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## RESEARCH ARTICLE

### Early-life circumstances and the risk of function-limiting long-term conditions in later life

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Older adults are particularly prone to function-limiting health issues that adversely affect their well-being. Previous work has identified factors from across the life course – childhood socio-economic status, childhood cognitive ability and education – that predict later-life functional outcomes. However, the independence of these contributions is unclear as later-in-the-life-course predictors are themselves affected by earlier ones. The present study capitalised on the recent linkage of the Scottish Mental Survey 1947 with the Scottish Longitudinal Study, using path analyses to examine the direct and indirect associations between life-course predictors and the risk of functional limitation at ages 55 (N = 2,374), 65 (N = 1,971) and 75 (N = 1,534). The odds of reporting a function-limiting long-term condition increased across later life. At age 55, reporting a functional limitation was significantly less likely in those with higher childhood socio-economic status, higher childhood cognitive ability and higher educational attainment; these associations were only partly mediated by other predictors. At age 65, adult socio-economic status emerged as a mediator of several associations, although direct associations with childhood socio-economic status and childhood cognitive ability were still observed. At age 75, only childhood socio-economic status and adult socio-economic status directly predicted the risk of a functional limitation, particularly those associated with disease or illness. A consistent pattern and direction of associations was observed with self-rated health more generally. These results demonstrate that early-life and adult circumstances are associated with functional limitations later in life, but that these associations are partly a product of complex mediation between life-course factors.

**key words** limiting long-term illness • functional limitations • later life • cognitive ability • socio-economic status • education

### key messages

- Early-life factors predict later-life functional limitation risk, but their independence is unclear
- Paths between early-life factors and functional limitation risk were examined at ages 55, 65 and 75
- Higher childhood socio-economic status and cognitive ability independently predicted lower risk
- There was also evidence of mediation between early-life factors and by adult socio-economic status

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## Introduction

Although average life expectancy has increased in developed countries, ‘disability-free’ or ‘healthy’ life expectancy has generally not kept pace (Salomon et al, 2012, for example). In the face of changing retirement policy and the forecast increase in healthcare expenditure it is increasingly important to understand what factors might contribute to good health and physical functioning in later life. Older adults are particularly at risk of function-limiting health conditions that can impair their independence, productivity and well-being (Ostchega et al, 2000, for example). Furthermore, in the UK, the prevalence of long-term or function-limiting illness increases over the life course, particularly over the age of 60 (Office for National Statistics, 2016: Table 005477).

A great deal of previous work has attempted to identify life-course factors which might predict the onset of functional limitations. Three early-life factors – higher childhood socio-economic status (SES), higher childhood cognitive ability and more education – have been consistently associated with a variety of later health-related outcomes, including lower morbidity risk (see, for example, Cohen et al, 2010; Hagger-Johnson et al, 2010; Smith et al, 2015). These same early-life factors have also been associated with functional outcomes more specifically. For example, in the Medical Research Council National Survey of Health and Development (MRC NSHD), lower childhood social class has been associated with an increased risk of poor strength, balance and chair-rising at age 53 (Guralnik et al, 2006). Notably, this association was not attenuated once an individual’s own adult social class was accounted for (see also Hurst et al, 2013). In the MRC NSHD, higher childhood cognitive ability has been shown to predict better balance and faster chair-rising times at age 53, even after adjusting for sex, height and weight (Kuh et al, 2009). In a study of community-dwelling older adults aged 65 to 85, more years of formal education has been associated with better performance on everyday activities (Puente et al, 2015). Notably, early-life advantage in childhood SES (Luo and Waite, 2005; Haas, 2008, both using the US Health and Retirement Survey), childhood cognitive ability (Poranen-Clark et al, 2016, using the Helsinki Birth Cohort), and education

(Zunzunegui et al, 2006; Bickel and Kurz, 2009, using the Leganés longitudinal study and the Bavarian School Sisters study respectively) have also been associated with self-reported functional health across the life course. The contribution of all three early-life factors to self-reported functional health at age 65 has recently been confirmed in a single study, using a subsample of the Scottish Mental Survey 1947, which tested cognitive function on almost every Scottish schoolchild born in 1936 (Forrest et al, 2018). This ‘long arm’ of childhood (Hayward and Gorman, 2004) is consistent with the role of childhood factors in building physical and cognitive reserve (Stern, 2009, for example), and the accrual of resources – including social and financial support and positive health behaviours – necessary to avoid or mitigate morbidity.

Whereas previous work has highlighted the importance of childhood SES, childhood cognitive ability and education for later-life functional limitations, the independence of these contributions is relatively unclear. For example, Luo and Waite (2005) noted that the association between childhood SES and functional limitations was attenuated by adjusting for education. Similarly, Forrest et al (2018) noted that when childhood SES, childhood cognitive ability and education were mutually adjusted, only education and childhood SES statistically significantly predicted the risk of long-term function-limiting conditions. These results suggest that there may be mediation between early-life predictors. Such a mediated structure has been observed in previous studies of mortality risk (Hart et al, 2003) and social status attainment (Deary et al, 2005). The independence of early-life factors is further complicated by potential mediation through later-life socio-economic circumstances (Singh-Manoux et al, 2005). For example, more intelligent individuals may have a lower risk of acquiring a functional limitation, but only because they also tend to be in higher-status, less-manual occupations in later life thereby giving them better access to socio-economic resources that can maintain health and limiting their exposure to risky environments. Finally, the structure underlying predictors of functional limitations is not necessarily stable across the latter part of the life course. Poranen-Clark et al (2016) observed a direct association between cognitive ability in early adulthood and functional ability at age 61, but only an indirect association with functional ability at age 71.

In order to address these concerns, the present study examined, in the same analyses, the association between the risk of functional limitations in later life (at ages 55, 65 and 75 years) and sex, childhood SES, childhood cognitive ability, education and adult SES. It further examined the correlational structure of these life-course predictors and their contributions to both functional limitation risk specifically and self-rated health more generally, including both direct and indirect (mediated) associations. To achieve this, the present study utilised the recent linkage of the Scottish Mental Survey 1947 and the Scottish Longitudinal Study (Huang et al, 2017). This linkage also allowed an examination of the factors predicting the relative odds of specific types of function-limiting long-term conditions (at age 75), and the factors predicting health more generally (at ages 65 and 75). Individuals with better childhood SES, higher childhood cognitive ability and more education may demonstrate a lower risk of experiencing a function-limiting long-term condition in later life; however, these contributions might not be independent or consistent across time, and might differ across types of functional limitation.

## Methods

The methods, analyses and hypotheses of the present study were preregistered as part of the Open Science Framework (see: <https://osf.io/cuvgz/>) prior to the data being analysed.

### *Sample*

The sample has previously been described as part of a previous study (Iveson et al, 2020). To reiterate, the sample was selected from the Scottish Longitudinal Study – a standing data set consisting of linked data from a 5.3% sample of the Scottish population (around 274,000 individuals, selected from 20 birth days). The sample used here (N = 4,162) was initially restricted to individuals who were born in 1936 and who, at age 11, took part in a Scotland-wide assessment of general cognitive ability – the Scottish Mental Survey 1947 (Scottish Council for Research in Education, 1949).

As a standing data set, the Scottish Longitudinal Study links data from the Scottish Mental Survey 1947 backwards to administrative records from the 1939 National Register and forwards to Scottish census records from 1991, 2001 and 2011. As the Scottish censuses provided functional-limitation outcomes, the sample was further restricted to only those who were present for at least the 1991 census (N = 2,374). Of these individuals, complete linked records (administrative records from 1939, Scottish Mental Survey 1947 records, and Scottish census records from 1991, 2001 and 2011) were available for 448 males and 423 females. The full sample of 2,374 individuals was present at the 1991 census, 1,971 individuals were present at the 2001 census (N = 267 died between the 1991 and 2001 censuses), and 1,534 individuals were present at the 2011 census (N = 437 died between the 2001 and 2011 censuses). Note that 2011 census data was imputed ‘at source’ by the census team according to their Edit and Imputation procedure ([www.scotlandscensus.gov.uk/census-methodology](http://www.scotlandscensus.gov.uk/census-methodology)), which replaced missing values with those of ‘similar’ individuals within the same census.

### *Assessments*

#### *Childhood socio-economic status (SES)*

Childhood SES was taken from the 1939 National Register. Historical Cambridge Social Interaction and Stratification scales (HISCAM) scores (Lambert et al, 2013) were derived from the Historical International Classification of Occupation (HISCO) codes of each parent and grandparent living with a sample member. HISCAM scores could range from 1 to 99 (Population Mean = 50, SD = 15). The highest HISCAM score for the household of each sample member was used as the measure of childhood SES.

#### *Childhood cognitive ability*

Childhood cognitive ability was taken from the Scottish Mental Survey 1947. As part of this survey, administered on 4 June 1947, individuals completed the Moray House Test No. 12 (MHT; Scottish Council for Research in Education, 1949). The MHT is a paper and pencil test of general cognitive ability in which participants complete

a series of problems – including verbal reasoning, numerical reasoning and other problems – within a 45-minute time limit. Raw scores (minimum = 0, maximum = 76) were used as a measure of childhood cognitive ability. The scores from this test have good concurrent validity with the individually administered Terman-Merrill revision of the Binet test (correlation coefficient of around 0.8; Maxwell, 1961).

### *Education*

Educational attainment by later life was taken from the most recent census (1991, 2001 or 2011) at which an individual appeared. This measure was backdated as the 2011 and 2001 censuses recorded more detailed information regarding educational qualifications relative to the 1991 census. As per Scottish census guidelines, educational attainment was categorised into levels: No qualifications; Level 1 qualifications (Senior certificate, and so on); Level 2 qualifications (Advanced senior certificate, and so on); Level 3 qualifications (Higher national certificate, and so on); and Level 4 qualifications. However, in the present study Level 4 qualifications were further separated into Level 4 – professional qualifications and Level 4 – degree-level qualifications (and above). This was done due to historical differences in the role of professional courses in the Scottish education system. The level of educational attainment was treated as numeric to allow imputation of missing values (see the section on statistical analyses), and was taken as the measure of education.

### *Adult socio-economic status (SES)*

Adult SES was taken from the same Scottish census at which the outcome measure was obtained (1991, 2001 or 2011). Most recent occupation was used to derive CAMSIS scores (Prandy and Lambert, 2004) which indicate occupational social class. CAMSIS scores could range from 1 to 99 (Population Mean = 50, SD = 15).

### *Function-limiting long-term conditions*

Function-limiting long-term conditions were taken from the 1991, 2001 and 2011 Scottish censuses. Two measures were extracted. The first of these was an individual's self-report indicating the presence or absence of a function-limiting long-term condition at a given census. Note that this same measure has been referred to as 'limiting long-term illness' by previous studies (Bartley and Plewis, 2002, for example), despite the censuses requiring individuals to include any illness, health problem or disability that limited daily activities or work. In the present report, the term 'conditions' is adopted to reflect the fact that this measure captures more than simply illness. Note that the term 'long-term' was not explicitly defined until the 2011 Scottish census, in which it was defined as conditions lasting at least 12 months. The presence of a function-limiting long-term condition was treated as a binary variable. The second measure of function-limiting long-term conditions was the type of functional limitation as self-reported at the 2011 Scottish census (this measure was not included in the 1991 or 2001 censuses). Individuals reported as many of the eight categories of limitation that applied to them. Categories included deafness/hearing loss, blindness/sight loss, learning disability, learning difficulty, developmental disorder, physical disability, mental health condition and illness/disease. Eight binary

dummy variables were created to indicate the presence of a specific type of functional limitation versus no limitation.

### *Self-rated health*

Self-rated health was taken from the 2001 and 2011 Scottish censuses (this measure was not included in the 1991 Scottish census). Individuals rated their general health over the 12 months prior to the census using Likert scales. However, these scales were not comparable between censuses: a three-item scale was used in the 2001 census ('Good', 'Fairly Good', and 'Not Good'), and a five-item scale was used in the 2011 census ('Very Good', 'Good', 'Fair', 'Bad', and 'Very Bad'). For both censuses, self-rated health was treated as an ordered categorical measure.

### *Covariates*

Age and sex were both included as covariates. Age in years was estimated at the same Scottish census at which the outcome measure was obtained (1991, 2001 or 2011). Sex was taken from core Scottish Longitudinal Study records.

### *Statistical analyses*

Two sets of analyses were conducted. The first assessed the odds of an individual reporting a function-limiting long-term condition at the 1991, 2001 and 2011 Scottish Censuses, separately. The univariate, age-adjusted and sex-adjusted associations between each predictor (HISCAM scores, MHT scores, educational attainment and CAMSIS scores) individually and the presence of a function-limiting long-term condition at each census were assessed using logistic regression (see the Supplementary Material, available at: <https://osf.io/czn7x/>). Path models were constructed for each of the censuses, with age in months (at the appropriate census) and sex as covariates (control variables), and with the presence of a function-limiting long-term condition as the binary outcome. For the 2011 census, we conducted a further path analysis of the odds of an individual reporting a specific type of function-limiting long-term condition. A single path model was constructed, with the binary dummy variables ('No Limitation vs Hearing Loss', and so on) simultaneously entered as outcomes. This meant that individuals could contribute multiple dummy variables to the path model, which was then adjusted for covariance between the conditions. Note that we did not include the dummy variables for learning disability, learning difficulty or developmental disorder, as these limiting conditions were likely acquired much earlier in the life course and were relatively rare (cumulative  $N < 30$ ). However, we retained the individuals who reported these types of function-limiting long-term conditions in the sample as many reported other types of condition.

The second set of analyses assessed the self-rated health of individuals at the 2001 and 2011 Scottish censuses. Univariate, age-adjusted and sex-adjusted associations between each predictor and self-rated health at each census were assessed using ordered logistic regression (see the Supplementary Material). Path models were constructed for the 2001 and 2011 censuses, with self-reported health as an ordered categorical variable (2001: 'Not Good', 'Fairly Good', 'Very Good'; 2011: 'Very Bad', 'Bad',

‘Fair’, ‘Good’, ‘Very Good’). Explicit testing indicated that neither of these path models violated the proportional odds assumption.

In each of the path models, for both functional limitation risk and self-rated health, predictors were entered in temporal order: childhood SES (HISCAM scores), childhood cognitive ability (MHT scores), education (educational attainment, treated as numeric), and adult SES (CAMSIS scores). Note that the treatment of education as numeric assumes that the distance between levels of education are equal; a similar analysis without this assumption (but with different estimation and list-wise deletion of missing values) is shown in the Supplementary Material. The specification of a temporal order was done in order to test the hypothesis that, as well as direct associations with functional limitation outcomes, the contribution of earlier life-course predictors was mediated by predictors from later in the life course. Each model tested: whether the contribution of childhood SES was mediated by childhood cognitive ability, education and adult SES; whether the contribution of childhood cognitive ability was mediated by education and adult SES; and whether the contribution of education was mediated by adult SES. The three models tested are shown in [Figure 1](#). HISCAM scores, MHT scores and CAMSIS scores were standardised ( $M = 0$ ,  $SD = 1$ ) prior to being entered in the models. Fit statistics were unavailable for the path models, as all models were saturated ( $\chi^2 = 0$ ,  $df = 0$ ).

Path models were estimated using maximum likelihood with robust standard errors. Among the three models, the lowest covariance coverage value was 0.631 (between HISCAM score and 1991 CAMSIS score), indicating good coverage. Missing data were assumed to be missing at random, and missing values in each model were imputed using full information maximum likelihood (see the Supplementary Material for a WLSMV alternative with list-wise deletion of missing values). Note that for the 2011 path model, missing census data had already been imputed at source (see the section ‘Sample’), so full information maximum likelihood was used to impute only non-census missing data. Within each model parameter weights were estimated for each association. Standardised coefficients are reported for each association; unstandardised coefficients are presented in Supplementary Material. Odds ratios and bootstrapped 95% Confidence Intervals were calculated. *P*-values were not corrected for multiple comparisons. All analyses were conducted in R (v3.3.3; [R Core Team, 2017](#)) using the ‘psych’ (v1.6.6; [Revelle, 2016](#)) and ‘lavaan’ packages (v0.5–23.1097; [Rosseel, 2012](#)).

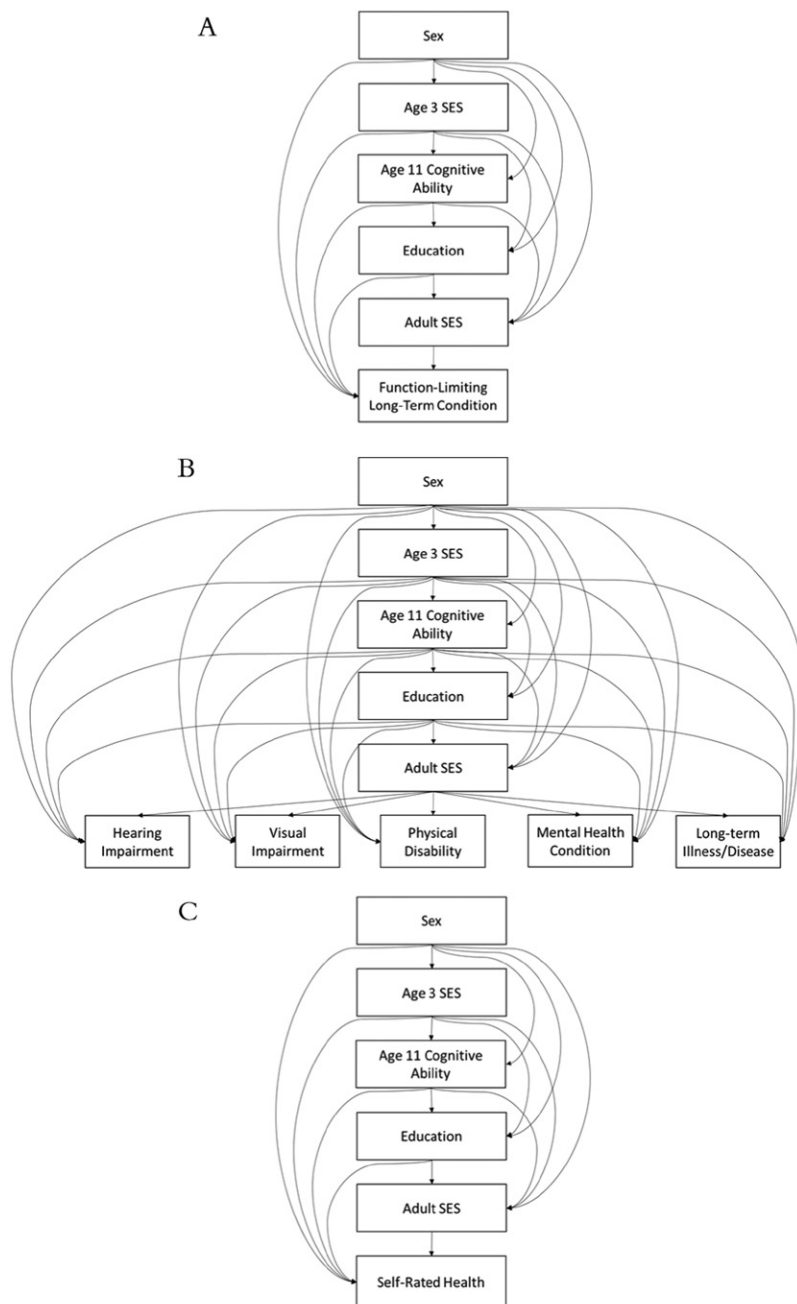
## Results

### *Sample description*

Summary statistics for the sample at each census, including the proportion of missing data, are shown in [Table 1](#). Correlations between life-course predictors are shown in the Supplementary Material. There were relatively similar proportions of males and females in each of the samples, and the rate of drop-out was similar between the sexes (Drop-out 1991–2001: male  $N = 228$ , female  $N = 175$ ; Drop-out 2001–2011: male  $N = 238$ , female  $N = 199$ ). As noted earlier, the primary cause of drop-out – individuals appearing in one census but not a later census – was death ( $N = 267$  died between the 1991 and 2001 censuses,  $N = 437$  died between the 2001 and 2011 censuses). In terms of early-life variables, the samples across the three censuses statistically significantly differed in terms of their MHT scores ( $F(2, 5,546) = 7.173$ ,



**Figure 1:** Path models used for assessing the association between sex, childhood SES, childhood cognitive ability, educational attainment and adult SES, as well as their associations with (a) the odds of a function-limiting long-term condition at each census, (b) the odds of a specific function-limiting long-term condition at the 2011 census, (c) self-rated health at the 2001 and 2011 censuses.



Note: SES = socio-economic status

$p = 0.007$ ,  $\eta^2 = 0.001$ ), educational attainment ( $F(2, 5,820) = 21.155$ ,  $p < 0.001$ ,  $\eta^2 = 0.004$ ) and CAMSIS scores ( $F(2, 5,049) = 77.058$ ,  $p < 0.001$ ,  $\eta^2 = 0.015$ ), but not in terms of their sex ( $X^2 = 5.365$ ,  $p = 0.068$ ,  $V = 0.030$ ) or HISCAM scores ( $F(2, 4,641) = 2.045$ ,  $p = 0.153$ ,  $\eta^2 < 0.001$ ). In terms of MHT scores, the 1991 sample demonstrated statistically significantly lower scores than did the 2011 sample ( $t(3,178) = -2.687$ , 95% CI  $[-2.364, -0.369]$ ,  $p = 0.007$ ), but no other comparisons were statistically significant (all  $ps > 0.150$ ). Educational attainment was statistically significantly higher in each successive sample (1991 vs 2001:  $t(4,121) = -2.376$ , 95% CI  $[-0.186, -0.018]$ ,  $p = 0.018$ ; 2001 vs 2011:  $t(3,213) = -2.256$ , 95% CI  $[-0.208, -0.015]$ ,  $p = 0.024$ ). For CAMSIS scores, the 2011 sample demonstrated statistically significantly lower scores than either the 1991 sample ( $t(3,233) = 9.089$ , 95% CI  $[3.467, 5.374]$ ,  $p < 0.001$ ) or the 2001 sample ( $t(3,106) = 9.186$ , 95% CI  $[3.594, 5.544]$ ,  $p < 0.001$ ). Childhood HISCAM scores were missing from around a fifth of individuals in each sample. Notably, this measure was taken at a household level, and so missing data may indicate households in which all individuals were economically inactive (and so had no occupational code). The frequency of such cases may be exacerbated by the absence of males who had already left the home to enlist in the armed forces. Coverage of MHT scores, on the other hand, was generally good, with scores missing for around 5% of individuals in each sample. Around 1% of individuals in each sample had missing educational attainment, probably representing individuals who did not complete the relevant question at any of the Scottish censuses. Education beyond schooling, particularly degree-level education, was relatively uncommon in each of the samples. Indeed, at each of the censuses, over half of participants reported no educational qualifications beyond school. Around a fifth of individuals had missing CAMSIS scores at 1991, and this proportion decreased across the censuses (17% in 2001, 2% in 2011). Note that the particularly low rate of missing CAMSIS scores in 2011 is probably due to missing data being imputed at source. Given that they are based on the most recent occupation, missing CAMSIS scores are likely to represent those who have never worked due to family and care commitments. The number of individuals who had never worked (2001:  $N = 38$ ; 2011:  $N = 28$ ) decreased across the latter censuses, indicating the selective drop-out over time of those individuals with a history of economic inactivity. Notably, this selective drop-out may itself be driven by functional impairments: missing CAMSIS scores may indicate those unable to work due to functional limitations, and the decline in missing CAMSIS scores may represent selective mortality of those functionally impaired. In line with this suggestion, the number of individuals with missing CAMSIS scores who also reported a functional limitation decreased over the three censuses (1991:  $N = 206$ ; 2001:  $N = 138$ ; 2011:  $N = 20$ )

Summaries of the functional outcomes measured across the three censuses are shown in [Table 1](#). The log odds of reporting a function-limiting long-term condition more than doubled between age 55 (0.14) and age 65 (0.32). However, there was very little increase in these odds between age 65 (0.32) and age 75 (0.37). In terms of the type of function-limiting long-term condition reported at age 75, function-limiting illnesses were the most common, followed closely by hearing impairments and physical disabilities. Developmental disorders, learning difficulties, learning disabilities and other conditions were relatively uncommon (cumulatively  $N < 30$ ). Notably, the majority of those reporting function-limiting long-term conditions reported only one type ( $N = 643$ ); comorbidities were relatively uncommon (two types of

**Table 1:** Descriptive statistics for the sample at each census

	1991 Census (N = 2,374)			2001 Census (N = 1,971)			2011 Census (N = 1,534)					
	Mean	SD	N	N Missing	Mean	SD	N	N Missing	Mean	SD	N	N Missing
<b>Sex (N)</b>				0 (0%)				0 (0%)				0 (0%)
Male			1,153 (49%)				925 (47%)				687 (45%)	
Female			1,221 (51%)				1,046 (53%)				847 (55%)	
<b>HISCAM score</b> (max possible = 99)	47.43	10.24		505 (21%)	47.55	10.27		422 (21%)	47.98	10.27		309 (20%)
<b>MHT score</b> (max possible = 76)	36.59	15.35		144 (6%)	37.21	15.13		113 (6%)	37.96	14.95		74 (5%)
<b>Further Education (N)</b>				34 (1%)				13 (1%)				10 (1%)
None			1,495 (63%)				1,151 (58%)				829 (54%)	
Level 1			379 (16%)				370 (19%)				310 (20%)	
Level 2			165 (7%)				156 (8%)				137 (9%)	
Level 3			73 (3%)				72 (4%)				65 (4%)	
Level 4 – professional			156 (7%)				144 (7%)				124 (8%)	
Level 4 – degree			72 (3%)				65 (3%)				59 (4%)	
<b>CAMSIS score</b> (max possible = 99)	45.73	14.12		467 (20%)	45.88	13.76		333 (17%)	41.31	14.09		28 (2%)
<b>Function-limiting long-term condition</b>				0 (0%)				107 (5%)				0 (0%)
No			1,884 (79%)				1,011 (51%)				711 (46%)	
Yes			490 (21%)				853 (49%)				823 (54%)	
<b>Type of functional limitation (N)*</b>	-	-	-	-	-	-	-	-	-	-	-	0 (0%)
None											511 (33%)	
Hearing Impairment											376 (25%)	
Visual Impairment											114 (7%)	

**Table 1:** Continued

	1991 Census (N = 2,374)			2001 Census (N = 1,971)			2011 Census (N = 1,534)		
	Mean	SD	N	Mean	SD	N	Mean	SD	N
Physical Disability									320 (21%)
Mental Health Condition									51 (3%)
Long-term Illness									651 (42%)
Self-rated Health (N)	-	-	-	-	-	20 (1%)	-	-	0 (0%)
<b>2001</b>									
Not Good						402 (20%)			
Fairly Good						677 (34%)			
Good						872 (44%)			
<b>2011</b>									
Very Bad									49 (3%)
Bad									156 (10%)
Fair									506 (33%)
Good									617 (40%)
Very Good									206 (14%)

Source: Scottish Longitudinal Study. HISCAM = Historical CAMSIS; MHT = Moray House Test No. 12. \*An individual could report more than one type of functional limitation.

Notes: Ns and percentages are shown for categorical variables. The proportion of missing data is also reported

limitation:  $N = 272$ ; three types of limitation:  $N = 89$ ; four types of limitation:  $N = 19$ ). Although coverage of functional outcomes was generally good, around 5% of individuals in the 2001 census had missing function-limiting long-term condition indicators at age 65. As the majority of these individuals did not have missing data from other 2001 census variables, it is possible that these missing values arise from individuals omitting the relevant questions on the census form. This being said, individuals with missing function-limiting long-term condition indicators at age 65 exhibited statistically significantly lower HISCAM scores ( $t(96) = -2.334$ , 95% CI [0.345, 4.264],  $p = 0.022$ ), MHT scores ( $t(111) = -5.580$ , 95% CI [5.556, 11.676],  $p < 0.001$ ) and CAMSIS scores ( $t(62) = -4.460$ , 95% CI [3.332, 8.746],  $p < 0.001$ ) than those with complete function-limiting long-term condition indicators. Missing function-limiting long-term condition indicators at age 65 was more common among females than males ( $X^2 = 6.416$ ,  $df = 1$ ,  $p = 0.011$ ,  $V < 0.001$ ), and among those with no further education than some further education ( $X^2 = 14.596$ ,  $df = 5$ ,  $p = 0.012$ ,  $V < 0.001$ ). Note that the majority of these individuals later appeared in the 2011 census, where any missing function-limiting long-term condition responses would have been imputed by the census team.

Self-rated health at ages 65 and 75 is summarised in [Table 1](#). At age 65 the majority of individuals reported being in good health. Similarly, individuals most frequently reported their health as ‘Good’ or ‘Very Good’ at age 75. Notably, fewer than half the number of individuals reported poor health (‘Not Good’, ‘Bad’, or ‘Very Bad’) at age 75 relative to age 65. This may indicate the selective drop-out of the most ill individuals in the sample, though we note, again, the differences in the scales between the 2001 and 2011 censuses, which limits the comparability of health at ages 65 and 75. Individuals who dropped-out between ages 65 and 75 (between the 2001 and 2011 censuses) were much more likely to report ‘Not Good’ health at age 65 than those who did not drop out ( $X^2 = 121.13$ ,  $df = 2$ ,  $p < 0.001$ ). Coverage of self-rated health was generally good, with around 1% of individuals missing a self-rated health measure at age 65. As with missing CAMSIS scores from age 65, this may represent cases in which individuals omitted the health question of the 2001 census.

### *Odds of a function-limiting long-term condition*

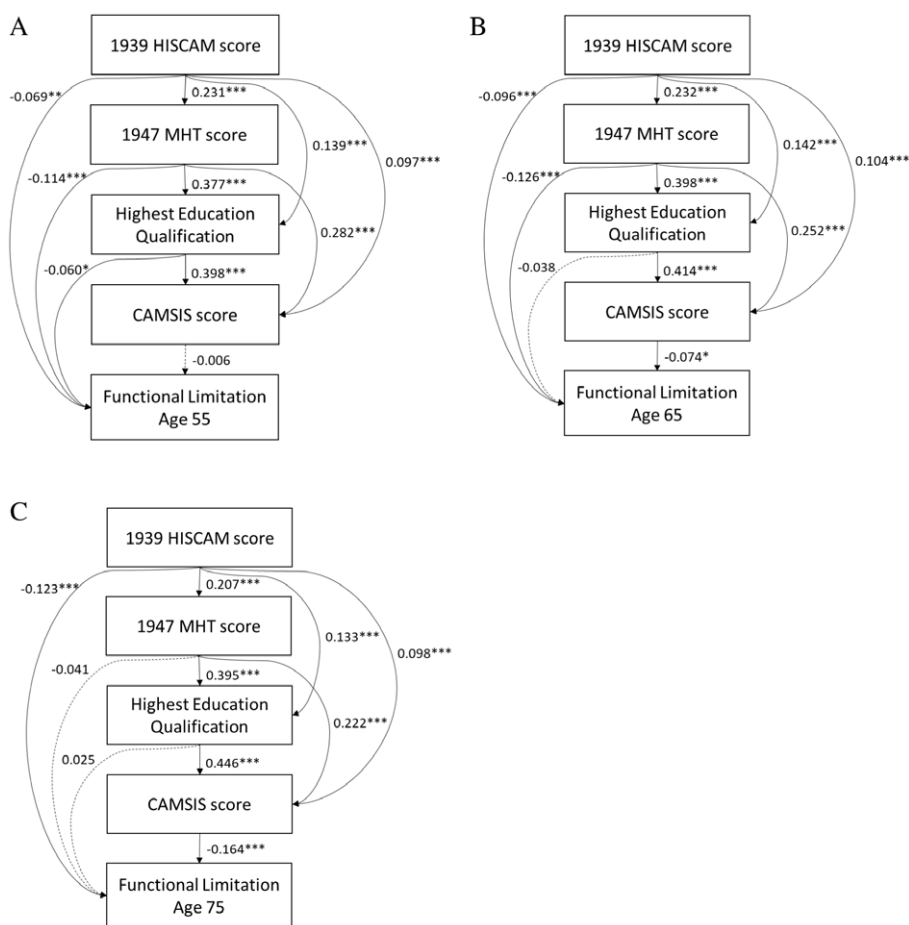
#### *Path analyses*

Univariate associations between predictors and the odds of reporting a function-limiting long-term condition at each census are shown in the Supplementary Material. For the path models, the direct and indirect associations between life-course predictors and the odds of a function-limiting long-term condition at ages 55, 65 and 75 (the 1991, 2001 and 2011 censuses) are shown in [Figure 2](#) (A, B and C respectively). There was statistically significant and temporally ordered association between life-course predictors themselves, with earlier measures predicting later ones, at ages 55, 65 and 75 (see the Supplementary Material). Furthermore, when examining the mutually adjusted associations between the life-course predictors and the odds of reporting a function-limiting long-term condition there was evidence of both direct and mediated contributions. However, the key predictors and the nature of their associations differed across ages 55, 65 and 75. For brevity, we describe only the important observations; the full path analyses are shown in the Supplementary Material. Note, however, that when taken together, the life-course predictors accounted for only a small portion

of the variance in the odds of reporting a function-limiting long-term condition at any of the censuses (age 55:  $R^2 = 0.034$ ; age 65:  $R^2 = 0.073$ ; age 75:  $R^2 = 0.055$ ).

At age 55, higher HISCAM scores, higher MHT scores and higher educational attainment were each directly associated with lower odds of reporting a function-limiting long-term condition (3%, 4% and 2% reductions per SD or level, respectively). Additional mediated paths were observed for HISCAM scores – mediated by MHT scores and educational attainment – and MHT scores – mediated by educational attainment, though these were much weaker than the direct associations (largest reduction 1% per SD). Unlike the univariate analysis (see the Supplementary Material), there were no statistically significant paths between CAMSIS scores and functional limitation odds. While the univariate analysis showed CAMSIS scores

**Figure 2:** Path models showing the associations between childhood SES, childhood cognitive ability, education, adult SES, and the odds of a function-limiting long-term condition at age 55 (A), age 65 (B), and age 75 (C).



Source: Scottish Longitudinal Study.

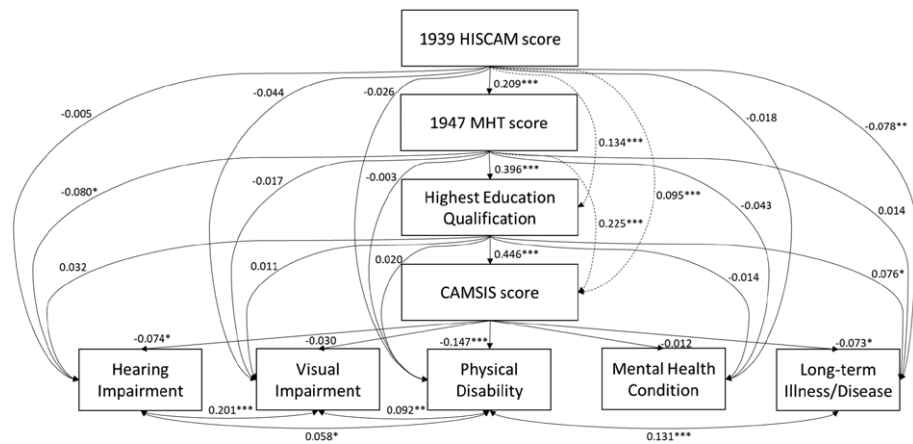
Notes: Total direct and total mediated effects are described in the main text. Single-headed arrows indicate regression paths (non-significant paths are dashed). Beside the arrows are coefficients after standardising all variables; therefore, they can be considered as standardised partial betas. \* $p < 0.05$ , \*\* $p < 0.01$ , \*\*\* $p < 0.001$ .

to be a statistically significant predictor of functional limitation odds at age 55, the path analysis indicates that adjusting for other life-course predictors attenuates this association.

At age 65, higher HISCAM scores and higher MHT scores were again directly associated with lower odds of reporting a function-limiting long-term condition (5% and 6% reductions per SD, respectively). Unlike at age 55, education did not directly predict functional limitation odds. Instead, CAMSIS scores entirely mediated the association between education and the odds of reporting a functional limitation. Furthermore, CAMSIS scores replaced educational attainment as a partial mediator of the contributions of both HISCAM scores and MHT scores. Higher CAMSIS scores directly predicted lower odds of reporting a functional limitation at age 65 (4% reduction per SD). This role of the CAMSIS score at age 65 is in line with the stronger association between CAMSIS scores and functional limitation odds seen in the univariate analysis, relative to age 55 (see the Supplementary Material).

At age 75, as at ages 55 and 65, higher HISCAM scores statistically significantly and directly predicted lower functional limitation odds at age 75 (6% reduction per SD). MHT scores, on the other hand, were not statistically significantly associated with the odds of reporting a function-limiting long-term condition. This contrasts to the univariate analyses (see the Supplementary Material), and suggests that adjusting for other life-course predictors may account for any association between MHT scores and functional limitation odds at age 75. Again, higher CAMSIS scores were directly associated with lower functional limitation odds (8% reduction per SD), and CAMSIS scores statistically significantly mediated part of the association between HISCAM scores and functional limitation odds. As part of sensitivity analyses (see the Supplementary Material), we removed those individuals with developmental disorders, learning impairments, learning disabilities and other unspecified conditions ( $N < 30$ ) in order to create a sample of individuals (aged 75) whose limitations more closely reflect those that are acquired in older age. Repeating the path analysis on this restricted sample did not alter the pattern of associations observed. Further path analysis by the type of functional limitation reported at age 75 is shown in [Figure 3](#) (see also the Supplementary Material). Lower odds of reporting a hearing impairment at age 75 ( $R^2 = 0.028$ ) were directly predicted by having higher MHT scores (3% reduction per SD) and having higher CAMSIS scores (3% reduction per SD). An additional indirect association between MHT scores and hearing impairment odds was mediated by CAMSIS scores. Lower odds of reporting a physical disability at age 75 ( $R^2 = 0.022$ ) were directly predicted by higher CAMSIS scores (6% reduction per SD). Lower odds of reporting a long-term illness or disease at age 75 ( $R^2 = 0.014$ ) were directly predicted by higher HISCAM scores (4% reduction per SD) and higher CAMSIS scores (3% reduction per SD). An additional indirect association between HISCAM scores and the odds of a long-term illness or disease was mediated by educational attainment. Note that the odds of reporting a hearing impairment statistically significantly covaried with the odds of reporting a physical limitation, and the odds of reporting a long-term illness or disease statistically significantly covaried with the odds of reporting a physical disability. None of the life-course predictors were statistically significantly associated with the odds of reporting a visual impairment ( $R^2 = 0.006$ , all  $\beta_s > -0.012$ ) or a mental health impairment ( $R^2 = 0.004$ , all  $\beta_s > -0.009$ ) at age 75.

**Figure 3:** Path model showing the associations between childhood SES, childhood cognitive ability, education, adult SES and the odds of specific types of function-limiting long-term condition at age 75.



Source: Scottish Longitudinal Study.

Notes: Total direct and total mediated effects are described in the main text. Single-headed arrows indicate regression paths (non-significant paths are dashed), and double-headed arrows indicate covariance between observed outcomes (non-significant covariances are omitted). Beside the arrows are coefficients after standardising all variables; therefore, they can be considered as standardised partial betas. \* $p < 0.05$ , \*\* $p < 0.01$ , \*\*\* $p < 0.001$ .

Analysis of completers ( $N = 1,458$ ) – those who appeared in all three census samples – demonstrated largely similar patterns of association between life-course predictors and the odds of reporting a function-limiting long-term condition with one notable exception (see the Supplementary Material). At age 55, only higher HISCAM scores were directly associated with functional limitation odds; the direct contributions of MHT scores and educational attainment were no longer significant. Note, however, that less of the variance in functional limitation odds was explained by the model ( $R^2 = 0.023$ ) relative to the full-sample analysis. This probably reflects the loss of power in the age-55 analysis specifically, where the difference in sample size is greatest.

### Self-rated health

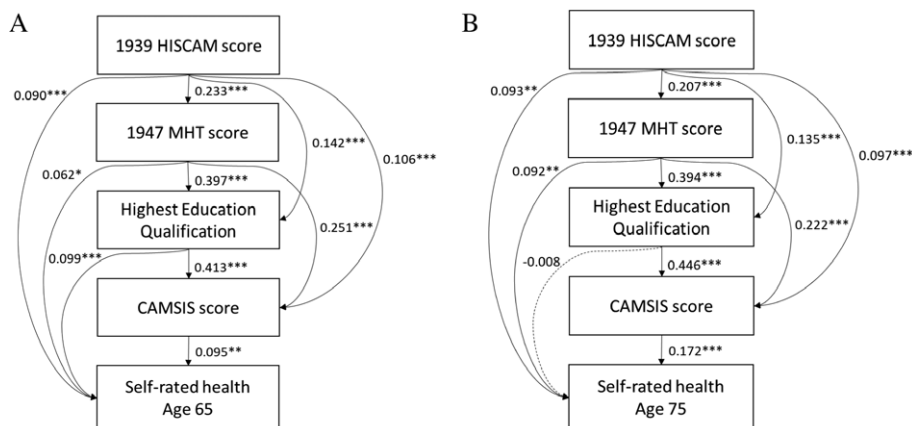
#### Path analyses

Univariate associations between life-course predictors and self-rated health are shown in Supplementary Material. For the path analyses, the direct and indirect associations between life-course predictors and self-reported health at age 65 and age 75 are shown in Figure 4 (A and B respectively; see also the Supplementary Material). Consistent with the path analyses already presented, the life-course predictors assumed a temporal order, with later factors being predicted by earlier factors. When taken together, the life-course predictors accounted for a small proportion of the variance in self-rated health at both age 65 ( $R^2 = 0.066$ ) and age 75 ( $R^2 = 0.069$ ).

At age 65, higher HISCAM scores (7% increase per SD), higher MHT scores (5% increase per SD), higher educational attainment (6% increase per level), and higher CAMSIS scores (8% increase per SD) were all directly associated with higher odds of reporting good health. Additional indirect effects were observed for HISCAM scores,



**Figure 4:** Path models showing the associations between childhood SES, childhood cognitive ability, education, adult SES, and self-rated health at age 65 (A) and at age 75 (B).



Source: Scottish Longitudinal Study.

Notes: Total direct and total mediated effects are described in the main text. Single-headed arrows indicate regression paths (non-significant paths are dashed). Beside the arrows are coefficients after standardising all variables; therefore, they can be considered as standardised partial betas. \* $p < 0.05$ , \*\* $p < 0.01$ , \*\*\* $p < 0.001$ .

MHT scores and educational attainment, with each being mediated by predictors later in the life course (see Figure 4A). For example, an indirect path between HISCAM scores and self-rated health was mediated by MHT scores, another by educational attainment and another by CAMSIS scores.

At age 75, only higher HISCAM scores (9% increase per SD), higher MHT scores (10% increase per SD) and higher CAMSIS scores (18% increase per SD) were significantly and directly associated with self-rated health. Additional indirect paths were observed between HISCAM scores and self-rated health – mediated by MHT scores and CAMSIS scores, separately – and between MHT scores and self-rated health – mediated by CAMSIS scores. The association between educational attainment and self-rated health was entirely mediated by CAMSIS score.

## Discussion

The present study examined the association between the risk of a function-limiting long-term condition in later life and factors from across the life course. Similar to previous work (see, for example, Deary et al, 2007; Iveson et al, 2020), a consistent and temporally ordered relationship between life-course predictors was observed, such that earlier factors predicted later ones. Age-3 SES predicted age-11 cognitive ability, lifetime educational attainment and adult SES; age-11 cognitive ability predicted lifetime educational attainment and adult SES; and lifetime educational attainment predicted adult SES. Poor childhood SES has consequences for development and achievement due to poorer childhood health and nutrition (Kramer et al, 1995; Koletzko et al, 1998), poorer parental involvement and access to learning resources (Sacker et al, 2002), and poorer access to social and financial support (Taylor and Seeman, 1999). Meanwhile, higher early-life cognitive ability confers a better ability

to complete higher educational qualifications (Strenze, 2007, for example), and both higher cognitive ability and higher educational attainment facilitate access to higher-status occupations (Deary et al, 2005).

Age 3 SES, age 11 cognitive ability, lifetime educational attainment and adult SES were also shown to be important though relatively weak predictors of functional limitation outcomes at age 55 and beyond. These associations were also observed with more general self-rated health at ages 65 and 75. The direction of these associations was consistent between the two health outcomes; life-course advantage predicted better health in later life. Note that this was mostly consistent with the hypotheses preregistered before analysis of the data (see <https://osf.io/cuvgz/>). Previous work has highlighted – individually – the importance of childhood SES (Luo and Waite, 2005; Haas, 2008), childhood cognitive ability (Poranen-Clark et al, 2016), education (Zunzunegui et al, 2006; Bickel and Kurz, 2009) and adult SES (Bartley and Plewis, 2002; Bartley et al, 2004; Sacker et al, 2005) as predictors of functional health. However, by examining childhood SES, childhood cognitive ability, education and adult SES simultaneously, the present study provides evidence of mediation between life-course factors in addition to their direct associations with functional health in later life. As such, the present study supports a ‘chains of risk’ interpretation (Ben-Shlomo and Kuh, 2002; Ben-Shlomo et al, 2016), with early-life disadvantage predicting later disadvantage that then predicts poor functional health. However, it also supports a broader ‘sensitive period’ interpretation in which different factors at different points of the life course are independently associated with functional health in later life, and in which factors present at certain points of the life course contribute more strongly to functional limitation risk than those from other points in the life course (such as the stronger contribution of adult SES to age-75 function than childhood SES).

### *Functional health at age 55*

At age 55, early-life advantage in terms of childhood SES, childhood cognitive ability and educational attainment was associated with lower odds of reporting a function-limiting long-term condition. These contributions were only partly mediated by later factors, and each predictor demonstrated a significant direct association with functional limitation risks. While consistent with previous studies of functional health (for example, Luo and Waite, 2005; Zunzunegui et al, 2006; Kuh et al, 2009; Puente et al, 2015; Poranen-Clark et al, 2016), the present study demonstrates that after mutual adjustment these life-course factors have independent contributions to the risk of a functional limitation. Unlike Luo and Waite (2005), for example, education only partly mediated the association between childhood SES and functional limitation risk. Furthermore, none of the associations with functional health at age 55 were mediated by adult SES. As such, the contribution of early-life advantage – in terms of higher childhood SES, higher childhood cognitive ability or higher educational attainment – cannot be explained simply by the association with better proximal circumstances. Among possible causal mechanisms, previous work has highlighted contributions of life-course factors to central nervous system integrity, health behaviours (such as smoking), environmental risks (working conditions, for instance), access to health services and access to social support (Feinstein, 1993; Luo and Wen, 2002; Kuh et al, 2009; Hagger-Johnson et al, 2010; Poranen-Clark et al,

2016), all of which determine physical health and the risk of acquiring a functional limitation in later life.

Of the direct contributions observed in the present study, childhood cognitive ability proved one the strongest predictors at age 55. The importance of childhood cognitive ability is consistent with previous studies examining the risk of morbidity (Hagger-Johnson et al, 2010, for example), and supports the role of cognitive ability in building resilience to morbidity across adulthood (Stern, 2009, for example) and in promoting health behaviours (Hagger-Johnson et al, 2010). Note, however, that the odds of reporting a function-limiting long-term condition at age 55 were much lower than in subsequent years (see also Office for National Statistics, 2016: Table 005477). At age 55, the majority of individuals are still healthy (National Records of Scotland, 2014: Table DC3102SC) and economically active (see Iveson et al, 2020). The association between early-life advantage and functional limitation risk may therefore represent the contribution to limitations acquired earlier in life, and not those commonly associated with older age (such as physical disability).

#### *Functional health at age 65*

At age 65, the odds of reporting a function-limiting long-term condition were much higher than at age 55. This increase coincides with population estimates in which the prevalence of function-limiting conditions increases dramatically after age 60 (Office for National Statistics, 2016: Table 005477), and probably represents the onset of functional limitations commonly associated with older age, such as hearing impairments and physical disability. At age 65, childhood SES and childhood cognitive ability remained significant and direct predictors of the odds of a function-limiting long-term condition. Consistent with previous work (see, for example, Power et al, 1999; Iveson and Deary, 2017), advantage in childhood cognitive ability and childhood SES also predicted higher self-rated health at this age. However, in addition to childhood SES and childhood cognitive ability, adult SES emerged as a significant and direct predictor of the odds of reporting a function-limiting long-term condition at age 65, and as a partial mediator of earlier life-course factors. The importance of adult SES as a predictor and as a mediator was also noted in the analyses of self-rated health. This is broadly consistent with previous work in the British Household Panel Survey, in which lower baseline adult SES predicted an increased risk of acquiring a function-limiting long-term condition over a ten-year follow-up, among healthy men and women aged 21–64 years (Bartley et al, 2004; see also the analysis of the Whitehall II Study by Singh-Manoux et al, 2005). Given the timing of the 2001 census for the present cohort, this may indicate the importance of socio-economic circumstances for health around retirement age (Di Gessa et al, 2017). Those with higher SES may be better protected against the increased risk of acquiring a functional limitation, particularly those associated with older age (such as Sacker et al, 2005).

#### *Functional health at age 75*

At age 75, the associations between the odds of reporting a function-limiting long-term condition and both childhood cognitive ability and education were no longer significant. Poranen-Clark et al (2016) similarly observed a direct association

between early-adulthood cognitive ability and functional ability at age 61 which was not present at age 71. Note, however, that childhood cognitive ability was a significant predictor of self-rated health at age 75, both directly and as mediated by adult SES. In the present study, the attenuation of cognitive ability and education contributions to functional limitation risk at age 75 may result from the selective drop-out of those individuals with lower childhood cognitive ability or with lower educational attainment (regression towards the mean). Indeed, the mean childhood cognitive ability and educational attainment increased for each successive sample, and lower childhood cognitive ability and lower educational attainment were both significant risk factors for poorer functional health at younger ages. Such drop-out is consistent with previous work highlighting lower childhood cognitive ability and lower education as strong predictors of mortality in later life (Iveson et al, 2017).

The only significant predictors of the odds of reporting a function-limiting long-term condition at age 75 were childhood and adult SES. Consistent with previous work (Guralnik et al, 2006; Hurst et al, 2013), the contribution of early-life disadvantage was independent of later-life socio-economic circumstances, suggesting that functional limitation risk is not purely driven by proximal factors. Importantly, sensitivity analyses demonstrated that the contribution of childhood and adult SES was driven by their association with acquired functional limitations – particularly with long-term illness or disease, physical disability and hearing impairments – and not with developmental functional limitations. The importance of socio-economic circumstances from across the life course supports the notion that material circumstances can be used to both avoid and to reduce the impact of age-related morbidity (see, for example, Staudinger et al, 1995; Huisman et al, 2003). It also reiterates the socio-economic inequality in later-life health and physical function highlighted by previous work (Huisman et al, 2003; Sacker et al, 2005).

### *Limitations*

Although the use of routinely collected administrative data enabled the present study to capture unique life-course data from a large and nationally representative cohort, the reliance on self-reported functional limitations may be seen as problematic. In reporting the presence of a function-limiting long-term condition, individuals were required to make a judgement about the definition of ‘long-term’. Although this definition was later clarified in the 2011 census, participants were still required to judge whether their condition had lasted or would last for 12 months or longer. This duration requirement may be particularly problematic for recent conditions, as individuals must predict how long they may last. Note that this changing definition also meant that associations had to be examined with functional limitation odds at ages 55, 65 and 75 separately, rather than with changes in functional limitation odds over the 20-year period. As such, no inferences about the predictors of longitudinal functional health can be made, and the models for age 55, 65 and 75 cannot be directly compared. The present study also did not examine sex differences in functional limitation risk beyond including sex as a covariate in the analyses. It is therefore unclear whether the direct and indirect predictors of functional limitation risk differ between males and females, as has been shown for predictors of economic activity in later life using the same cohort (Iveson et al, 2020). Furthermore, by capturing

only long-term functional limitations, the present study does not account for more acute limitations associated with age, such as falls. Note, however, that the patterns of associations observed between life-course factors and the odds of reporting a function-limiting long-term condition were largely replicated in the analyses of self-rated general health. Unlike function-limiting long-term conditions, self-rated general health was assessed contemporaneously and did not specify durations of illness. Given the broadness of self-rated general health, this indicates that the same early-life factors associated with function-limiting long-term conditions may also predict functional limitations beyond this narrow definition. The use of routinely collected administrative data also means that the study does not have access to measures that could implicate specific mechanisms by which life-course factors affect health, such as those relating to workplace conditions or health behaviours.

## Conclusion

The importance of childhood SES, childhood cognitive ability and education to functional limitation risk across older age demonstrates the lasting impact that early-life disadvantage can have on an individual's health (see [Hayward and Gorman, 2004](#); [Haas, 2008](#)). Given the goal of healthier ageing and longer working lives in many developed countries, the identification of early-life factors which contribute to functional ability at ages 55 and 65 provides an opportunity for early intervention through government policy. However, by age 75 the contribution of early-life factors is largely outweighed by the impact of proximal socio-economic circumstances, highlighting the need to combat socio-economic inequalities much later in life in order to support disability-free life expectancy.

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### Data availability

The authors take responsibility for the integrity of the data and the accuracy of the analysis. Scottish Longitudinal Study data are available to other researchers using the Safe Setting located at Ladywell House, Edinburgh. Access is contingent on governance approval and training (<https://sls.lscs.ac.uk/>).

### Conflict of interest

The authors declare that there is no conflict of interest.

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