Cognitive change before old age (11 to 70) predicts cognitive change during old age (70 to 82)

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Abstract

Identifying predictors of cognitive decline within older age helps to understand its mechanisms and to identify those at greater risk. Here we examine how cognitive change from 11 to 70 years is associated with cognitive change within older age (70 to 82 years) in the Lothian Birth Cohort 1936 longitudinal study (N=1091 at recruitment). Using latent growth curve models, we estimate rates of change from age 70 to 82 in general cognitive ability (*g)* and in three cognitive domains: visuospatial, memory and processing speed. *g* accounted for 71.3% of interindividual change variance. Greater 11-70 cognitive gain predicted slower decline in *g* over 12 subsequent years (β = .163, p = .001), independently of cognitive level at age 70, and domain-specific change beyond *g*. These results contribute toward identifying people at higher risk of age-related cognitive decline.

Statement of relevance

Age-related cognitive decline is a significant threat to the quality of life in older age. Its economic and social impact on society will increase together with the steadily rising life expectancy. How can we preserve cognitive health in older age? Researchers have made significant advances in identifying protective and risk factors. However, most studies focus on a limited age range, and cognitive change mechanisms are not yet completely understood. This work takes advantage of almost life-spanning longitudinal data to test if cognitive trajectory across childhood and adulthood can predict cognitive trajectories in older age. Our findings show that earlier change is associated with later change. Some factors related to individual differences in cognitive change might thus operate over much of the adult life course, and certainly before older age. This knowledge can help identify individuals at higher risk of decline and understand the mechanisms and factors responsible.

1. Introduction

This work addresses individual differences in cognitive ageing from a novel perspective. Rather than studying how differences in age-related cognitive decline are associated with other factors, we examine cognitive change consistency across the life course. We and others have shown that *level* of cognitive ability ascertained in childhood relates strongly to *level* of cognitive ability in older age (Deary, 2014). Here, instead, we ask whether individual differences in cognitive trajectories across the earlier part of the life course (11 to 70 years) predict subsequent cognitive change, from age 70 to 82. The latter period of life generally sees more rapid and clinically important cognitive changes. Individual differences in cognitive ageing probably reflect an accumulation of small influences from numerous factors (Corley, Cox, & Deary, 2018), many of which are likely to be already present in early- and mid-life (e.g., genetic factors, early-life cognitive ability, physical fitness, smoking). Therefore, it is essential to characterise the relationship between earlier-period and later-period cognitive trajectories across the life course.

Cognitive decline is one of the most feared aspects of ageing. It will affect a growing number of people as the world population ages: in many countries, the proportion of older adults is increasing (Rousson & Paccaud, 2010; United Nations DESA, 2015), and the longer life expectancy is not always matched by an increment in healthy life expectancy (Abbafati et al., 2020; Prince et al., 2015). Even non-pathological cognitive decline can affect daily life and activities. Reduced cognitive functioning is associated with lower quality of life, leading to loss of autonomy, illness and death (Batty, Deary, & Zaninotto, 2016; Deary et al., 2009). Thus, the clear personal, societal, and financial consequences of cognitive ageing, even among the non-clinical majority, motivate urgent scientific investigation. During later phases of life, beginning approximately at age 70, the risk of cognitive decline increases (Deary et al., 2009; Marmot, Banks, Blundell, Lessof, & Nazroo, 2003; Salthouse, 2010), as does the risk of dementia (Berr, Wancata, & Ritchie, 2005; Jorm & Jolley, 1998; Santoni et al., 2015).

There is considerable inter-individual variability within the general trend of cognitive ageing (e.g., Zaninotto, Batty, Allerhand, & Deary, 2018). Understanding the nature, predictors, and mechanisms underlying such individual differences is essential for tackling the disruptive effects of cognitive decline and designing ways to cope with the changes, promoting a successful ageing model. In this context, where some cognitive changes occur across adulthood, from the 20s (Salthouse, 2010; Tucker-Drob, 2019), the timing of interventions becomes an especially complicated matter (Plassman, Williams, Burke, Holsinger, & Benjamin, 2010). The accurate prediction of trajectories of cognitive decline is critical; it will help understand potential mechanisms better and identify those at relatively high risk (Brayne, 2007; Deary et al., 2009).

Longitudinal studies have emphasized the need to distinguish cognitive *change* from cognitive *level*; they show that an individual's cognitive level at any given age is, at best, weakly associated with their cognitive trajectory (Karlamangla et al., 2009; Tucker-Drob, Brandmaier, & Lindenberger, 2019). Accordingly, factors related to peak cognitive level in adulthood do not necessarily have a comparable association with cognitive decline rates (Corley et al., 2018; Ritchie et al., 2016; Tucker-Drob, 2019). Research on correlates of cognitive ageing has tested genetic, socio-demographic, health, and lifestyle factors. Among the stronger predictors of steeper cognitive decline are sex (being male), lower physical fitness, and possession of the *APOE* ε4 allele, whereas others (e.g. childhood IQ, education) exhibit weaker effects (Blondell, Hammersley-Mather, & Veerman, 2014; Plassman et al., 2010; Ritchie et al., 2017; Tucker-Drob, 2019; Zaninotto et al., 2018).

We are unaware of research examining whether differences in cognitive change from childhood to later adulthood are predictive of the subsequent gradient of cognitive decline in older age. This is an important omission in research. If we knew that individual differences in cognitive change between, say, age 11 and 70 were associated with cognitive changes from age 70 to 82, we would have more confidence that addressing factors operating before older age could ameliorate cognitive decline in older age.

Here, we test the hypothesis that cognitive change in general and domain-specific abilities after 70 (i.e., visuospatial, memory and processing speed) might be predicted by cognitive change up to age 70. We use longitudinal data spanning 71 years from the Lothian Birth Cohort 1936 (LBC1396).

2. Methods

2.1 Participants

The LBC1936 is a longitudinal study of cognitive, brain, and general ageing. Participants were all born in 1936 and most took a test of general mental ability, the Moray-House Test (MHT) No. 12, at age 11 years, as part of the Scottish Mental Survey (SMS) of 1947 (Scottish Council for Research in Education, 1949). Between 2004 and 2007, i.e., at about age 70, 1091 probable SMS participants living in the Lothian area were recruited to join in the first wave of follow up testing to form the LBC1936. As of 2020, the LBC1936 participants have taken part in five assessment waves at approximately three-year intervals from age 70 to age 82. A description of the types of data collected at each wave is given in Taylor et al. (2018).

At baseline (Wave 1), the LBC1936 sample consisted of 1091 individuals (543 females, mean age = 69.58 years, sd = 0.83). Table 1 presents sample demographics for all waves. Participants for whom age-11 MHT scores in childhood were not available (n = 63) or deviated more than 3.5 sd from the sample mean (n = 6) were excluded from analyses involving age 11 to 70 cognitive change. The study was approved by the Lothian Research Ethics Committee (LREC/2003/2/39; Wave 1), the Multi-Centre Research Ethics Committee for Scotland (MREC/01/0/56; Wave 1), and the Scotland A Research Ethics Committee (07/MRE00/58; waves 2-5).

Table 1. Sample characteristics by wave

	Wave 1	Wave 2	Wave 3	Wave 4	Wave 5
N	1091	866	697	550	431
M/F	548/543	448/418	360/337	275/275	209/222
Mean age (SD)	69.58 (0.83)	72.54 (0.71)	76.30 (0.68)	79.38 (0.62)	82.06 (0.47)

Note. N = number of participants participating in each wave of assessment, M= males, F = females. Age is expressed in years.

2.2 Measures

The Moray House Test No. 12 (MHT) was completed by participants at age 11 years and age 70 years (Wave 1) in the present study. It was called a “verbal reasoning” test, but its items assess a range of abilities, including word classification, reasoning, analogies, arithmetic, spatial reasoning, and following directions. The test provides a single general cognitive ability score, with a maximum value of 76. The MHT score correlated at about .80 with the Stanford-Binet Scale in a validation test conducted during the SMS (Deary, 2014; Scottish Council for Research in Education, 1949).

Cognitive ability from age 70 to 82 was assessed using a battery of 10 tests related to three cognitive domains, administered at each Wave from 1 to 5. Three tasks evaluated visuospatial ability: Matrix Reasoning and Block Design from the Wechsler Adult Intelligence Scale III^{UK} (WAIS IIIUK - Wechsler, 1998a), and Spatial Span forward and backward (the sum score of the two was used in the analyses) from the Wechsler Memory Scale III^{UK} (WMS IIIUK - Wechsler, 1998b). Three tests from the WMS III^{UK} evaluated verbal memory: Verbal Paired Associates immediate and delayed, Logical Memory immediate and delayed (for these two tasks, total scores were the sum of scores in the two conditions), and Digit Span backwards. Finally, speed of information processing was ascertained by the Symbol Search and Digit-Symbol Substitution tasks from the WAIS III^{UK}, by a Visual Inspection Time task (Deary et al., 2007), and by a Four-choice Reaction Time task (Deary, Der, & Ford, 2001). In the analyses, reaction times were multiplied by -1, so that, for all tests, higher scores indicated better performance. For a detailed description of test characteristics and administration, see Deary, Gow, & Taylor et al. (2007).

2.3 Statistical analysis

We hypothesized that individual differences in cognitive change observed between age 11 and 70 years would be significantly associated with individual differences in cognitive change between 70 and 82. To test this hypothesis, we conducted the following steps, which are described in greater detail below: (i) estimate cognitive change from 11-70 using the MHT scores measured at both ages; (ii) build measurement models for cognitive abilities from age 70-82 using data from the larger set of 10 cognitive tests; (iii) test the degree to which 11-70 cognitive change predicts cognitive ageing between 70-82; and (iv) test whether 11-70 cognitive change is independently predictive of 70-82 change beyond just age 70 cognitive level.

2.3.1 Deriving measures of cognitive change

Cognitive change from 11 to 70 was modelled as the unstandardized residuals of the regression between MHT scores at Wave 1 (age 70) and age-adjusted MHT scores at age 11. This procedure has been used in previous LBC studies, such as Cherrie et al. (2018).

Cognitive change from age 70 to age 82 was estimated using a Factor-of-Curves model (FOCUS - McArdle, 1988). At the lowest level of the FOCUS model, ten linear latent growth curves (LGC) estimated change for each of the ten cognitive tests. Wave 1 (age 70) scores were considered the origins of the curves and scores from subsequent waves (ages 73, 76, 79, 82) were weighted based on the mean number of years that had passed since Wave 1. The LGCs provided, for each cognitive task, a baseline level parameter, representing mean scores at Wave 1 (age 70), and a slope parameter, representing mean change per year for the subsequent 12 years.

At the higher level of the FOCUS model, baseline level and slope for each of the three cognitive domains (speed, memory, and visuospatial) and for *g* were estimated as second-order factors from cognitive tasks' baseline levels and slopes. In this model, we fit a bifactor structure: each task parameter loaded onto its domain factor and the general factor simultaneously. The general factor was constrained to be orthogonal to the cognitive domain factors (Figure 1). Cognitive abilities are typically represented by hierarchical structures, with the most specific (i.e., individual task parameters) at the bottom and the most general (i.e., *g* parameters) at the top, separated by intermediate levels (i.e., domain parameters). This is also how LBC1936 data have been modelled in previous studies (Ritchie et al., 2016). In the present study, the bifactor model offered an advantage over the hierarchical model: it allowed common variance (*g*) to be partialled directly out of the cognitive test scores, and domains to be modelled as factors using variance from which *g* had been removed. Thus, we used the bifactor model to estimate the degree to which individual differences in cognitive ability changes from age 11 to 70 were associated with individual differences in *g* and orthogonal, domain-specific changes from age 70 to age 82. To repeat, any domain-related associations are independent of change that was common to all cognitive domains.

2.3.2 Estimating associations between age 11 to 70 and age 70 to 82 cognitive change

We asked whether our measure of cognitive change between age 11 and 70 predicted subsequent cognitive declines in older age. To do so, we introduced 11-70 change in the model of cognitive change from age 70 to 82 (previously constructed – see above), as a predictor of the age-70 levels and the subsequent slopes of general and domain-specific cognitive abilities within older age. Factor loadings and intercepts obtained from the measurement model were fixed to aid model convergence, whereas the regression coefficients and residual factor variances were freely estimated. We introduced sex and the interaction term sex × cognitive change from 11 to 70 as covariates alongside our main predictor, to test whether the magnitude of any age 11-70 versus age 70-82 cognitive change correlation differed significantly as a function of sex.

Finally, we ascertained whether the measure of 11-70 cognitive change accounted for unique variance in 70-82 decline in *g* beyond baseline general ability at age 70. We recognize that 11-70 cognitive change would be correlated with baseline level of cognitive functioning; as discussed above, the latter has previously been shown to correlate weakly with cognitive ageing (Zaninotto et al., 2018). To examine the individual effects of the two measures (i.e., age 70 baseline level and age 11-70 cognitive change) we fitted a multiple regression model, with general cognitive decline 70-82 as a dependent variable, sex as a control variable, and with 11-70 change and the FOCUS *g* intercept (i.e., age 70 level) as simultaneous predictors of slope. Testing the magnitude of both predictors' effects, we ascertained whether cognitive change from age 11 to age 70 years would prove more informative than simple age 70 scores in predicting trajectories of decline in *g*.

2.3.3 Supplementary analyses

We calculated our main cognitive predictor (i.e., MHT change from age 11 to 70) as a regression-based score because these are arguably less affected by random measurement error compared to raw difference scores (Campbell & Kenny, 2002; Cronbach & Furby, 1970). However, we recognise that there is no clear consensus on the optimal measurement of change. Therefore, we conducted a supplementary analysis in which we used a raw difference score, also accounting for change reliability (see Supplementary Methods for additional detail).

Even though the current data benefitted from a narrow age range, there were small age differences for each assessment wave in older age. To ensure that these age differences did not substantially impact our results, we conducted a supplementary analysis. We fit a second version of the cognitive measurement model described, covarying the observed task scores with mean-centred age in days at the time of assessment.

Finally, in supplementary results, we present the association between 11-70 cognitive change and individual cognitive domains, without partialling out general cognitive variance (Supplementary Methods).

2.3.4 Peak-based measures of cognitive change

The longitudinal data from the LBC1936 cohort provides insight on cognitive change over most of the human life course. The lack of assessments between ages 11 and 70 makes it difficult to identify specific phases of cognitive change, such as childhood development or the beginning of decline in adulthood. However, we can use some existing data to partially fill the 60-year gap. One of the other measures collected in the LBC1936 is the National Adult Reading Test (NART - Nelson & Willison, 1991). The verbal skills assessed by the NART improve throughout adulthood and are robust to some normal and pathological decline (Lezak, Howieson, Loring, Hannay, & Fischer, 2004). Various follow-up studies of the SMS, using the MHT, have validated the NART as an estimate of prior/premorbid cognitive ability (Crawford, Deary, Starr, & Whalley, 2001; Deary & Brett, 2015; McGurn, Deary, & Starr, 2008). Deary, Whalley and Crawford (2004) showed that NART-included cognitive change estimates correlate strongly with measures of actual lifetime cognitive change. As a counterpoint to our primary analysis, we used age-70 NART score as an estimate of peak cognitive ability in adulthood. We then computed two additional regression-based indicators of cognitive change: age-11 MHT to estimated peak adult cognitive ability (i.e., age-70 NART); and estimated peak adult cognitive ability to age-70 MHT. The intention was to distinguish a phase of cognitive development from childhood to adulthood peak, from a phase of decline from peak to age 70. Consistent with the main analysis, age-11 MHT score was adjusted for age before regressing NART on it. Each of these indicators was tested as a predictor of cognitive change from 70 to 82, by introducing it in the cognitive measurement models in the same way we did with 11-70 cognitive change.

2.3.4 Software, fit and multiple comparison correction

All models were estimated in the R environment (R Core Team, 2020) using package Lavaan (Rosseel, 2012) and a FIML (Full Information Maximum Likelihood) algorithm, which capitalises on information available from individuals even if they did not complete all assessments. We evaluated model fit based on the RMSEA, SRMR, CFI and TLI indices: RMSEA lower than .05, SRMR lower than .08, and CFI and TLI larger than .95 indicate good model fit (Hu & Bentler, 1999). The resultant *p*-values for the associations of interest were corrected for multiple comparisons with false discovery rate (FDR - Benjamini & Hochberg, 1995) using the "*p.adjust*" function from package Stats (R Core Team, 2020). Throughout the manuscript, we present standardised model estimates and the results marked as significant are those that survive FDR correction.

a)

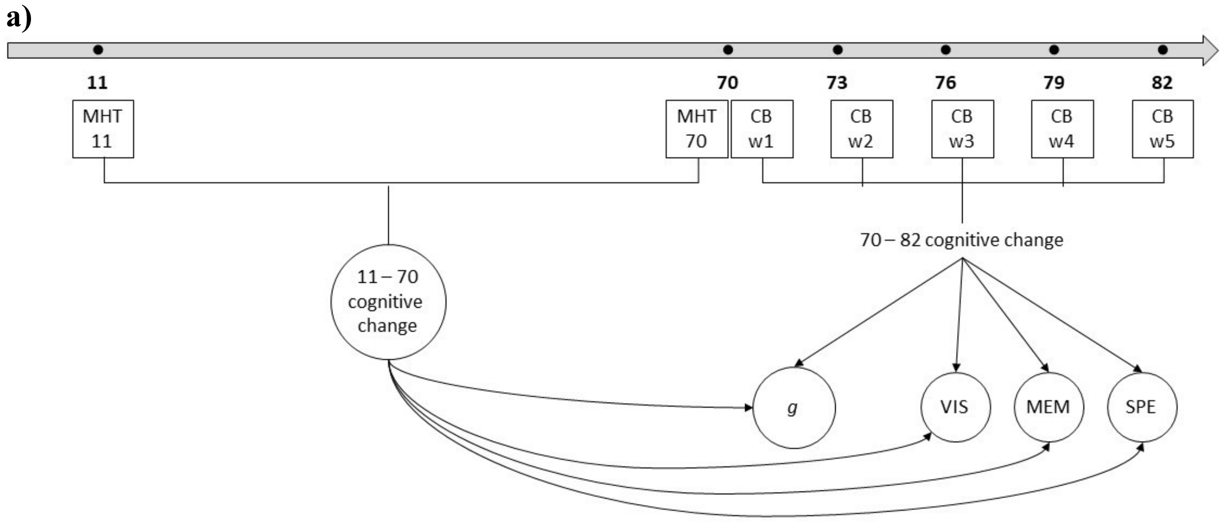


Figure 1a. Main analysis' diagram: age 11 to 70 cognitive change predicts age 70 to 82 cognitive change.
Note. 11- 70 Cognitive change estimated from Moray House Test (MHT) scores. 70 -82 Cognitive change in general cognitive ability (*g*) and in visuospatial (VIS), verbal memory (MEM), and processing speed (SPE) domains estimated from Cognitive Battery (CB) scores at Waves 1 through 5. 11-70 Cognitive change is used to predict 70-82 cognitive change.

b)

Figure 1b. Bifactor measurement model of cognitive level and change.

Note. Factor of curves models (not illustrated) are used to derive baseline level (bl) and slope (s) parameters for each cognitive task. General cognitive ability (g) baseline level and slope (left) and domain-specific baseline level and slope (right) are extracted as second-level latent factors fron task parameters (center). BLD = block design, MTR = matrix reasoning, SSP = spatial span, VPA = verbal paired associates, LGM = logical memory, DSB = digit span backward, SBS = symbol search, DSS = digit-symbol substitution, ITT = inspection time, CRT = four-choice reaction time.

3. Results

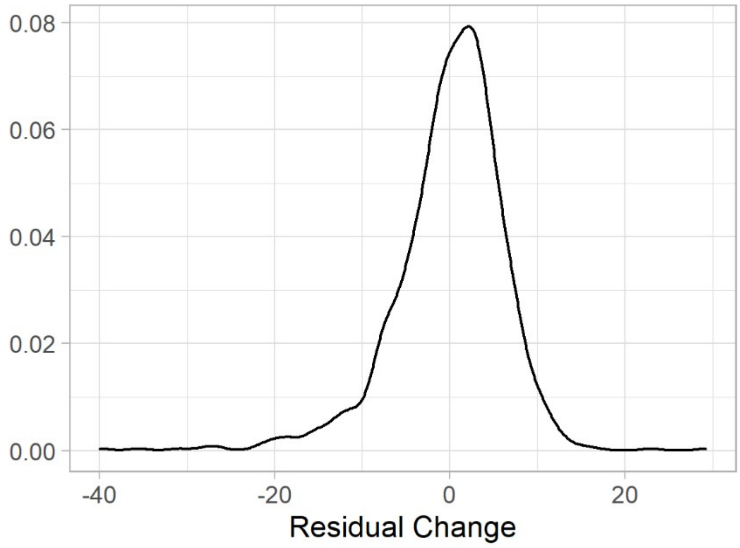
3.1 Deriving measures of cognitive change

Raw MHT scores showed a general improvement between age 11 (M = 49.26, SD = 11.34) and age 70 (M = 64.23, SD = 8.80), with a mean increase of 15.23 points (SD = 8.36), on a maximum possible score of 76 (+ 0.26 points per year, SD = 0.15). Figure 2 illustrates the distribution of the regression residuals of MHT age 70 on MHT age 11 interpreted as cognitive change measure in the analyses. Table 2 reports the correlation of the regression residuals with MHT at age 11 and 70, with *g* at age 70 (based on the cognitive battery), and with the raw change in MHT scores between age 11 and 70 (see sect. 2.3.3 and Supplemental material). The regression-based measure of MHT change had M = 0.00 and SD = 6.27.

Fit indices for the bifactor model of the levels and slopes of the ten cognitive tests are presented in Table S1, factor loadings in Table S2.

The cognitive measurement model fits the data well. An average of 43% of task variance in baseline levels was shared within *g*, 22.3% within domain, and 34.7% was task-specific. On average, 71.3% of slope variance was captured by *g*, 19.6% by domain factors, and 9.1% was task-specific. The strongest indicators of *g* slope, i.e., of change rates in general cognitive ability, were the processing speed tasks. Their loadings on the *g* slope factor ranged between 0.899 and 0.945, meaning that, on average, 85.5% of their slope variance was captured by *g*. This, in turn, resulted in little domain-specific slope variance beyond *g*: only 7.5%, on average, was shared exclusively among processing speed tasks (against 17.5% shared among visuospatial tasks, and 37.8% among verbal memory tasks).

Figure 2: Density plot of residual change scores of individual participants



Note: Residuals of the regression of Moray House Test scores at age 70 on age-corrected Moray House Test scores at age ~ 11

Table 2: Bivariate correlations between measures of general cognitive ability and 11-70 cognitive change

	11-70 residual change	MHT 11	MHT 70	g 70
11-70 residual change	-			
MHT 11	.00	-		
MHT 70	.74***	.68***	-	
g 70	.43***	.59***	.73***	-
11-70 raw change	.75***	-.67***	.10**	-.08*

Note: MHT 11 = Moray House Test scores at age ~ 11; MHT 70 = Moray House Test scores at age ~ 70 (Wave 1); *g* 70 = general cognitive ability at age ~ 70 (Wave 1); *g* was estimated through a Structural Equation Model including ten cognitive tests.
* p < .05 ** p< .01 *** p < .001

3.2. Cognitive change from 11 to 70 as a predictor of individual differences in later-life cognitive trajectories

Results of the present study's principal analyses are presented in Table 3. Table S1 reports model fit indices, which were good. A greater relative improvement in MHT score between age 11 and age 70 was associated with slower decline in *g* from age 70 to 82 (β = .163, p =.001): individuals who gain the most in MHT scores between age 11 and age 70 also tend to preserve their cognitive ability better from age 70 to 82. A more marked improvement in MHT score between age 11 and 70 was also associated with significantly higher *g* baseline level at age 70 (β = .429, p < .001).

MHT change between 11 and 70 remained a significant predictor of age 70-82 cognitive decline even after baseline age 70 level of *g* was entered as an independent variable in the multiple regression (11-70 change β = .185, p < .001; *g* baseline level β = .080, p = .104). Cognitive trajectories from age 11 to 70 thus appear more informative than does cognitive functioning at age 70 in predicting subsequent cognitive decline rates from age 70 to 82.

The next analyses involved changes in the cognitive domains from which variance in *g* had been removed. However, concerning their importance, note that there is about 3.5 times more slope variance in *g* than in the domains. The small amount of variance captured at the domain level warrants caution in interpreting these following results. More favourable 11-70 MHT cognitive trajectories were associated with less decline in verbal memory (β = .139, p =.021), but also with a steeper decline in processing speed (β = -.198, p =.018) (Table 3). There was no main effect of 11-70 MHT cognitive trajectory on visuospatial ability. However, we observed a significant cognitive change × sex interaction effect on the slope of visuospatial ability (β = -.229, p =.010), indicating that greater 11-70 relative improvement in MHT is associated with a steeper decline in visuospatial skills in women.

Table 3. Associations of cognitive change from 11 to 70 with later-life trajectories of general and domain-specific[1] cognitive abilities.

Effect	Baseline Level			Slope		
	β	C.I.	*p*	β	C.I.	*p*
g						
11-70 Change	**.429**	**[.37, .49]**	**.000**	**.163**	**[.07, .26]**	**.001**
Sex	**-.149**	**[-.21, -.08]**	**.000**	.088	[.01, .17]	.037
11-70 Change × Sex	.066	[.0. .13]	.056	.012	[-.08, .11]	.811
Visuospatial Ability						
11-70 Change	-.070	[-.16, .02]	.139	-.176	[-.36, .00]	.055
Sex	-.071	[-.16, .02]	.110	.090	[-.07, .25]	.279
11-70 Change × Sex	-.032	[-.12, .06]	.491	**-.229**	**[-.40, -.05]**	**.010**
Verbal Memory						
11-70 Change	.061	[-.02, .15]	.157	**.139**	**[.02, .26]**	**.021**
Sex	**.369**	**[.30, .44]**	**.000**	.044	[-.06, .15]	.415
11-70 Change × Sex	-.060	[-.14, .02]	.162	.016	[-.10, .14]	.790
Processing Speed[2]						
11-70 Change	.016	[-.07, .10]	.730	**-.198**	**[-.36, -.03]**	**.018**
Sex	**.368**	**[.29, .44]**	**.000**	-.114	[-.26, .03]	.123
11-70 Change × Sex	-.083	[-.17, .00]	.063	-.043	[-.21, .13]	.61

Note. Standardized coefficients and p-values. *11-70 change × sex* = 11 to 70 cognitive change × sex interaction; proportion of domain-specific slope variance accounted for beyond *g* was: visuospatial 17.5%, verbal memory 37.8%, processing speed 7.5%. Bold typeface denotes FDR significant (q < .05).

[1] Bifactor model results: domain-specific variance does not include variance common to all tasks (captured by *g*)

[2] The slope of 4-choice RT task loaded negatively on the domain factor.

3.3. Supplementary analyses

Supplementary Material presents results from our analyses (i) employing raw measures of 11-70 MHT change, first on the entire sample and then on the subsample showing reliable change in scores, (ii) correcting for within-wave age differences, and (iii) fitting individual domain models but without partialling out general variance.

When conducting analyses on raw 11-70 MHT change, the direction and magnitude of effects on g level and change in the entire sample were consistent with those observed in the main analysis. No association with g slope was detected when assuming test-retest reliability of .90 for MHT scores at age 11 and 70. Raw 11-70 change had a significant positive association with the slope of visuospatial ability, but not with the other two domains (see Table S3).

Overall, the pattern of results reported above did not change when controlling for age differences within each wave of testing, as illustrated in Table S4.

The direction and size of effects in individual domain models (Table S5) are essentially similar to those observed on g in the main analysis, reflecting the large proportion of variance shared across domains.

3.5. NART-based measures of cognitive change and individual differences in later-life cognitive trajectories

We found that MHT change from age 11 to age 70 — i.e. across nearly six decades — predicted subsequent cognitive changes from age 70 to 82. We then used age-70 NART score as a measure of peak adult cognitive ability to investigate whether change from childhood to peak ability or change from peak ability to age 70 might be differentially important. Cognitive abilities were modelled using the same bifactor model as in the main analysis (see 2.3.1). MHT-11 to peak cognitive change had M = 0, SD = 5.82; it correlated with 11-70 cognitive change $r = .37$, $p < .001$. Peak to MHT-70 cognitive change had M = 0, SD = 6.59; it correlated with 11-70 change $r = .73$, $p < .001$

Having higher NART scores than expected on the basis of age-11 MHT was associated with higher age-70 baseline level in *g* and domain-specific verbal memory (Table 4; $\beta = .169$ and .217, respectively, $p < .001$). However, this estimated 'early' cognitive change had no association with the change rates of any cognitive abilities investigated.

Having higher MHT-70 scores than expected on the basis of NART was associated with higher *g* level at age 70 (Table 5; $\beta = .481$, $p < .001$). It also predicted steeper decline after 70 in domain-specific visuospatial ability ($\beta = -.234$, $p = .008$). Overall, cognitive change over shorter timespans, either between age 11 and peak or between peak and age 70, appeared unable to predict decline rates in *g*. Supplementary Material reports model fit indices and individual domain models for these last analyses (Tables S1 and S5).

Table 4. Associations of age 11 to peak cognitive change with later-life trajectories of general and domain-specific[1] cognitive abilities.

Effect	Baseline Level			Slope		
	β	C.I.	*p*	β	C.I.	*p*
g						
11- NART Change	**.169**	**[.10, .24]**	**.000**	.071	[-.02, .16]	.108
Sex	**-.212**	**[-.28, -.14]**	**.000**	.070	[-.01, .15]	.096
11- NART Change × Sex	.018	[-.06, .09]	.641	-.025	[-.11, .06]	.574
Visuospatial Ability						
11- NART Change	.070	[-.02, .16]	.127	-.093	[-.26, .08]	.285
Sex	-.067	[-.15, .02]	.132	.091	[-.08, .26]	.285
11- NART Change × Sex	.009	[-.08, .10]	.851	-.139	[-.31, .03]	.107
Verbal Memory						
11- NART Change	**.217**	**[.14, .30]**	**.000**	.071	[-.04, .18]	.191
Sex	**.349**	**[.28, .42]**	**.000**	.029	[-.07, .13]	.580
11- NART Change × Sex	.023	[-.06, .1]	.577	.018	[-.09, .13]	.737
Processing Speed[2]						
11- NART Change	.015	[-.07, .1]	.727	-.050	[-.20, .10]	.522
Sex	**.367**	**[.29, .44]**	**.000**	-.100	[-.25, .05]	.182
11- NART Change × Sex	-.021	[-.11, .07]	.628	.004	[-.15, .16]	.964

Note. Standardized coefficients and p-values. *NART* = National Adult Reading Test; *11- NART Change* × *sex* = 11 to peak cognitive change × sex interaction; proportion of domain-specific slope variance accounted for beyond *g*: visuospatial 17.5%, verbal memory 37.8%, processing speed 7.5%. Bold typeface denotes FDR significant.

[1] Bifactor model results: domain-specific variance does not include variance common to all tasks (captured by *g*)

[2] The slope of 4-choice RT task loaded negatively on the domain factor.

Table 5. Associations of peak to age 70 cognitive change with later-life trajectories of general and domain-specific[1] cognitive abilities.

Effect	Baseline Level			Slope		
	β	C.I.	*p*	β	C.I.	*p*
g						
NART - 70 Change	**.481**	**[.43, .53]**	**.000**	.079	[-.01, .17]	.091
Sex	**-.141**	**[-.20, -.08]**	**.000**	.081	[.00, .16]	.059
NART - 70 Change × Sex	.077	[.01, .14]	.020	.001	[-.09, .09]	.990
Visuospatial Ability						
NART - 70 Change	-.061	[-.15, .03]	.182	**-.234**	**[-.41, -.06]**	**.008**
Sex	-.069	[-.16, .02]	.123	.077	[-.09, .24]	.364
NART - 70 Change × Sex	-.051	[-.14, .04]	.259	-.080	[-.26, .10]	.384
Verbal Memory						
NART - 70 Change	-.010	[-.09, .07]	.808	.102	[-.01, .22]	.086
Sex	**.363**	**[.29, .43]**	**.000**	.042	[-.06, .15]	.435
NART - 70 Change × Sex	-.050	[-.13, .03]	.241	-.017	[-.13, .10]	.777
Processing Speed[2]						
NART - 70 Change	.043	[-.04, .13]	.324	-.179	[-.34, -.02]	.028
Sex	**.372**	**[.30, .44]**	**.000**	-.118	[-.26, .03]	.113
NART - 70 Change × Sex	-.073	[-.16, .01]	.091	.029	[-.14, .19]	.728

Note. Standardized coefficients and p-values. *NART* = National Adult Reading Test; *NART - 70 change* × *sex* = peak to 70 cognitive change × sex interaction; proportion of domain-specific slope variance accounted for beyond *g*: visuospatial 17.5%, verbal memory 37.8%, processing speed 7.5%. Bold typeface denotes FDR significant.

[1] Bifactor model results: domain-specific variance does not include variance common to all tasks (captured by *g*)

[2] The slope of 4-choice RT task loaded negatively on the domain factor.

4. Discussion

Our main finding is that individual differences in cognitive change between age 11 and 70 – measured on the same general ability test – significantly predict individual differences in *g* change from age 70 to 82 in this narrow-age cohort. We are not aware of other studies comparing cognitive change rates across these periods of life. The association we observed is modest but is at the upper bounds of effect sizes typically observed for individual risk and protective factors for cognitive ageing in this cohort (e.g. Corley et al., 2018) and others (e.g. Zaninotto et al., 2018). Moreover, age 11-70 change was informative about decline rates even when controlling for cognitive level at 70, thus offering independent predictive value. These findings accord with an account of differential preservation (Salthouse, Babcock, Skovronek, Mitchell, & Palmon, 1990), whereby individuals with similar cognitive levels decline at different rates depending on the amount of cognitive change experienced from youth to older adulthood. Our results encourage the search for cognitive change determinants relatively early in the life course, not just because they matter in themselves, but because they are relevant to later-life cognitive decline.

The bifactor model differentiated variance shared among all cognitive tasks, and therefore attributed to *g*, from variance specific to each cognitive domain. Compared to a previous study on the same cohort, which considered the first three assessments (Ritchie et al., 2016), the present investigation on Waves 1 to 5 revealed a higher proportion of shared slope variance. This shift is consistent with Tucker-Drob's (2019) meta-analytic finding of dynamic dedifferentiation: *g* accounts for increasing amounts of variance with advancing age. Data from this and other studies (ibidem) shows that starting at age ~70 years, more than half of inter-individual variability stems from differences in the decline of general cognitive function, rather than of specific abilities. Therefore, accounting for change in *g* should be a primary focus of research on cognitive ageing.

The association of earlier cognitive change (11-70) with later cognitive decline (70-82) in *g* appeared robust in our study. Supplementary analyses showed that neither using an alternative measure of earlier cognitive change, nor introducing age as additional covariate changed this result appreciably.

The predictive effect of 11–70 cognitive change seemed pervasive across domains of cognitive functioning, being significant also with regard to domain-specific decline. Greater relative improvement in MHT scores from age 11 to 70 was associated with better preservation of verbal memory and with steeper decline in processing speed and visuospatial abilities at later age (the latter only in women). These effects were less stable than those on *g* (e.g., they did not survive FDR correction in the age-adjusted model); however, we note again the small amount of domain-specific variance compared to general variance. Altogether, our results support the initial hypothesis that changes between childhood and late adulthood might be relevant to a broad range of cognitive changes after age 70, especially concerning general cognitive ability. These are the first data suggesting that those with more positive earlier trajectories are at lower risk of subsequent decline into older age.

Why did 11-70 change predict change in *g* better than in cognitive domains? First, in older age, there was much more variance in *g* change than in domain-specific changes. Second, the nature of the MHT test might have been relevant. The MHT correlates strongly with the Stanford-Binet overall IQ score in childhood (Deary, 2014) and with *g* in adulthood (Deary, Johnson, & Starr, 2010). Therefore, it was likely to be good at predicting subsequent change in *g*. Performance in specific cognitive domains at age 11 and 70 could have predicted domain-specific change better. We think it would be valuable if that could be tested for memory, which was the domain least related to *g* and is a signature of some types of mild cognitive impairment and dementia.

New questions arise as to what lifetime period might be most informative about age-related cognitive decline: would it be, say, between childhood and early adulthood, or from mid- to later-life?

We partially answered such questions using the age-70 NART as an indicator of participants' peak cognitive ability and assessing change in rank orders from age-11 MHT to NART and from NART to age-70 MHT. Previous LBC studies showed that NART-based cognitive change estimates correlate strongly with actual cognitive change (Deary et al., 2004). Despite this, the absence of significant associations with rates of change in *g* suggests that neither MHT11-peak change nor peak-MHT70 change are in themselves sufficient to anticipate cognitive trajectories in older age. In this study, the longer timespan (i.e., from age 11 to 70) proved more informative about change rates in older age. However, additional research and alternative measures of cognitive change over shorter intervals (i.e., childhood to early adulthood, early to late adulthood) are needed to determine the relationship of cognitive change trajectories.

4.2 Limitations

Limitations should be considered when interpreting our results and may help inform future research. The LBC studies provide direct measures of participants' cognitive abilities in childhood and older age. However, no cognitive tests were administered in the years between ages 11 and 70 (i.e., 1947 and 2007). Therefore, information on this period is not as thorough as information collected from participants in their older age. However, we judge that a robust index such as the NART represents a valuable resource in the absence of direct assessments. We hope that our efforts to bridge this gap will motivate further research into potential critical periods during which earlier-life cognitive change anticipates later-life cognitive decline.

LBC1936 cohort members tend to be healthier, better educated, and perform better on cognitive ability tests compared to the population average (Taylor et al., 2018), likely leading to some restriction of range and a slight reduction in effect sizes (e.g., Johnson, Corley, Starr, & Deary, 2011). Finally, participants were all born in a single year and come from a particular geographical setting, thereby limiting our results' generalizability, albeit removing the possibility of cohort effects in a mixed-age sample.

5. Conclusion

Research indicates that individual differences in cognitive decline arise from many diverse factors, each exercising a small influence (Corley et al., 2018; Deary, Gow, Pattie, & Starr, 2012). Tracing cognitive change trajectories back through the life course requires data that are rarely available. The present study shows that cognitive change between ages 11 and 70 is independently informative of cognitive change trajectories from age 70 to 82, beyond cognitive level at age 70. Therefore, the results support identifying individuals at higher risk of cognitive decline before the critical years in which dementia risk accelerates. The positive side to the findings is that, to some extent, those who fare better cognitively from age 11 to 70 tend to be at lower risk of cognitive decline from 70 to 82. As Fred Astaire (1899-1987) reportedly said, “Old age is like everything else… to make a success of it, you’ve got to start young.”

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