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The stability of intelligence from age 11 to age 90 years: The Lothian Birth Cohort 1921

Ian J. Deary[1], Alison Pattie[1], John M. Starr[1,2]

[1]Centre for Cognitive Ageing and Cognitive Epidemiology, Department of Psychology, University of Edinburgh, Edinburgh, UK and [2]Alzheimer Scotland Dementia Research Centre, Department of Psychology, University of Edinburgh, Edinburgh, UK

Corresponding author:

Ian J. Deary, Centre for Cognitive Ageing and Cognitive Epidemiology, Department of Psychology, University of Edinburgh, Edinburgh, EH8 9JZ, United Kingdom.

E-mail: i.deary@ed.ac.uk

Abstract

As a foundation for studies of human cognitive aging, it is important to know the stability of individual differences in cognitive ability across the life course. Few studies have tested the same individuals in youth and in old age. We examine the stability and concurrent validity of individual differences in the same cognitive test administered to individuals at age 11 years and again at age 90. The sample is the Lothian Birth Cohort 1921 (N = 106). The correlation of Moray House Test scores between age 11 and 90 is .54. This estimate is a valuable foundation for estimating the degree to which individual differences in cognitive ability in very old age are accounted for by the life-long stable trait, and by the causes of cognitive change across the life course. The Moray House Test showed strong concurrent validity with 'gold-standard' cognitive tests at age 11 and age 90.

Keywords

Intelligence, IQ, cognition, ageing, longitudinal study, cohort, Scottish Mental Survey, Lothian Birth Cohort, Moray House Test, Binet Test, Raven's Matrices

Introduction

The demographic change in societies has brought about more research interest in human ageing (Lutz, Sanderson, & Scherbov, 2008, Martin, 2011). Although age affects many aspects of functioning, high priority has been given to cognitive function, especially how it might be retained as people grow older (Plassman, Williams, Burke, Holsinger, & Benjamin, 2010). Losing cognitive functions with age is associated with a loss of independence in carrying out everyday tasks (Tucker-Drob, 2011). A fundamental item of information for cognitive ageing studies is how much of the variance in human intelligence is stable across the life course, which is also informative about how much has changed. Knowing the long-term stability of individual differences in cognitive abilities will allow researchers to estimate how much variance can be accounted for by factors that might influence age-related cognitive changes. This is especially important for the concept of cognitive reserve, which is the idea that higher prior cognitive ability confers some protection from the effects of brain pathology on cognitive function in old age (Singh-Manoux, Marmot, Glymour, Sabia, Kivimaki et al., 2011; Staff, 2012). Formally to test this idea requires knowledge of how strongly prior, youthful cognitive ability itself is associated with cognitive function at various stages of old age.

There are few reports of the correlations between intelligence test scores obtained in youth with those obtained when the same participants reach maturity and older ages. From around age 11 years, the correlation between intelligence tested then and at 40 was at or above .7 (McCall, 1977). Correlations of about this magnitude have been found when cognitive ability tests have been administered in the late teens or early 20s and then

again in the early to mid-60s (Owens, 1966; Schwartzman, Gold, Andres, Arbuckle, & Chaikelson, 1987). A smaller effect size was found (.46) when a cruder estimate of cognitive ability was obtained at follow up (Plassman, Welsh, Helms, Brandt, Page et al., 1995). Here, we offer an estimate of the stability of intelligence as measured by the same test in childhood and in old-old age.

We have previously reported the correlations (raw, uncorrected Pearson's r) between Moray House Test cognitive ability scores at age 11 and scores from the same test taken at 70 (r = .67; Lothian Birth Cohort 1936), 77 (r = .63; Aberdeen Birth Cohort 1921), 79 (r = .66; Lothian Birth Cohort 1921), and 87 (r = .51; Lothian Birth Cohort 1921) (Deary, Whalley, Lemmon, Crawford, & Starr, 2000; Deary, Whiteman, Starr, Whalley, & Fox, 2004; Gow, Johnson, Pattie, Brett, Roberts et al., 2011). We judge that the present report is a valuable and unusual addition to these, for the following reasons. First, providing the association (and its confidence intervals) between scores from the same intelligence test at age 11 and 90 years is likely to be the longest follow-up study of intelligence differences that will ever be undertaken. As such, it will provide information about the stability of intelligence differences across as much of the life course as will ever be tested in a number large enough not to have wide confidence intervals. The sample whose data and results we report is still moderately large, with an N of around 100. Second, the data used here are from a new wave of data collection and have not been reported previously. Third, there are several other standard cognitive tests taken at age 90. These provide concurrent validity for the Moray House Test at age 90, something which is already available from age 11 (Scottish Council for Research in Education, 1933; Deary,

Whalley, & Starr, 2009, chapter 1). These new data also provide an opportunity formally to test how different are various cognitive tests' correlations with the same Moray House Test taken concurrently in old-old age and almost 80 years earlier. This is a rare opportunity to discover the extent to which diverse cognitive tests in old age are dependent upon cognitive ability from childhood. As the analyses will show, these data provide an insight into the mix of fluid and crystallized skills that contribute to different cognitive tests.

The principal aim of the present study is to report the stability of individual differences in intelligence from age 11 years to age 90 years in a narrow-age sample. The secondary aim is to describe and test the differences in correlation between the same test taken at age 11 and age 90 with several other tests that are commonly used as indices of important cognitive domains.

Method

Participants

The study participants are members of the Lothian Birth Cohort 1921 (LBC1921). Most of the cohort had taken part in the Scottish Mental Survey of 1932 (Scottish Council for Research in Education, 1933; Deary, Whalley, & Starr, 2009) which, on June 1st of that year, applied a validated test of general mental ability to almost all children born in 1921 and attending school in Scotland. From 1999 to 2001, people living in Edinburgh and the surrounding area of Scotland were invited to take part in a study of cognitive ageing. Recruits from this period formed wave 1 of the LBC1921, and were 550 in number. The

tracing, recruitment and testing in the first 3 waves of the LBC1921 study are described in previous reports (Deary, Whiteman, Starr, Whalley, & Fox, 2004; Deary, Gow, Pattie, & Starr, 2012). The present study's analyses are based on data collected during wave 4 of the study, which took place during 2011 and 2012. Examinations took place as close to the participants' 90th birthdays as was possible. Most participants attended for examination at the Wellcome Trust Clinical Research Facility at the Western General Hospital in Edinburgh. Some, because of mobility problems or distance from the research clinic, were tested at home. The numbers at each wave of testing and the causes of attrition are shown in Figure 1. The principal analyses in this report concern scores taken in childhood and again at wave 4. Although there is a small range of ages on both occasions, we shall refer to them as age 11 and age 90 years.

Cognitive measures

Moray House Test No. 12 (MHT). The same MHT was administered at age 11 years and age 90. It is a paper-and-pencil test of general mental ability. The time limit is 45 minutes and the maximum possible score is 76. There is a preponderance of verbal reasoning items, with some numerical and other types of item as we have described elsewhere (Deary et al., 2004). The test is reprinted in full in the Scottish Mental Survey 1933 monograph (Scottish Council for Research in Education, 1933). The correlation between the MHT and the Stanford Revision of the Binet test in 1932, when the subjects were 11 years old, was .81 in boys and .78 in girls (N = 500 for each; Scottish Council for Research in Education, 1933, p. 100). At age 11 the test was administered to groups in

school. At age 90 it was administered individually. On both occasions it was self-completed.

National Adult Reading Test (NART). The NART is widely used to estimate prior or premorbid cognitive ability (Nelson & Willison, 1991). The participant is asked to pronounce 50 words that are irregular in grapheme-phoneme association and/or stress.

Mini-Mental State Examination (MMSE). This short interview-based test is often used as a screening test for dementia (Folstein, Folstein, & McHugh, 1975). The maximum score is 30. A score of less than 24 is often used as an indicator of possible dementia.

Raven's Progressive Matrices (Raven). This paper-and-pencil test requires the participant to choose which of a number of answer options correctly provides the missing piece of an abstract pattern (Raven, Court, & Raven, 1977). It is a test of non-verbal reasoning. There are 60 items. A time limit of 20 minutes was applied.

Wechsler Logical Memory. This test from the Wechsler Memory Scale-Revised requires the participant to recall as much information as possible from two stories which the tester reads aloud (Wechsler, 1987). Each has 25 idea units, and recall takes place after each story. Recall takes place immediately after the story and after a delay during which other mental tests are completed. Immediate and delayed recall scores correlated very highly, and so only the delay score was used when principal components analysis was applied to the data. This is used as a test of verbal declarative memory.

Wechsler Letter-Number Sequencing. In each item of this test from the Wechsler Adult Intelligence Scale-III^{UK}, the participant is asked to listen to a jumbled series of numbers and letters read aloud by the tester (Wechsler, 1998). They then try to recall the series, but by giving the numbers first in ascending order followed by the letters in alphabetical order. The score is the number of correct items. This is used as a test of working memory.

Verbal Fluency. In this test the participant was asked to name as many words as possible beginning with the letters C, F, and L (Lezak, 1995). One minute was given for each word. The score is the total allowed words over all three letters. This is used as a test of executive functioning.

Wechsler Digit Symbol. This paper-and-pencil test from the Wechsler Adult Intelligence Scale-Revised requires the participant to place a given symbol below rows of single-digit numbers according to a given code, which is displayed explicitly on the answer sheet during the test (Wechsler, 1981). Participants are asked to complete as many items as possible in 2 minutes without making errors. This is used as a test of processing speed.

4-Choice reaction time. This is tested using a stand-alone device with a small LCD screen and response buttons (Deary, Der, & Ford, 2001). On each of 40 trials, a number (1, 2, 3 or 4) appears on the screen and the participant is asked to press the appropriate button as quickly as possible. There are 8 practice trials and the inter-stimulus interval varies between 1 and 3 seconds. The score used is the mean reaction time in milliseconds.

Demographic and health measures

Sex and age (in days, at the time of testing at age 11 and age 90) were recorded. Smoking status (ever-, ex-, or current-smoker) was recorded at interview. Years of full time education was recorded. Parental social class and the social class of the participant's own main occupation during working life were recorded at interview. Each was graded on a 1 to 5 scale, with 1 representing the most manual occupations and 5 the most manual (General Register Office, 1956). The presence of key chronic illnesses was recorded at interview: hypertension, cardiovascular disease, hypertension, diabetes, cancer, dementia, thyroid disease, and arthritis. Depressive mood symptoms were recorded using the Hospital Anxiety Depression Scales (Zigmond & Snaith, 1983). Possession of the e4 allele of the gene for apolipoprotein E (APOE) was typed on DNA extracted from venous blood (Wenham, Price, & Blandell, 1991).

Results

Of the 129 LBC1921 subjects tested (Figure 1), there were 106 participants (49 men, 57 women) who had Moray House Test scores from childhood and at wave 4 of the LBC1921 study; 79 were tested at the Wellcome Trust Clinical Research Facility, and 27 were tested at home. The mean (SD) age at the 1932 MHT test was 10.9 (.3) years, and at wave 4 was 90.1 (.2) years. The mean (SD) MHT score at age 11 was 49.0 (11.1), and at age 90 was 51.9 (14.4). The MHT score at age 90 was significantly higher than the age 11 MHT score ($t = -2.428$, d.f. = 105, $p = .017$), with an effect size (Cohen's d) of .23. At mean age 90 years the Moray House Test score (mean, SD) for these same 106

participants was lower and more spread than it had been at mean age 79 (63.4, 8.2) and age 87 (57.8, 11.1).

Of the 106 LBC1921 participants with MHT data at age 11 and age 90, 54 had never smoked, 47 were ex-smokers, and 5 were still smoking at 90. When asked about current health, 0 rated it Poor, 14 Fair, 35 Good, 44 Very Good, and 13 Excellent. The number with certain medical conditions was as follows: hypertension = 71; diabetes = 3; cardiovascular disease = 51; cerebrovascular disease = 13; neoplasia = 22; thyroid disease = 15; dementia = 2 (and 3 uncertain); and arthritis = 53. Five had a HADS-Depression score > 8, and none had a score > 11. Four had an MMSE score < 24. The mean (SD) number of years of full time education was 11.5 (2.7). Childhood social class/adult social class distribution, based on 5 categories from 1 = most professional to 5 = most manual were as follows: 18/35, 26/34, 37/35, 14/0, 6/2. Of the 104 who had given blood for genetic testing, there were 22 APOE e4 carriers and 82 non-carriers.

The correlation between the raw MHT scores at age 11 and age 90 was .554 (95% CI = .388 to .692, N = 106; CI obtained by bootstrapping, based on 1000 samples) (Figure 2). For these 106 participants, the correlations between MHT scores at age 90 and the MHT scores from age 79 (wave 1) and age 87 (wave 3) were .727 and .842, respectively (both $p < .001$). Age in days at the MHT test in 1932 correlated .280 ($p < .01$) with raw MHT score. Age in days at the age-90 test correlated -.063 ($p = .52$) with raw MHT score at age 90. MHT scores at both ages 11 and 90 were adjusted for age (in days) at the testing occasion. This was done by regressing the MHT score on age in days and saving the

standardized residuals. The correlation of these age-corrected MHT scores was .544 (95% CI = .381 to .682). It is .537 (95% CI = .371 to .675) if only the age 11 MHT scores are age-corrected. After omitting the 2 subjects with a history of dementia and 3 whose history was uncertain, the correlations was .511 (95% CI = .340 to .657; N = 101). After omitting a further 2 participants whose MMSE score was < 24, the correlation was .451 (95% CI = .295 to .581; N = 99).

Correlations between the MHT scores at age 11 (age-corrected) and MHT age 90 and other cognitive tests at age 90 are shown in Table 1. The MHTs at both ages correlate significantly with all of these other cognitive tests. The highest correlations between tests taken at age 90 and the MHT taken at age 11 (those > .3) are the National Adult Reading Test (.566), Raven's Progressive Matrices (.496), Mini-Mental State Examination (.397), and Digit Symbol (.325). The highest correlations between MHT taken at age 90 and other tests taken at the same age are with Raven's Matrices (.747), Digit Symbol (.679), Mini-Mental State Examination (.632), and Letter-Number Sequencing (.606); the lowest correlation is .381, with verbal fluency. The difference between these other tests' correlations with MHT at age 11 and age 90 was tested for significance. In all cases, the correlations were higher with the contemporaneous MHT at age 90. Only the differences of the MHT age 11 and MHT age 90 correlations with National Adult Reading Test and Verbal Fluency were not significantly different, and the effect sizes for these two tests were similar, despite the almost-80 year lag in testing.

The correlations among MHT at age 11 and MHT at age 90 and the other cognitive test scores obtained at age 90 were explored further using principal components analysis (Table 1). All tests had high (> .5) loadings on the first unrotated principal component. Eigenvalues suggested the extraction of two components. The first accounted for 45.6% of the total variance, and the second accounted for 11.8%. These were rotated using direct oblimin rotation. Rotated component 2 has only two loadings > .35, which are MHT age 11 (.886) and National Adult Reading Test (.829). This appears to be a prior (crystallized) intelligence component. Rotated component 1 has loadings > .58 with all of the other tests except Verbal Fluency (.385). This appears to be a current (fluid) ability component. Verbal fluency has similar and modest loadings on the two rotated components. The correlation between the two rotated components was .40.

Discussion

An estimate of the correlation between intelligence—as measured using the Moray House Test—tested at age 11 and age 90 years is .54, with a 95% CI of .37 to .67. Whether this correlation itself or its square is the effect size best suited to estimating the shared variation across the life course is complex (Johnson, 2011, especially her Figure 6). The mean scores at age 90 are still between a quarter and a fifth of a standard deviation higher than they were at age 11, and considerably lower and more spread than they were for the same participants at age 79 and 87. The MHT at ages 11 and 90 correlated significantly with all other cognitive tests given at age 90. However, most of the MHT age 90 correlations were significantly higher than those with MHT age 11, including correlations with tests of general cognitive status, non-verbal reasoning, verbal declarative memory,

processing speed, and working memory. The MHT age 11 and age 90 scores had remarkably similar correlations with a test of irregular word pronunciation at age 90.

Our aim was to provide a correlation between scores on the same test taken about as far apart in the human life course as is ever likely to be examined. In Scotland, using the most up-to-date data available, about 14% of men and 24% of women from the LBC1921 generation survive to age 90 (Office of National Statistics, 2011). We already published on the LBC1921 at age 87 (Gow, Johnson, Pattie et al., 2011). However, at age 90— when mean MHT test scores are similar to what they were at age 11—we envisage that this will be the last such report with a moderately large sample (N ~100), and we do not foresee other reports that will have such a longitudinal spread. We also provided new and substantial evidence for the concurrent validity of the MHT in old age. It has a high correlation with multiple domains of fluid-type cognitive ability, especially Raven's Progressive Matrices which assesses non-verbal reasoning and has very high loading on fluid general cognitive ability (Carroll, 1993, p. 597; Jensen, 1998, p.38). The MHT was long known to have concurrent validity at age 11, where its correlation with the Stanford Revision of the Binet Test was ~.80 in a sample drawn from the same background population; i.e., children born in 1921 and attending schools in Scotland in June 1932 (Scottish Council for Research in Education, 1933).

The demographic, lifestyle and extensive medical information we reported here show that, by age 90, there is considerable pathology in the LBC1921's medical histories. We have not modeled these with respect to how they might contribute to change in cognitive

ability from age 11 to age 90. Our aim was to report the stability of cognitive differences in the acknowledged presence of and despite this heterogeneity. In further reports we shall examine contributions to cognitive changes in analyses that use data collected in all four waves of the LBC1921, which will have greater power to detect such contributions. To the extent that lower mental ability in youth is associated with greater cognitive decline in older age, then not omitting the few participants with possible early dementia could inflate our estimate of the true correlation. However, there is as yet no unequivocal evidence that mental ability in youth is associated with individual differences in the amount of normal cognitive ageing (Gow, Johnson, Mishra, Richards, Kuh et al., 2012), or with the likelihood of developing the most common form of dementia (McGurn, Deary, & Starr, 2008).

Another factor that must be acknowledged in the LBC1921 sample members who were tested at age 90 is that, with their mean (SD) of 49.0 (11.1) on the MHT at age 11, they scored higher and were less spread than the Scottish population, which had a mean (SD) of 34.5 (15.5) (Maxwell, 1961). We are cautious, though, in suggesting that it is possible to recruit a sample representative of the original population or that one should correct the MHT age 11-age 90 correlation, given this restriction of range. It is well documented that the Edinburgh area is the highest MHT-scoring area in Scotland, so the LBC1921 sample's mean is not the Scottish population mean (Deary, Whalley, & Starr, 2009, p. 26). Also, a score on the MHT at age 11 is a predictor of survival to old age (Whalley & Deary, 2001; Deary et al., 2004). Therefore, older samples will unavoidably have higher means and less spread, and so any correction of the correlation based on the childhood

SD would go against the fact that older samples no longer have that same distribution of original cognitive ability, irrespective of how comprehensively they have been recruited.

Nevertheless, there are probably still some factors that make the estimate of the MHT correlation from age 11 to age 90 an underestimate. For example, lower cognitive ability is associated with attrition from longitudinal studies (Dykiert, Gale, & Deary, 2009; Nishiwaki, Clark, Morton, & Leon, 2005). On the other hand, we note that, in the LBC1921 sample who had MHT scores at age 11 and age 90, the SD at age 90 (14.4) was larger than that at age 11 (11.1). It is possible that, whatever has led to the increasedvariance in MHT scores—chronic illnesses, for example—might be associated with MHT scores at age 11. It is known that childhood intelligence is associated with diverse illness and health outcomes (Deary, Weiss, & Batty, 2010). However, if such a magnification effect on the correlation over time were correct, one would also expect to see an association between childhood cognitive ability and cognitive change within old age, and we have not found that to date (Gow et al., 2011, 2012). Overall, then, the correlation presented here offers, with these caveats, a lower-bound estimate of the childhood versus old-old age cognitive ability association in relatively healthy (i.e., free from acute, severe illness), largely non-demented, mostly community-dwelling people at age 90.

In conclusion, individual differences in general mental ability show moderately high stability from childhood to old-old age. In addition to measurement error and attenuation of the stability effect size caused by restriction of range in the sample, the non-stable

variance provides a target for those seeking the causes of cognitive change across the life course.

Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

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Table 1

Pearson correlations and principal components analysis between Moray House test scores at age 11 and age 90 and other cognitive tests at age 90.

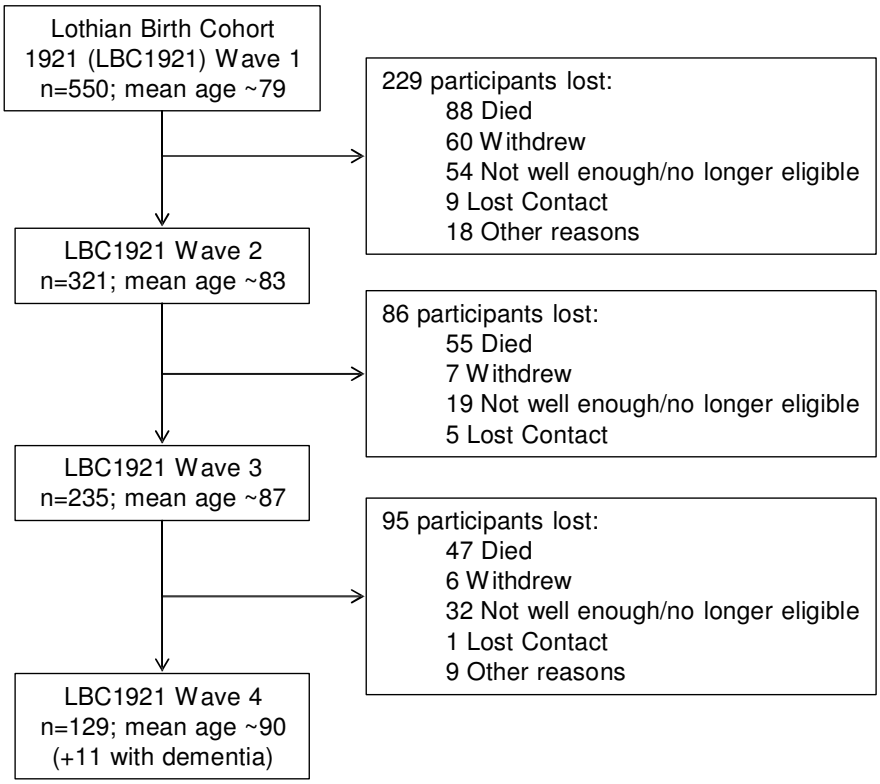
	Correlations[a]				Principal components analysis[b]		
	MHT age 11 (age corrected)	MHT age 90	Correlation difference between MHT 11 and MHT 90 (p)		1st unrotated PC	Rotated component 1	Rotated component 2
MHT age 11 (age corrected)					.525	-.067	.886
MHT age 90	.537				.894	.708	.332
Mini-Mental State Examination	.397	.632	.002		.645	.681	-.002
National Adult Reading Test	.566	.591	.74		.598	.049	.829
Raven's Progressive Matrices	.496	.747	<.001		.821	.660	.291
Logical Memory Immediate	.278	.508	.003				

Logical memory Delay	.202	.505	<.001		.530	.585	-.040
Digit Symbol	.325	.679	<.001		.756	.780	.023
Letter-Number Sequencing	.254	.606	<.001		.706	.803	-.086
4-Choice Reaction time Mean	-.257	-.480	.005		-.592	-.703	.114
Verbal Fluency	.293	.381	.16		.578	.385	.318

Note. [a]All correlations are $p < .01$, except * where $p < .05$ (Ns range from 102 to 106). [b]Based on N = 93 with full data on all variables. Logical Memory Immediate is omitted from the PCA because of its high correlation (r = .906) with Logical memory Delay.

Figure 1

Numbers of participants at each wave of testing in the Lothian Birth Cohort 1921.



Key to terms.

Withdrew = did not wish to continue to participate.

Not well enough/no longer eligible = withdrew for health reasons, including too frail to travel, and participants who have severe visual impairments or who have dementia (except wave 4, when 11 people with dementia were examined at home by a physician and not seen for Moray House Test or other testing).

Other reasons = e.g. living too far to travel, caring for a spouse, GP refusal, a missed appointment.

Figure 2

Moray House Test raw scores for the Lothian Birth Cohort at age 11 years and age 90 years.