusted for sex, period and linear terms for age. Higher probability of attrition was associated with lower cognitive performance [standardized odds ratio (OR) 0.71, standard S.E. $=0.02$, $p<0.001$], poorer mental health (standardized OR 0.89, S.E. $=0.02$, $p<0.001$), and poorer physical functioning (standardized OR 0.86, S.E. $=0.02$, $p<0.001$). However, these attrition patterns did not contribute to the widening associations between cognitive performance and health because, if anything, the attrition attenuated rather than strengthened the estimated associations. For instance, regressing mental health on cognitive performance at phase 5 (adjusted for sex and age) in all participants who had data at phase 5 yielded the coefficient of $B=1.27$ (S.E. $=0.34$, $p<0.001$; $n=5776$). When the same linear regression model was fitted in participants who had data at phases 5 and 6 (i.e. excluding drop-outs between phases 5 and 6), the regression coefficient was $B=1.01$ (S.E. $=0.36$, $p<0.001$; $n=5033$). A similar, small attenuation effect was evident at other follow-up phases (data not shown).

Discussion

Findings from the longitudinal Whitehall II occupational cohort indicate that the importance of cognitive performance in predicting adult mental health and physical functioning may increase with age, resulting in widening health differences associated with cognitive performance. On average, cognitive performance was more strongly related to physical functioning than to mental health. However, the age-related changes in these associations were more pronounced for mental health than for physical functioning: mental health differences associated with cognitive performance widened with age from 39 to 76 years, whereas the physical functioning differences widened only between 39 and 60 years but not after 60 years of age.

The methodological strengths of the study include a large sample size and a longitudinal design with repeated measures of cognitive performance and health outcomes. Attrition analyses suggested that, although cognitive performance and health measures were associated with selective attrition, the selective attrition in question was unlikely to contribute to the widening health differences associated with cognitive performance observed in the data. The main caveat to our findings is that the participants were from an occupational cohort, which may limit the generalizability of the findings.

Performance in cognitive tests has been shown to predict a wide range of mental and physical health outcomes (e.g. Hart *et al*. 2004; Bosma *et al*. 2007; Der *et al*. 2009; Gale *et al*. 2008). Although this association has been observed in samples representing different age periods in adulthood, there are, to our knowledge, no previous longitudinal studies examining this association at different ages in the same sample. The widening health differences observed in our data are therefore novel and imply that cognitive performance may become a more salient correlate of health at older ages.

There are at least four plausible mechanisms that could explain associations between cognitive performance and health (Whalley & Deary, 2001; Gottfredson & Deary, 2004; Batty *et al*. 2007*a*) and these could be extended to explain the effects of age observed in this study. First, cognitive performance and health may share a common cause, and such a common cause might account for the present findings if its impact were increasingly evident with age. For instance, vascular risk factors (e.g. hypertension, coronary heart disease and dyslipidaemia) become more prevalent with age and they have been associated with both cognitive performance (Singh-Manoux & Marmot, 2005; Singh-Manoux *et al*. 2008*a*, *b*) and health (Rugulies, 2002; Kumari *et al*. 2004).

Second, cognitive performance may be related to health behaviours (Batty *et al*. 2007*b*, *c*). In this case, any association between cognitive performance and

https://doi.org/10.1017/S0033291709991024 Published online by Cambridge University Press

health, and physical health in particular, would be expected to strengthen as physical illnesses associated with adverse health behaviours become more prevalent with age. However, as we observed widening differences in physical functioning before but not after the age of 60, this seems an unlikely explanation of our findings. Third, despite the prospective study design, the association between cognitive performance and health may reflect reverse causality; that is, cognitive performance may be affected by mental and physical health (Yaffe *et al*. 1999; Ganguli *et al*. 2006; Chodosh *et al*. 2007; Dotson *et al*. 2008).

Fourth, cognitive performance may predict selection into more 'healthy' social environments, for example high SES (Batty *et al*. 2007*a*, 2008; Jokela *et al*. 2009*b*), or be a marker of such environments. Previous research in the present and other cohorts suggests that health inequalities associated with SES may increase with age (Sacker *et al*. 2005; Chandola *et al*. 2007). In agreement with these observations, we found that, before the age of 60, SES explained the increasing role of cognitive performance either completely (in the case of mental health) or in part (in the case of physical functioning). However, SES did not attenuate the association between cognitive performance and health after age 60, implying that socio-economic circumstances may be relevant in explaining the cognition–health association primarily in working-age populations. Alternatively, the SES measure used in the present study, employment grade, may have failed to capture post-retirement socio-economic conditions completely, so the lack of attenuation might be caused by residual confounding.

Contrary to our hypothesis, cognitive performance predicted mental health more strongly in retired than in non-retired participants. This finding suggests that retirement might involve cognitively challenging social changes, as retiring individuals reorganize their lives and adjust to new daily activities without the structure of work that has characterized most of their adult lives (Kim & Moen, 2001). The modifying role of retirement accounted for the widening differences in mental health after the age of 60; that is, mental health differences associated with cognitive performance became more pronounced as more participants became retired. Retirement did not moderate the association between cognitive performance and physical functioning, indicating that the changing circumstances related to retirement may not be as relevant for physical health in early old age.

The observed associations between cognitive performance and health trajectories need to be interpreted keeping in mind the examined age range of 39–76 years. On average, mental health was at its lowest level between ages 45 and 50 and began to increase after this age period, whereas physical functioning decreased consistently between the ages of 39 and 76 years. Thus, cognitive performance was associated with a steeper age-related increase in mental health and a less steep decline in age-related physical functioning. This suggests that high cognitive performance may be associated with both health gains and health losses related to ageing. However, it is noteworthy that these were only modifications of a general age-related trend because individuals with different levels of cognitive performance all followed the same general mental health and physical functioning trajectories. Further research is needed to assess whether the relationship of cognitive performance with mental and physical health reflect common or separate underlying mechanisms.

In sum, the present findings indicate that the association between cognitive performance and health may be dependent on age and age-related social transitions. Our data suggest that cognitive epidemiology, the study of the role of cognition in health (Deary & Batty, 2007), would benefit from closer attention to the role played by ageing in shaping this association across the life course. This is particularly relevant as the importance of multiple psychological and social factors in explaining the cognition–health association is likely to vary over the life course. Future research should assess the extent to which other social (and biological) factors, in addition to SES and retirement, contribute to these age-related changes.

Acknowledgements

The Whitehall II study has been supported by grants from the British Medical Research Council (MRC); the British Heart Foundation; the British Health and Safety Executive; the British Department of Health; the National Heart, Lung, and Blood Institute (grant HL36310); the National Institute on Aging (grant AG13196); the Agency for Health Care Policy and Research (grant HS06516); and the John D. and Catherine T. MacArthur Foundation Research Networks on Successful Midlife Development and Socioeconomic Status and Health. M.K. was supported by the Academy of Finland (grants 117604, 124322, and 124271). J.E.F. was supported by the MRC (grant G8802774), A.S.M. by a 'European Young Investigator Award' from the European Science Foundation, M.J.S. by the British Heart Foundation and M.G.M. by an MRC Research Professorship.

Declaration of Interest

None.

References

Batty GD, Deary IJ, Gottfredson LS (2007*a*). Premorbid (early life) IQ and later mortality risk: systematic review. *Annals of Epidemiology* **17**, 278–288.

Batty GD, Deary IJ, Macintyre S (2007*b*). Childhood IQ in relation to risk factors for premature mortality in middle-aged persons: the Aberdeen Children of the 1950s study. *Journal of Epidemiology and Community Health* **61**, 241–247.

Batty GD, Deary IJ, Schoon I, Gale CR (2007*c*). Mental ability across childhood in relation to risk factors for premature mortality in adult life: the 1970 British Cohort Study. *Journal of Epidemiology and Community Health* **61**, 997–1003.

Batty GD, Shipley MJ, Mortensen LH, Boyle SH, Barefoot J, Grønbaek M, Gale CR, Deary IJ (2008). IQ in late adolescence/early adulthood, risk factors in middle age and later all-cause mortality in men: the Vietnam Experience Study. *Journal of Epidemiology and Community Health* **62**, 522–531.

Borkowski JG, Benton AL, Spreen O (1967). Word fluency and brain damage. *Neurophysiologia* **5**, 135–140.

Bosma H, van Boxtel MP, Kempen GI, van Eijk JT, Jolles J (2007). To what extent does IQ 'explain' socio-economic variations in function? *BMC Public Health* **25**, 179.

Chandola T, Ferrie J, Sacker A, Marmot M (2007). Social inequalities in self reported health in early old age: follow-up of prospective cohort study. *British Medical Journal* **334**, 990.

Chodosh J, Kado DM, Seeman TE, Karlamangla AS (2007). Depressive symptoms as a predictor of cognitive decline: MacArthur Studies of Successful Aging. *American Journal of Geriatric Psychiatry* **15**, 406–415.

Deary IJ, Batty GD (2007). Cognitive epidemiology. *Journal of Epidemiology and Community Health* **61**, 378–384.

Der G, Batty GD, Deary IJ (2009). The association between IQ in adolescence and a range of health outcomes at 40 in the 1979 US National Longitudinal Study of Youth. *Intelligence*. Published online 20 January 2009. doi:10.1016/j.intell.2008.12.002.

Dotson VM, Resnick SM, Zonderman AB (2008). Differential association of concurrent, baseline, and average depressive symptoms with cognitive decline in older adults. *American Journal of Geriatric Psychiatry* **16**, 318–330.

Drentea P (2002). Retirement and mental health. *Journal of Aging and Health* **14**, 167–194.

Gale CR, Hatch SL, Batty GD, Deary IJ (2008). Intelligence in childhood and risk of psychological distress in adulthood: the 1958 National Child Development Survey and the 1970 British Cohort Study. *Intelligence*. Published online 8 October 2008. doi:10.1016/j.intell.2008.09.002.

Ganguli M, Du Y, Dodge HH, Ratcliff GG, Chang CC (2006). Depressive symptoms and cognitive decline in late life: a prospective epidemiological study. *Archives of General Psychiatry* **63**, 153–160.

Gelman A, Hill J (2007). *Data Analysis Using Regression and Multilevel/Hierarchical Models*. Cambridge University Press: Cambridge.

Gottfredson LS (2004). Intelligence: is it the epidemiologists' elusive 'fundamental cause' of social class inequalities in health? *Journal of Personality and Social Psychology* **86**, 174–199.

Gottfredson LS, Deary IJ (2004). Intelligence predicts health and longevity, but why? *Current Directions in Psychological Science* **13**, 1–4.

Hart CL, Taylor MD, Davey Smith G, Whalley LJ, Starr JM, Hole DJ, Wilson V, Deary IJ (2003). Childhood IQ, social class, deprivation, and their relationships with mortality and morbidity risk in later life: prospective observational study linking the Scottish Mental Survey 1932 and the Midspan studies. *Psychosomatic Medicine* **65**, 877–883.

Hart CL, Taylor MD, Smith GD, Whalley LJ, Starr JM, Hole DJ, Wilson V, Deary IJ (2004). Childhood IQ and cardiovascular disease in adulthood: prospective observational study linking the Scottish Mental Survey 1932 and the Midspan studies. *Social Science and Medicine* **59**, 2131–2138.

Hatch SL, Jones PB, Kuh D, Hardy R, Wadsworth ME, Richards M (2007). Childhood cognitive ability and adult mental health in the British 1946 birth cohort. *Social Science and Medicine* **64**, 2285–2296.

Heim AW (1970). *AHA4 Group Test for General Intelligence*. Windsor: ASE/NFER-Nelson Publishing Co. Ltd.

Holland CA, Rabbitt PMA (1991). The course and causes of cognitive change with advancing age. *Reviews in Clinical Gerontology* **1**, 81–86.

Jokela M, Batty GD, Deary IJ, Gale CR, Kivimäki M (2009*a*). Childhood IQ and early mortality: assessing the role of childhood and adult risk factors in the 1958 British birth cohort. *Pediatrics*. Published online 10 August 2009. doi:10.1542/peds.2008-1536.

Jokela M, Elovainio M, Singh-Manoux A, Kivimäki M (2009*b*). IQ, socioeconomic status, and early mortality: the U.S. National Longitudinal Survey of Youth. *Psychosomatic Medicine* **71**, 322–328.

Kim JE, Moen P (2001). Is retirement good or bad for subjective well-being? *Current Directions in Psychological Science* **10**, 83–86.

Kumari M, Seeman T, Marmot M (2004). Biological predictors of change in functioning in the Whitehall II study. *Annals of Epidemiology* **14**, 250–257.

Marmot M, Brunner E (2005). Cohort profile: the Whitehall II study. *International Journal of Epidemiology* **34**, 251–256.

Marmot MG, Davey Smith G, Stansfeld S, Patel C, North F, Head J, White I, Brunner E, Feeney A (1991). Health inequalities among British civil servants: the Whitehall II study. *Lancet* **337**, 1387–1393.

Martin LT, Kubzansky LD, LeWinn KZ, Lipsitt LP, Satz P, Buka SL (2007). Childhood cognitive performance and risk of generalized anxiety disorder. *International Journal of Epidemiology* **36**, 769–775.

Mein G, Martikainen P, Hemingway H, Stansfeld S, Marmot M (2003). Is retirement good or bad for mental and physical health functioning? Whitehall II longitudinal study of civil servants. *Journal of Epidemiology and Community Health* **57**, 46–49.

Naumova EN, Must A, Laird NM (2001). Tutorial in biostatistics: evaluating the impact of 'critical periods' in longitudinal studies of growth using piecewise mixed effects models. *International Journal of Epidemiology* **30**, 1332–1341.

Rugulies R (2002). Depression as a predictor for coronary heart disease. A review and meta-analysis. *American Journal of Preventive Medicine* **23**, 51–61.

Sabia S, Guéguen A, Marmot MG, Shipley MJ, Ankri J, Singh-Manoux A (2008). Does cognition predict mortality in midlife? Results from the Whitehall II cohort study. *Neurobiology of Aging*. Published online 9 June 2008. doi:10.1016/j.neurobiolaging.2008.05.007.

Sacker A, Clarke P, Wiggins RD, Bartley M (2005). Social dynamics of health inequalities: a growth curve analysis of aging and self assessed health in the British household panel survey 1991–2001. *Journal of Epidemiology and Community Health* **59**, 495–501.

Schnittker J (2005). Cognitive abilities and self-rated health: is there a relationship? Is it growing? Does it explain disparities? *Social Science Research* **34**, 821–842.

Singer JB, Willett JB (2003). *Applied Longitudinal Data Analysis: Modeling Change and Event Occurrence*. Oxford University Press: Oxford.

Singh-Manoux A, Ferrie JE, Lynch JW, Marmot M (2005). The role of cognitive ability (intelligence) in explaining the association between socioeconomic position and health: evidence from the Whitehall II prospective cohort study. *American Journal of Epidemiology* **161**, 831–839.

Singh-Manoux A, Gimeno D, Kivimäki M, Brunner E, Marmot MG (2008*a*). Low HDL cholesterol is a risk factor for deficit and decline in memory in midlife: the Whitehall II study. *Arteriosclerosis, Thrombosis, and Vascular Biology* **28**, 1556–1562.

Singh-Manoux A, Marmot M (2005). High blood pressure was associated with cognitive function in middle-age in the Whitehall II study. *Journal of Clinical Epidemiology* **58**, 1308–1315.

Singh-Manoux A, Sabia S, Lajnef M, Ferrie JE, Nabi H, Britton AR, Marmot MG, Shipley MJ (2008*b*). History of coronary heart disease and cognitive performance in midlife: the Whitehall II study. *European Heart Journal*. Published online 22 July 2008. doi:10.1093/j.eurheartj/ehn298.

Strenze T (2007). Intelligence and socioeconomic success: a meta-analytic review of longitudinal research. *Intelligence* **35**, 401–426.

Ware JE, Snow KK, Kosinski M, Gandek B (1993). *SF-36 Health Survey Manual and Interpretation Guide*. New England Medical Center: Boston.

Ware Jr. JE (2000). SF-36 health survey update. *Spine* **25**, 3130–3139.

Whalley LJ, Deary IJ (2001). Longitudinal cohort study of childhood IQ and survival up to age 76. *British Medical Journal* **322**, 819.

Yaffe K, Blackwell T, Gore R, Sands L, Reus V, Browner WS (1999). Depressive symptoms and cognitive decline in nondemented elderly women: a prospective study. *Archives of General Psychiatry* **56**, 425–430.

Zammit S, Allebeck P, David AS, Dalman C, Hemmingsson T, Lundberg I, Lewis G (2004). A longitudinal study of premorbid IQ score and risk of developing schizophrenia, bipolar disorder, severe depression, and other nonaffective psychoses. *Archives of General Psychiatry* **61**, 354–360.