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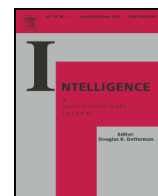
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Intelligence in youth and health at age 50



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ABSTRACT

Background: The link between intelligence in youth and all-cause mortality in later-life is well established. To better understand this relationship, the current study examines the links between pre-morbid intelligence and a number of specific health outcomes at age 50 using the NLSY-1979 cohort.

Methods: Participants were the 5793 participants in the NLSY-79 who responded to questions about health outcomes at age 50. Sixteen health outcomes were examined: two were summary measures (physical health and functional limitation), 9 were diagnosed illness conditions, 4 were self-reported conditions, and one was a measure of general health status. Linear and logistic regressions were used, as appropriate, to examine the relationship between intelligence in youth and the health outcomes. Age, sex and both childhood and adult SES, and its sub-components – income, education, & occupational prestige – are all adjusted for separately.

Results & conclusion: Higher pre-morbid intelligence is linked with better physical health at age 50, and a lower risk for a number of chronic health conditions. For example, a 1 SD higher score in IQ was significantly associated with increased odds of having good, very good, or excellent health, with an odds ratio of 1.70 (C.I. 1.55–1.86). Thirteen of the illness outcomes were significantly and negatively associated with IQ in youth; the odds ratios ranged from 0.85 for diabetes/high blood sugar to 0.65 for stroke, per one standard deviation higher score in IQ. Adjustment for childhood SES led to little attenuation but adult SES partially mediated the relationship for a number of conditions. Mediation by adult SES was not consistently explained by any one of its components—income, education, and occupation status. The current findings contribute to our understanding of lower intelligence as a risk factor for poor health and how this may contribute to health inequalities.

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1. Introduction

The initial findings of the field that has come to be known as cognitive epidemiology established a link between intelligence in youth and all-cause-mortality, with lower intelligence being linked with higher mortality risk (O'Toole & Stankov, 1992; Whalley & Deary, 2001; Calvin et al., 2011; Deary, Weiss, & Batty, 2010). Gottfredson (2004) suggested that individual differences in intelligence might help explain social inequalities in health. In order to better understand the relationship between intelligence and mortality rates, efforts have been made to map out the etiological processes underlying this association.

Focusing on cause-specific mortality might help to elucidate the potential mechanisms underlying the link between intelligence and all-cause-mortality by highlighting those diseases that have a stronger or weaker relationship with intelligence. For example, a consistent association between pre-morbid intelligence and mortality from coronary heart disease (CHD) has been found (Kajantie et al., 2012; Lawlor, David Batty, Clark, McIntyre, & Leon, 2008; Batty, Mortensen, Nybo

Anderssen, & Osler, 2005; Silventoinen, Modig-wennerstad, & Tynelius, 2007; Hart et al., 2004; Batty, Shipley, Gale, Mortensen, & Deary, 2008b; Deary, Whiteman, Starr, Whalley, & Fox, 2004; Hemmingsson, Melin, Allebeck, & Lundberg, 2006; Ariansen et al., 2014). On the other hand, studies testing for a link between intelligence and mortality due to cancer have had mixed findings (Batty et al., 2009; Batty et al., 2007c, 2007d; Hart, Taylor, Smith, Whalley, Starr, Hole, Wilson, & Deary, 2003; Hemmingsson et al., 2006).

Beyond the major causes of death, studies of intelligence in youth in relation to cause specific mortality are often hampered by low numbers of deaths. In addition, many, if not most such studies rely on linkage to death registers and may have little or no information on intervening factors. Hence there is a need for studies of intelligence and morbidity, both in general and for specific conditions. Such studies may reinforce findings from mortality studies—e.g., finding that there is an association between lower intelligence in youth and risk of developing non-fatal disease, as has been shown in the case of cardiovascular disease (Deary et al., 2004; Hemmingsson et al., 2006) and coronary heart disease (Hart et al., 2004). They may also shed light on the relation between intelligence and conditions, syndromes and symptoms beyond the major causes of mortality. Studies of morbidity may also have richer information on potential confounding and mediating factors.

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In the examination of intelligence and morbidity, Der, Batty, and Deary (2009) studied the associations between IQ in youth and a number of health conditions at 40 years of age. Their study was based on a sample of 7476 adults from the US National Longitudinal Survey of Youth, 1979 cohort (NLSY-79). Summarizing some of the key findings, they found that higher IQ was associated with a reduced chance of being diagnosed with heart problems, hypertension, diabetes, arthritis/rheumatism and chronic lung disease at age 40, and better overall physical and mental health. Controlling for childhood SES had little attenuating effect on these relationships.

The Der et al. (2009) study was informative but there are a number of ways in which it could be improved. For instance, both childhood and adulthood SES are associated with health inequalities (Wilkinson & Marmot, 2003) and intelligence (Lubinski, 2009; McLoyd, 1998); both should be included when examining the association between intelligence in youth and later health outcomes. It is thought that adult SES may mediate the association between cognitive ability and health outcomes to varying degrees, and childhood SES may partially confound it, though evidence to date suggests that the extent to which it confounds the association is slight; a systematic review found that adjustment for adult SES attenuated the relationship between childhood IQ and all-cause-mortality by 33.5% but adjustment for childhood SES only attenuated it by 4% (Calvin et al., 2011). Other studies in the field have also found that adult SES has a greater attenuating effect than childhood SES does on the relationship between intelligence in youth and health outcomes later in life (Hemmingsson et al., 2006; Jokela, Batty, Deary, Gale, & Kivimäki, 2009), though the interpretation of this attenuation is still uncertain (Deary, Weiss, & Batty, 2010).

Whereas SES is often represented by a compound index, as it is in the present study, it is also potentially informative to examine individually the impact of its components – education, income, and occupation status – on the relationship between childhood intelligence and later health. A link between higher childhood intelligence and greater educational attainment has been found both in general (Jencks, 1979; Deary, Strand, Smith, & Fernandes, 2007) and in this specific cohort (Herrnstein & Murray, 1998). Controlling for education has been found to have a greater attenuating effect on the relationship between childhood IQ and all-cause mortality than controlling for childhood and adulthood SES (Calvin et al., 2011). Positive associations between intelligence and income (Zagorsky, 2007) and between intelligence and occupational class (Schmidt & Hunter, 2004) have also been found, and both of these are also inversely associated with health (Marmot, 2002; Marmot et al., 1991; Weiss, Gale, Batty, & Deary, 2009).

The NLSY-79 cohort that was used in the age-40 study by Der et al. (2009) has now been followed up at age 50 and they have completed a health survey. Health information recorded at age 50 has a number of advantages over that collected at age 40. The respondents will be more likely to have chronic health conditions (D Kuh, Ben-Shlomo, Lynch, Hallqvist, & Power, 2003). The health survey used at age 50 contains a greater proportion of diagnosed health conditions and well-established health scales which have strong reliability and validity (Ware, Kosinski, & Keller, 1996), whereas the majority of questions in the 40+ health module were self-reported conditions.

The aims of the present study are: substantially to expand upon the findings from the study by Der, Batty, & Deary on intelligence in youth and health outcomes at age 40 (2009) by: investigating the relationship between intelligence in young adulthood and physical health at age 50; and testing the extent to which any associations are explained by childhood SES, adult SES and its three components (education, income, and occupation status). It is hypothesized that higher IQ in youth will be associated with better physical health and functioning at age 50 and will also be associated with lower rates of a number of diagnosed and self-reported physical health outcomes. Childhood SES, adult SES, education,

income, and occupation status are hypothesized to attenuate the observed effects to varying degrees. More specifically, it is hypothesized that adult SES will have a greater attenuating effect on the relationship between intelligence and health outcomes than childhood SES. It is hypothesized that education, on its own, may lead to more attenuation than either income or occupation status.

2. Methods

2.1. Participants

This study was based on data from the National Longitudinal Study of Youth 1979 (NLSY-79). The initial sample was representative of non-institutionalized young people who lived in the United States. It was a random household sample and consisted of 12,686 individuals aged 14–21 years on the 31st of December 1978. There were 6283 males (50%) and 6403 females (50%), and 16% were Hispanic/Latino, 25% were Black, and 59% were non-Black & non-Hispanic.

The NLSY-79 survey collected information on a variety of topics such as health, education, achievement tests, employment and attitudes. The initial interview for NLSY-79 took place in 1979 (Bureau of Labor Statistics & U. S. D. of L., n.d.). The respondents were re-interviewed annually until 1994 and biennially thereafter. The most recent data available derive from the 2012 survey. It had a 57.5% retention rate from the initial sample and consisted of a total of 7301 individuals, with 48% males. The respondents were between 47 and 56 years of age (Bureau of Labor Statistics & U. S. D. of L., n.d.).

The 50+ health module was used in the present study. The data in this module were collected over three waves in the 2008, 2010, and 2012. Respondents completed this module when they were approximately 50 years old (range 49–55). In total, 46% of the initial NLSY-79 sample have completed the 50+ health module, 48% of whom were male. A number of the questions that appeared in the 40+ health module were also present in the 50+ health module; in such cases, the latter acted as follow-up questions (Bureau of Labor Statistics & U. S. D. of L., n.d.).

2.1.1. Measures

The data were downloaded from the National Longitudinal Study (NLS) Web Investigator site on 15/11/2014 (Bureau of Labor Statistics & U. S. D. of L., n.d.).

2.1.2. Intelligence

The measure of intelligence used in the NLSY-79 was the Armed Forces Qualifications Test (AFQT), 1989 re-normed version. This score is derived from four of the 10 subtests in the Armed Services Vocational Aptitude Battery (ASVAB). The subtests assessed the following: arithmetic reasoning (AR), mathematics knowledge (MK), word knowledge (WK), and paragraph comprehension (PC) (Welsh, Kucinkas, & Curran, 1990). The ASVAB has been found to be a reliable and valid measure of intelligence. It has been found to be a predictor of academic and job performance as well as a predictor of first-term attrition rates and self-paced school completion time (Palmer, Hartke, Ree, Welsh, & Valentine, 1988; Welsh et al., 1990). To be consistent with the study done on the 40+ health module (Der et al., 2009) the AFQT variable used in the present study was downloaded from The Bell Curve Page (Herrnstein & Murray, 1998). This variable was scored as a percentage, and then was z-scored.

2.1.3. Health outcomes

The current study examines 16 health outcomes from the 50+ health module. Nine of the health outcomes were self-reports of diagnosed health conditions, and four were other self-reported health conditions. The diagnosed conditions were elicited by questions of the form, "Has a doctor ever told you that you have....". The other self-reported conditions were responses to questions such as asked

“Do you have or suffer from....”. Both types of questions could receive a Yes/No response (see Table 3 for a list of these 13 health outcomes).

It is important to note that, in many cases, the questions relating to reports of doctor diagnoses are likely to be better-validated measures than the regular self-report questions. With regard to this, it has been found that regular self-report questions tend to have poorer agreement with medical records when the condition of interest has vaguely defined diagnostic criteria (e.g., arthritis) than when it has clearly defined diagnostic criteria (e.g., diabetes) (Haapanen, Miilunpalo, Pasanen, Oja, & Vuori, 1997; Lampe, Walker, Lennon, Whincup, & Ebrahim, 1999). So, in such instances, the diagnosed self-report question may be more valid because a clinical diagnosis provides respondents with an objective indicator of whether or not they have the condition.

Two further health outcomes were taken from the 12-item Short-Form Health Survey (SF-12). One of these outcomes was the SF-12 physical health measure, which is a summary measure of 6 items referring to physical health in the 12-item Short-Form Health Survey (SF-12). A higher score on this outcome indicates better health (Ware et al., 1996). The other item that was drawn from the SF-12 survey was a self-reported health-status question. This was initially a categorical response variable with a 5-point scale: Excellent, Very Good, Good, Fair, and Poor. We dichotomized this to contrast good, very good, or excellent health versus fair or poor health. The SF-12 items and survey that were used in this study have strong validity and reliability (Resnick & Parker, 2001).

There was a summary measure for physical functioning. This was included in the 50+ health module. The physical functioning score was summed across 12 questions. The twelve questions were posed in the format, “How difficult is it for you to run a mile,” “How difficult is it for you to stoop, kneel, or crouch,” etc. Each question was answered on a 5-point Likert scale. The scores had a range of 12–60, with higher scores indicating poorer physical functioning. All of the summary measures were z-transformed to zero mean and unit SD.

2.1.4. Control variables

There were a number of control variables: childhood age, adult age, sex, childhood SES, as well as a composite-adult SES variable along with the three constituent parts (education, income and occupational status). The following describes how these variables were created.

Adult age was derived by subtracting the year that respondents completed the 50+ health module from their year of birth. Their year of birth was also a derived variable that was arrived at by subtracting their baseline age, at the first interview in 1979, from 1979.

Childhood SES was z-transformed composite variable of parental income, education, and occupation status, which was derived by Herrnstein and Murray. Higher scores on the childhood SES variable indicate a more advantaged socio-economic position (Herrnstein & Murray, 1998). The adult SES variable was also a derived variable. The method used to make this variable was similar to that used by Herrnstein and Murray (1998). In other words, adult SES is an average of z-scored adult education, income, and occupation status. Higher scores on the composite adult SES variable and on each of its constituent components indicate more advantaged socio-economic position.

The variable used for adult education was the ‘Highest Grade Completed’, as of 2012. The variable used for income was ‘Total Net Family Income In Past Year’. To be consistent with Herrnstein and Murray (1998), income was logged and z-transformed.

The third component of the adult SES variable was occupation status. This was coded according to the US 3-digit, 2000 census code, which is explained in NLSY-79 Attachment 1: Census Industrial & Occupational Classification (Bureau of Labor Statistics & U. S. D. of L., n.d.). This was then used to derive an Occupational status hierarchy. Herrnstein and Murray used the 1960 Duncan SEI scale but because many changes had been made to the census occupation classification system between 1980 and 1990 (Frederick, 2010), an updated version of the 1960

Duncan SEI scale was used. This scale was developed by Hauser and Warren (1996) and was constructed in a similar way to the Duncan SEI (Frederick, 2010).

2.2. Analysis

Two sets of analyses were conducted. One set of analyses was a complete case analysis. Complete cases were defined as those 4132 respondents who had complete data for IQ, age, sex, educational attainment, occupational status, and adult income. The numbers used for each analysis vary slightly from this due to small numbers (<3%) of missing data for the health outcomes.

Because of the relatively high proportion of missing data for the adult SES variable, a second set of analyses was performed using multiple imputations. Twenty-eight imputations were created using the multivariate normal regression method for arbitrary patterns of missing data. The variables imputed were income, education, and occupation status as these had the highest rates of missing data, with 21%, 6% and 14% missing, respectively. Twenty-eight imputations were selected as 28% of the composite-adult SES values were missing. To note, imputations were only conducted on those who were present for the 50+ health module.

In both sets of analyses a series of hierarchical regression analyses were conducted, i.e. logistic regressions for the dichotomous outcomes and linear regressions for the summary health measures. For each health outcome, six separate models were analyzed. The baseline model adjusted for childhood age and sex. Model 2 additionally adjusted for childhood SES. Model 3 added composite adult SES to the variables included in Model 2. Models 4, 5, and 6 were the same as Model 3 but each replaced the composite adult SES with one of its constituents: income, education, or occupational status. All analyses were conducted in STATA 13.0.

The complete case analyses are the primary focus of the Results section. The results from the imputed analysis are briefly covered at the end of this section, and are covered in more detail as the Supplementary material.

3. Results

3.1. Descriptive statistics

The present analysis was based upon a sample of 5793 participants who responded to the 50+ health module. There were 1619 missing values for adult SES; 1239 were missing for income, 818 for occupational status, 339 for education, and 293 for IQ. Table 1 shows differences in selected characteristics between those who did and did not complete the 50+ health module. Those who completed it were significantly more likely to be female, had slightly lower IQ scores (-0.04 SD) and were significantly older ($+1.29$ years) than those who did not complete the 50+ health module. There were no significant differences between the two groups in income, education, occupation status, or adult SES.

Among the 5793 participants who completed the 50+ Health Module, there was a significant and positive association between IQ and childhood SES ($r = 0.56$, $P < 0.001$), adult SES ($r = 0.64$, $P < 0.001$), and the sub-components of adult SES, income ($r = 0.47$, $P < 0.001$), education ($r = 0.60$, $P < 0.001$), and occupational status ($r = 0.47$, $P < 0.001$) see Table A.1 in Appendix A.

Table 2 displays the results of the linear regression analysis for the continuous measures of physical health and physical functioning summary measures regressed on IQ. When childhood age and sex were adjusted for in the initial model, IQ was significantly associated with better health and physical functioning. For physical health a one standard deviation higher score in IQ was associated with beta 0.16 (C.I. 0.13 to 0.18), $P < 0.001$. For physical functioning, a one standard deviation higher score in IQ was associated with beta -0.17 (C.I. -0.20 to

Table 1
Differences in selected variables between those who completed the 50+ health module and those who did not.

	Completed 50+ health module	N	% male	Mean	SD	P*
AFQT (IQ)	Yes	5500		−0.278	0.012	0.03
	No	6378		−0.237	0.014	
Age	Yes	5793		51.60 yrs.	0.02	<0.00
	No	6893		50.31 yrs.	0.03	
Income	Yes	4554		\$78,135	0.01	0.50
	No	1553		\$78,286	0.03	
Education	Yes	5454		13.20 yrs.	0.01	0.71
	No	1836		13.27 yrs.	1.00	
Occupation status	Yes	4975		35.87 pts.	0.01	0.26
	No	1708		36.31 pts.	0.02	
Adult SES	Yes	4174		0.06	0.01	0.76
	No	1445		0.07	0.02	
Sex	Yes	5793	22%			<0.00
	No	6893	29%			

Note.

* P-value for the difference between groups. P-value for the difference in completion of the 50+ health module by sex.

−0.14), $P < 0.001$. When childhood SES was included there was slight attenuation in the association between IQ and both physical health and physical functioning, but the associations with both health outcomes remained significant. When adjusting for adult age and adult SES, there was substantial attenuation across both outcomes. The betas for physical health and physical functioning were reduced markedly to −0.006 and −0.012, respectively and were no longer significant.

The results for the logistic regressions of the relationship between IQ and self-report health-status are presented in Table 2. In the baseline model, which controls for childhood age and sex, a 1 SD higher score in IQ was significantly associated with increased odds of having good, very good, or excellent health over fair or poor health, with an odds ratio of 1.70 (C.I. 1.55 to 1.86). Adjusting for childhood SES attenuated this relationship slightly. Adjusting for adult age and adult SES attenuated the effect markedly to 1.11 and to non-significance.

The results for logistic regression analysis of the relationship between IQ in youth and the presence or absence of 13 health conditions are presented in Table 3. The questions for the first nine health conditions asked respondents to report whether a doctor had ever diagnosed them with the particular health condition. The other four questions in this section asked respondents to report whether or not they had the condition, with the question on heart attack acting as a follow-up to the question on heart problems in general.

In the baseline model, which controls for childhood age and sex, seven of the nine doctor-diagnosed conditions were significantly and negatively associated with IQ. Higher IQ was associated with lower odds of having the following conditions: high blood pressure/hypertension, diabetes or high blood sugar, chronic lung disease, heart problems in general,

congestive heart failure, stroke, and arthritis/rheumatism. The odds ratios for these conditions range from 0.85 for diabetes/high blood sugar to 0.65 for stroke, per one standard deviation higher score in IQ. Two of the four self-reported health conditions also had a significant association with IQ; these were heart attack and use of mobility aids. The odds ratios for these conditions were 0.59 and 0.74, per SD higher score in IQ, respectively. On the other hand, cancer/malignant tumor, osteoporosis, asthma, and pain/stiffness of joints were not significantly associated with IQ. After adjusting for childhood SES, there was little attenuation of the effects. After adjustment for childhood SES, all of the diagnosed conditions that were initially significant remained significant, except for diabetes/high blood sugar; osteoporosis became significant. The two significant self-reported health conditions were also slightly attenuated but both remained significant. Adjusting for adult SES had a marked attenuating effect on all of the health outcomes, except for high blood pressure/hypertension. Significant results only remained for high blood pressure/hypertension and heart attack, with odds ratios of 0.85 and 0.69, respectively. Additionally, pain or swelling/stiffness of joints became significant and the effect was reversed, and a 1 SD higher score in IQ was associated with an odds ratio of 1.11.

The results of the regression analysis that adjust for the three sub-components of adult SES (income, education, and occupation status) for all of the health outcomes in the complete case analyses are presented in Tables A.2 and A.3 in Appendix A. These tables show how IQ in youth is associated with each of the 16 health outcomes when income, education attainment, and occupation status are each adjusted for individually. Looking across the health outcomes, in the majority of cases the effect of adjusting for the composite adult SES measure was found to lead to greater attenuation than adjusting for income, education, or occupation status individually. Across these three sub-components, income was found to explain much of the attenuation for a number of health outcomes.

The results for the complete case analysis were compared to the results from the multiply imputed analysis. The results for the summary measures (physical health & physical functioning), the self-report health status, and the 13 health conditions can be found in Tables A.4 and A.5 on Appendix A more detailed description of the results can be found in the Supplementary materials.

For the summary measures and self-reported health status the same general patterns were found across the imputed and complete case results. However, in both cases the effect sizes tended to be slightly larger in the imputed analysis. Adjusting for adult SES in the imputed analysis led to less attenuation of the effect for the summary measures and the effects remained significant, for both the summary measure and for self reported health status.

A similar overall pattern was found when comparing the imputed results to the complete case results for the 13 doctor-diagnosed and self-reported health conditions. The effect sizes were comparable in both sets of analysis. The pattern of attenuation by adult SES was somewhat variable across the two analyses; however, the same three

Table 2
Regression analyses of the relation between a SD higher score in IQ in youth and physical health, physical functioning, and health status at age 50, with adjustment for potential confounding or mediating variables (complete case analysis).

	Model 1 (baseline)			Model 2 (childhood SES)			Model 3 (adult SES)		
	Beta	C.I.	P value	Beta	C.I.	P value	Beta	C.I.	P value
Physical health	0.156	0.128 to 0.183	<0.001	0.127	0.094 to 0.160	<0.001	−0.006	−0.044 to 0.032	0.746
Mobility difficulty	−0.169	−0.196 to −0.142	<0.001	−0.143	−0.176 to −0.111	<0.001	−0.012	−0.049 to 0.025	0.528
Health status ^a	1.70	1.55 to 1.86	<0.001	1.59	1.43 to 1.77	<0.001	1.11	0.98 to 1.26	0.101

Note. The effect of IQ on physical health & physical functioning was analyzed using linear regression analysis, beta = regression coefficient.

Sample size: SF-12 physical health (3985) and physical functioning (3923).

Sample size (4014): Poor–Fair (659) and Good–Very Good–Excellent (3355).

Model 1: IQ, sex, childhood age.

Model 2: IQ, sex, childhood age + childhood SES.

Model 3: IQ, sex, childhood age, adult age, childhood SES + adult SES.

^a The effect of IQ on health status model was analyzed using logistic regression analysis, beta = odds ratio.

health outcomes (high blood pressure/hypertension, heart attack, & pain/stiffness of joints) were the only outcomes that remained significantly related to childhood IQ in both analysis.

4. Discussion

The current study examined the relationship between IQ in youth and a range of health outcomes at age 50 years, adjusting for childhood and adult SES. Before adjusting for SES, the results confirm that pre-morbid intelligence is significantly associated with a large number of health outcomes at age 50. Those with a higher IQ in youth tend to have better overall physical health and tend to be less likely to have a number of chronic health conditions. After adjusting for childhood SES pre-morbid intelligence remained significantly associated with most health outcomes at age 50. Therefore, it appears that social background does not account for pre-morbid intelligence–health associations. However, these associations were attenuated markedly after adjusting for adult SES.

Unlike other cognitive epidemiology studies, the present study looked at how IQ affected a large number of chronic health conditions, many of which had been diagnosed by a doctor. There are some notable findings on a few health conditions. By age 50, cardiovascular disease and the conditions associated with it – high blood pressure, heart problems in general, congestive heart failure, stroke, and heart attack – were significantly associated with intelligence in youth. The odds ratios of having these conditions range from 0.59 (stroke) to 0.80 (high blood pressure), per SD advantage in IQ. This is consistent with previous findings of a link between IQ and CVD related mortality and morbidity (Ariansen et al., 2014; Batty, Mortensen, & Osler, 2005; Batty et al., 2008a, Batty et al., 2008b; Hart et al., 2004; Hemmingsson et al., 2006; Kajantie et al., 2012; Lawlor et al., 2008; Silventoinen et al., 2007).

Chronic lung disease is also significantly associated with intelligence in youth, with an odds ratio of 0.71 per SD higher score in IQ. This is consistent with previous findings of a link between IQ and mortality and morbidity due to lung disease and more general lung functioning (Der et al., 2009; Emery, Nancy, Svartengren, & G M., 1998; Richards, Strachan, Hardy, Kun, & Wadsworth, 2005). The present study did not find a relationship between intelligence and cancer morbidity, this is consistent with other studies that looked at pre-morbid intelligence and cancer morbidity (Batty et al., 2007c, 2007d; Der et al., 2009; Hart et al., 2003) and studies that looked at cancer mortality (Batty et al., 2007c, 2007d; Hart et al., 2003). However, a higher pre-morbid intelligence has been found to be associated with a reduced

risk of lung cancer morbidity and mortality (Hart et al., 2004), an increased risk of skin cancer morbidity and mortality (Batty et al., 2007c, 2007d), and an increased risk of mortality from any type of cancer (Kuh et al., 2009).

Diabetes was also significantly associated with intelligence in youth, with an odds ratio of 0.85 per SD advantage in IQ. This finding is also consistent with other research on pre-morbid intelligence and diabetes and other metabolic conditions (Lawlor, Clark, Davey Smith, & Leon, 2006; Der et al., 2009; Halkjaer, Holst, & Sørensen, 2003; Schmidt, Johannesdottir, Lemeshow, Lash, Ulrichsen, Botker, & Sorensen, 2013). However, it is important to mention that not all studies on diabetes have found a significant relationship with pre-morbid intelligence (Paile-Hyvärinen et al., 2009).

Childhood SES was found to explain a very small part of the relationship between IQ and health, which was similar to what was found for health at age 40 (Der et al., 2009). Given IQ in youth and childhood SES correlate strongly ($r = .56$), the extent of attenuation by childhood SES is less than would be expected. This suggests that childhood SES may not be a strong confounder of the relationship between IQ in youth and health outcomes in adulthood. Adult SES led to more attenuation than childhood SES. For example, looking at the average odds ratio across the self-report health conditions, which were significant in the baseline model, the effect size was reduced from an average OR of 0.75 at baseline, to 0.73 after adjusting for childhood SES, and to 0.90 after adjusting for adult SES. Adult SES tended to account for more of the relationship between IQ and most of the health outcomes than childhood SES did, which is consistent with other research (Calvin et al., 2011; Hemmingsson et al., 2006; Jokela, Elovainio, Singh-Manoux, Kivimäki, 2009; Batty et al., 2008a, 2008b; Hart et al., 2003; Hemmingsson, Melin, Allebeck, & Lundberg, 2009; Deary et al., 2008; Jokela et al., 2009).

Other studies that look at the mediating role of adult SES tend to take income, education, or occupation status as single indicators of adult SES. As the present study combined all three of these together the current findings help us to get a better understanding of the role played by adult SES in the relation between intelligence in youth and later health. The composite adult SES variable had a greater attenuating effect than income, education, and occupation status did on the associations between IQ in youth and chronic lung disease, heart problems in general, congestive heart failure, stroke, osteoporosis, arthritis/rheumatism, heart attack, pain or stiffness/swelling of joints, use of mobility aids, self-reported health status, as well as for the physical health and physical functioning summary measure. A possible explanation for the greater mediating role-played by adult SES, compared to the smaller

Table 3

Logistic regression analyses of the relation between a SD higher score in IQ in youth and 13 different health conditions at age 50, with adjustment for potential confounding or mediating variables (complete case analysis).

Health at 50: complete cases	Number (%) of cases	Number	Model 1 (baseline)			Model 2 (childhood SES)			Model 3 (childhood and adult SES)		
			OR	C.I.	P value	OR	C.I.	P value	OR	C.I.	P value
High blood pressure or hypertension	1471 (37)	4010	0.80	0.75 to 0.86	<0.001	0.82	0.76 to 0.89	<0.001	0.85	0.783 to 0.94	0.001
Diabetes or high blood sugar	543 (14)	4012	0.85	0.77 to 0.93	<0.001	0.91	0.82 to 1.02	0.103	0.99	0.87 to 1.13	0.920
Cancer or malignant tumor (excluding skin cancer)	114 (3)	4011	1.16	0.96 to 1.40	0.133	1.06	0.84 to 1.33	0.622	1.02	0.783 to 1.33	0.899
Chronic lung disease	212 (5)	4008	0.71	0.62 to 0.82	<0.001	0.68	0.57 to 0.80	<0.001	0.99	0.81 to 1.20	0.894
Heart problems in general	214 (5)	4007	0.79	0.69 to 0.90	0.001	0.75	0.64 to 0.89	0.001	0.92	0.76 to 1.12	0.427
Congestive heart failure	56 (1)	4010	0.66	0.50 to 0.86	0.002	0.61	0.44 to 0.84	0.002	0.80	0.55 to 1.17	0.256
Stroke	84 (2)	4012	0.65	0.52 to 0.81	<0.001	0.62	0.47 to 0.80	<0.001	0.80	0.58 to 1.08	0.145
Osteoporosis	115 (3)	4005	0.83	0.68 to 1.01	0.058	0.76	0.61 to 0.96	0.023	0.87	0.66 to 1.13	0.294
Arthritis or rheumatism	993 (25)	4012	0.84	0.78 to 0.90	<0.001	0.87	0.80 to 0.95	0.002	1.02	0.92 to 1.13	0.703
Heart attack	89 (2)	4003	0.59	0.48 to 0.73	<0.001	0.53	0.42 to 0.69	<0.001	0.69	0.51 to 0.93	0.014
Asthma	272 (7)	4015	0.96	0.85 to 1.09	0.556	0.89	0.77 to 1.04	0.148	1.04	0.87 to 1.24	0.644
Pain or stiffness/swelling of joints	2006 (50)	4012	0.95	0.893 to 1.01	0.107	0.95	0.89 to 1.03	0.222	1.11	1.02 to 1.22	0.016
Use of mobility aids	177 (4)	4011	0.74	0.64 to 0.86	<0.001	0.76	0.63 to 0.91	0.003	1.10	0.88 to 1.36	0.405

Note.

Model 1: IQ, sex, childhood age.

Model 2: IQ, sex, childhood age + childhood SES.

Model 3: IQ, sex, childhood age, adult age, childhood SES + adult SES.

mediating effects of income, education, and occupation status individually, could be that the composite indicator has less measurement error. We note, though, that the marked attenuation of the intelligence–health associations by adult SES measures does not afford any single straightforward explanations along the lines of the environmental privileges of higher social class being the causal factor. We addressed this elsewhere (Deary, Penke, & Johnson, 2010), we considered other possible causal accounts (Deary, Weiss, & Batty, 2010), and we have reported genetic correlations between social class measures and intelligence (Marioni et al., 2014). We especially note the high genetic correlation between intelligence and education, and so it is possible that education is acting as largely a proxy for intelligence rather than as an environmental SES measure (Marioni et al., 2014).

The current study also found that for in the case of the relationships between IQ and high blood pressure/hypertension and diabetes/high blood sugar the attenuation by income was approximately the same as the attenuation by adult SES. And looking across the sub-components of adult SES for physical health, physical functioning, health status, heart problems in general, congestive heart failure, asthma, and use of mobility aids income led to greater attenuation than either education or occupation status. A possible explanation for this could be that a number of these health outcomes, most notably the cardiovascular outcomes, are related to stress (Black & Garbutt, 2002). The attenuation by adult SES, which is strongly influenced by income, could be due to the fact that those with higher intelligence are more likely to obtain a higher SES and therefore might experience less stress (Marmot, 2004; Sapolsky, 2005), which could be largely a result of their higher income. These findings on income could also be partly explained by other work that looks at the effects of income on health. It has been suggested that an income of less than \$5000 USD negatively affects health due to absolute poverty and material deprivation – i.e., lack of clean water, damp and poorly ventilated housing. But for those with an income that falls between \$5000 and \$70,000 USD (income figures from 1993 dollars) health is negatively affected by relative poverty, not absolute poverty, and this influences an individual's ability to control their life circumstances and limits their ability to participate in society (Marmot, 2002). In the current findings relative poverty likely mediates the effect of childhood intelligence on health outcomes.

It is important to highlight that in both the complete case and imputed analysis there was very little change in effect size for high blood pressure/hypertension across all six models. Per SD higher score in IQ, the odds ratio for this condition ranged from 0.80 in the baseline model to 0.85 when adjusting for Adult SES. These findings may indicate that more intelligent people may manage their high blood pressure better. Or it may indicate a non-modifiable link between IQ and high blood pressure/hypertension. On the other hand, there may be unaccounted for variables that modify this relationship, such as obesity, smoking, or levels of alcohol consumption, all of which have been found to be associated with childhood intelligence (Anstey, Low, Christensen, & Sachdev, 2009; Chandola, Deary, Blane, & Batty, 2005; Kanazawa, 2013) and are known risk factors for high blood pressure/hypertension. Future studies could investigate these possible pathways. It is also interesting to point out that high blood pressure is not a debilitating condition on its own but is a risk factor for many health outcomes such as heart attack, stroke, (Farley, Dalal, Mostashari, & Frieden, 2010) and diabetes (Ishihara, Yukimura, Aizawa, Yamada, Ohto & Yoshizawa, 1987). This may highlight a fundamental underlying biological pathway between IQ and some chronic health conditions.

Regarding a possible biological pathway between IQ and health, the findings on high blood pressure/hypertension, and all of the other significant findings in the present study, could be explained by the system integrity theory or could be due to an individual's history of bodily-insults. The system-integrity explanation points to the possibility of correlated bodily factors from early life that influence an individual's physiological makeup which affects their physical and cognitive functioning

(Calvin, Deary, & Batty, 2007; Deary, 2012). Another possible explanation may be the impact of bodily-insults that have occurred across an individual's life-course. Exposure to certain physical and social elements at different life stages (gestation, infancy, childhood, adolescence, or adulthood) can have damaging and lasting effects on the structure and functioning of the body, which, in turn, could increase the risk of health conditions (Barker, 2004; Kuh et al., 2003). Another pathway that may link intelligence to health outcomes could be how well established and known the risk factors are for different diseases, which relates to the ability to prevent the onset and progression of a disease. For example, the risk factors for conditions such as heart disease and diabetes are well established and individuals with a higher intelligence may be more likely to be aware of, and avoid, these risk factors. For instance, higher pre-morbid intelligence has been found to be associated with a lower prevalence of metabolic syndrome, which is a risk factor for cardiovascular disease (Batty, Deary, Schoon, & Gale, 2007b; Batty et al., 2008a; Chandola et al., 2005; Lindgarde, Furu, & Ljung, 1987; Starr et al., 2004). However, the risk factors for other conditions such as many types of cancers are not well established so intelligent people would not be more likely to avoid these risk factors.

4.1. Strengths & limitations

The current research has some strength. The first is that this study utilises a pre-morbid measure of intelligence that is taken in youth. The age is optimal, being at the end of most fluid cognitive maturity and earlier than would be expected for age-associated cognitive decline. If the intelligence measure is taken later in adulthood there are concerns surrounding reverse causality (Batty, Deary, & Gottfredson, 2007a), whereby cognitive decline occurs following the onset of certain chronic conditions (Batty, Deary, & Gottfredson, 2007a). A second strength of this study is that it is based on a large and representative sample of adult Americans aged 50 years old.

A third strength of the current research is that it studied health at age 50, which is an age when chronic health conditions start to be more prevalent. Therefore the risk of developing many of these chronic conditions increases with age. And the impact of risk factors, including IQ, might accumulate over time (Kuh et al., 2003). So the number of incidences of a chronic disease is likely to be greater at age 50 than at age 40, and this tends to be the case. For example, based on the nationally representative sample from the 2012 National Health Interview Survey (NHIS) in the US, rates of heart disease were 3.8% for those aged 18–44 and were 12.1% for those aged 45–65; similarly, rates of diabetes were 2.4% in the former age group and 12.7% in the latter age group. Another strength is that this study includes a greater breadth of diagnosed health conditions than the health at 40 study did. This is valuable because these types of questions are less likely to be influenced by reporting bias than the purely self-reported questions (Haapanen et al., 1997; Lampe et al., 1999).

Although this study benefits from a number of strengths there are some limitations. First, there are a high number of missing data for the adult SES variable. And because of this, the number of observations used in the complete case analysis was reduced though still large. The health measures in this study are self-reported. Such measures tend to have lower validity than clinically diagnosed conditions in medical records. However, the SF-12 scales used in the study do have high reliability and validity (Resnick & Parker, 2001).

There is also the possibility of reporting bias due to differences in health literacy whereby those with higher intelligence will have better symptom recognition, better recall of conditions, and more accurate reporting of these in the health module (Beier & Ackerman, 2003; Gottfredson, 2004). Conversely, people with a lower IQ might under-report their health conditions. The net effect of such reporting bias would be to bias results towards the null, i.e. our estimates of effect size here might be under-estimates. Evidence suggests health literacy is equivalent to general intelligence (Reeve & Basalik, 2014; Gottfredson,

2004; Mottus, Murray, Wolf, Starr, & Deary, 2014; Murray, Johnson, Wolf, & Deary, 2011; Wolf et al., 2012).

The findings of the current study show that there is an association between IQ and multiple health outcomes at age 50. It suggested that adult SES substantially mediates the effect of IQ for a number of health outcomes, though the interpretation of that is not clear. Future research could examine more closely the relationship between IQ and high blood-pressure/hypertension and the mediating role played by income in the relationship between IQ and health. The current findings contribute

to our understanding of the risk factors of poor health and health inequalities. Hence, it can be used to inform health and social policies that aim to reduce the burden of illness for the individual, society, and economy.

Appendix B. Supplementary data

Supplementary data to this article can be found online at <http://dx.doi.org/10.1016/j.intell.2015.08.001>.

Appendix A

Table A.1

Correlation matrix of explanatory and control variables.

	IQ in youth	Child SES	Adult SES	Income	Education	Occupational status
IQ in youth	1.00					
Child SES	0.562	1.00				
Adult SES	0.640	0.454	1.00			
Income	0.472	0.325	0.755	1.00		
Education	0.603	0.450	0.829	0.416	1.00	
Occupational status	0.474	0.323	0.838	0.435	0.581	1.00

Note. All correlations P < 0.001.

Complete case analysis: Models 4, 5, and 6

Table A.2

Linear regression analyses of the relation between a SD increase in IQ in youth and physical health and Physical functioning at age 50, with adjustment for potential confounding or mediating variables, across Model 4–Model 6 of the complete case analysis.

	Model 4 (Model 2 + adult age + income)			Model 5 (Model 2 + adult age + education)			Model 6 (Model 2 + adult age + occ status)		
	Beta	C.I.	P value	Beta	C.I.	P value	Beta	C.I.	P value
Physical Health	0.020	–0.014 to 0.055	0.250	0.071	0.034 to 0.109	0.001	0.085	0.050 to 0.121	<0.001
Mobility Difficulty	–0.046	–0.079 to –0.012	0.008	–0.080	–0.117 to –0.044	<0.001	–0.100	–0.135 to –0.066	<0.001
Health status*	1.22	1.09 to 1.37	<0.001	1.40	1.24 to 1.57	<0.001	1.43	1.27 to 1.60	<0.001

Note. The effect of IQ on physical health & physical functioning was analyzed using linear regression analysis, beta = regression coefficient.

Sample size: SF-12 physical health (3985) and physical functioning (3923).

Sample size (4014): Poor–Fair (659) Good–Very Good–Excellent (3355).

Model 4: IQ, sex, childhood age, adult age, childhood SES, income.

Model 5: IQ, sex, childhood age, adult age, childhood SES, education.

Model 6: IQ, sex, childhood age, adult age, childhood SES, occupation status.

* The effect of IQ on health status model was analyzed using logistic regression analysis, beta = odds ratio.

Table A.3

Logistic regression analyses of the relation between a SD increase in IQ in youth and 13 different health conditions at age 50, with adjustment for potential confounding or mediating variables, across Model 4–Model 6 of the complete case analysis.

Health at 50: complete cases	Number (%) of cases	Number	Model 4 (Model 2 + adult age + income)			Model 5 (Model 2 + adult age + education)			Model 6 (Model 2 + adult age + occu status)		
			OR	C.I.	P value	OR	C.I.	P value	OR	C.I.	P value
High blood pressure or hypertension	1471 (37)	4010	0.86	0.79 to 0.94	0.001	0.81	0.74 to 0.89	<0.001	0.83	0.76 to 0.90	<0.001
Diabetes or high blood sugar	543 (14)	4012	0.98	0.87 to 1.10	0.689	0.95	0.84 to 1.08	0.427	0.93	0.83 to 1.05	0.247
Cancer malignant tumor (excluding skin cancer)	114 (3)	4011	1.11	0.87 to 1.41	0.418	1.01	0.78 to 1.31	0.922	1.00	0.78 to 1.28	0.976
Chronic lung disease	212 (5)	4008	0.86	0.72 to 1.03	0.108	0.84	0.69 to 1.01	0.070	0.75	0.61 to 0.89	0.002
Heart problems in general	214 (5)	4007	0.88	0.74 to 1.05	0.150	0.80	0.66 to 0.97	0.023	0.80	0.67 to 0.96	0.016
Congestive heart failure	56 (1)	4010	0.78	0.56 to 1.10	0.157	0.65	0.45 to 0.94	0.020	0.63	0.45 to 0.89	0.009
Stroke	84 (2)	4012	0.72	0.55 to 0.96	0.024	0.68	0.51 to 0.92	0.011	0.67	0.51 to 0.89	0.006
Osteoporosis	115 (3)	4005	0.83	0.65 to 1.06	0.142	0.77	0.60 to 1.01	0.055	0.83	0.65 to 1.06	0.133
Arthritis or rheumatism	993 (25)	4012	0.96	0.87 to 1.05	0.353	0.96	0.87 to 1.06	0.454	0.92	0.84 to 1.01	0.087
Heart attack	89 (2)	4003	0.63	0.48 to 0.83	0.001	0.60	0.45 to 0.80	0.001	0.57	0.44 to 0.75	<0.001
Asthma	272 (7)	4015	1.02	0.87 to 1.20	0.791	0.94	0.79 to 1.11	0.446	0.93	0.79 to 1.09	0.376
Pain or stiffness/swelling of joints	2006 (50)	4012	1.03	0.95 to 1.11	0.497	1.06	0.97 to 1.15	0.177	1.02	0.94 to 1.11	0.585
Use of mobility aids	177 (4)	4011	1.01	0.83 to 1.22	0.960	0.83	0.67 to 1.02	0.070	0.86	0.70 to 1.04	0.124

Note.

Model 4: IQ, sex, childhood age, adult age, childhood SES, income.

Model 5: IQ, sex, childhood age, adult age, childhood SES, education.

Model 6: IQ, sex, childhood age, adult age, childhood SES, occupation status.

Table A.4

Regression analyses of the relation between a SD higher score in IQ in youth and physical health, physical functioning, and health status at age 50, with adjustment for potential confounding or mediating variables (imputed analysis).

	Model 1 (baseline)				Model 2 (childhood SES)			Model 3 (adult SES)			Model 4 (Model 2 + adult age + income)				Model 5 (Model 2 + adult age + education)			Model 6 (Model 2 + adult age + occ status)		
	Obs	Beta	C.I.	P value	Beta	C.I.	P value	Beta	C.I.	P value	Obs	Beta	C.I.	P value	Beta	C.I.	P value	Beta	C.I.	P value
Physical health	5443	0.202	0.177 to 0.228	<0.001	0.165	0.134 to 0.196	<0.001	0.040	0.005 to 0.076	0.025	5443	0.071	0.038 to 0.103	<0.001	0.107	0.072 to 0.142	<0.001	0.122	0.088 to 0.155	<0.001
Mobility difficulty	5360	-0.216	-0.241 to -0.191	<0.001	-0.176	-0.206 to -0.146	<0.001	-0.056	-0.091 to -0.021	0.002	5360	-0.090	-0.122 to -0.058	<0.001	-0.113	-0.147 to -0.079	<0.001	-0.134	-0.167 to -0.101	<0.001
Health status ^a	5496	1.81	1.68 to 1.94	<0.001	1.68	1.54 to 1.82	<0.001	1.27	1.15 to 1.40	<0.001	5496	1.38	1.26 to 1.51	<0.001	1.48	1.35 to 1.63	<0.001	1.53	1.39 to 1.67	<0.001

Note. The effect of IQ on physical health & physical functioning was analyzed using linear regression analysis, beta = regression coefficient.

^a The effect of IQ on health status was analyzed using logistic regression analysis, beta = odds ratio.

Table A.5

Logistic regression analyses of the relation between a SD increase in IQ in youth and 13 different health conditions at age 50, with adjustment for potential confounding or mediating variables across Model 1–Model 6 of the imputed analysis.

50+ health module: imputed	Number	Model 1 (baseline)			Model 2 (childhood SES)			Model 3 (adult SES)			Model 4 (Model 2 + adult age + income)			Model 5 (Model 2 + adult age + education)			Model 6 (Model 2 + adult age + occ status)		
		OR	C.I.	P value	OR	C.I.	P value	OR	C.I.	P value	OR	C.I.	P value	OR	C.I.	P value	OR	C.I.	P value
High blood pressure or hypertension	5490	0.77	0.73 to 0.81	<0.001	0.81	0.75 to 0.86	<0.001	0.83	0.77 to 0.90	<0.001	0.84	0.78 to 0.90	<0.001	0.80	0.74 to 0.86	<0.001	0.81	0.75 to 0.87	<0.001
Diabetes or high blood sugar	5493	0.82	0.76 to 0.89	<0.001	0.91	0.84 to 1.00	0.051	0.99	0.89 to 1.10	0.814	0.97	0.88 to 1.07	0.493	0.95	0.86 to 1.05	0.330	0.94	0.85 to 1.03	0.198
Cancer malignant tumor (exc. skin)	5491	1.11	0.96 to 1.29	0.166	1.12	0.93 to 1.34	0.240	1.10	0.89 to 1.36	0.400	1.15	0.95 to 1.40	0.157	1.10	0.90 to 1.36	0.356	1.06	0.87 to 1.29	0.549
Chronic lung disease	5488	0.69	0.62 to 0.77	<0.001	0.68	0.60 to 0.78	<0.001	0.90	0.78 to 1.05	0.187	0.81	0.70 to 0.93	0.003	0.82	0.71 to 0.96	0.010	0.74	0.64 to 0.86	<0.001
Heart problems in general	5489	0.81	0.72 to 0.90	<0.001	0.81	0.71 to 0.93	0.002	0.99	0.85 to 1.16	0.946	0.93	0.80 to 1.07	0.281	0.92	0.79 to 1.06	0.244	0.87	0.75 to 1.00	0.055
Congestive heart failure	5487	0.69	0.56 to 0.84	<0.001	0.68	0.53 to 0.86	0.002	0.86	0.65 to 1.15	0.302	0.82	0.63 to 1.06	0.127	0.74	0.56 to 0.97	0.031	0.72	0.55 to 0.94	0.016
Stroke	5494	0.66	0.56 to 0.78	<0.001	0.64	0.53 to 0.78	<0.001	0.81	0.64 to 1.02	0.074	0.74	0.59 to 0.91	0.005	0.72	0.57 to 0.90	0.004	0.71	0.57 to 0.88	0.002
Osteoporosis	5487	0.84	0.72 to 0.97	0.021	0.84	0.70 to 1.00	0.053	0.97	0.78 to 1.20	0.772	0.92	0.76 to 1.12	0.401	0.87	0.71 to 1.07	0.192	0.91	0.74 to 1.10	0.328
Arthritis or rheumatism	5493	0.81	0.76 to 0.86	<0.001	0.83	0.78 to 0.90	<0.001	0.95	0.87 to 1.03	0.237	0.90	0.84 to 0.98	0.011	0.91	0.84 to 0.99	0.025	0.87	0.81 to 0.95	0.001
Heart attack	5482	0.62	0.52 to 0.72	<0.001	0.63	0.52 to 0.76	<0.001	0.76	0.61 to 0.96	0.020	0.71	0.58 to 0.87	0.001	0.71	0.57 to 0.88	0.002	0.67	0.54 to 0.82	<0.001
Asthma	5500	0.87	0.79 to 0.96	0.007	0.81	0.71 to 0.91	0.001	0.91	0.79 to 1.05	0.205	0.90	0.79 to 1.02	0.107	0.84	0.73 to 0.97	0.014	0.83	0.73 to 0.95	0.008
Pain or stiffness/swelling of joints	5491	0.94	0.89 to 0.99	0.015	0.96	0.90 to 1.02	0.214	1.09	1.02 to 1.18	0.018	1.03	0.96 to 1.10	0.457	1.05	0.98 to 1.13	0.196	1.02	0.95 to 1.09	0.540
Use of mobility aids	5494	0.70	0.62 to 0.78	<0.001	0.75	0.65 to 0.86	<0.001	0.96	0.82 to 1.13	0.655	0.91	0.78 to 1.05	0.201	0.81	0.69 to 0.94	0.006	0.82	0.71 to 0.95	0.009

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