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Losing One's Grip: A Bivariate Growth Curve Model of Grip Strength and Non-verbal Reasoning from Age 79 to 87 Years in the Lothian Birth Cohort 1921

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***Objectives*.** Grip strength and reasoning are associated in old age. This is one of the few longitudinal studies addressing whether aging of one causes decline in the other, or whether they share causal influences.

***Methods*.** The Lothian Birth Cohort 1921 were assessed for grip strength and non-verbal reasoning at ages $M = 79$ (N = 550), $M = 83$ (N = 321), and $M = 87$ (N = 207) years. Associations among intercepts and slopes for grip strength and reasoning, and covariates, were examined by fitting a bivariate growth curve structural equation model.

***Results*.** Grip strength and reasoning declined with age. They were each significantly correlated on each occasion. Their intercepts were significantly correlated (.20), but not their slopes. Neither intercept was significantly associated with its own or the other’s slope. Better reasoning was associated with higher childhood intelligence, more professional occupations, male sex, and being taller. There were no significant reasoning slope associations. Stronger grip strength was associated with male sex, being taller, and drinking less alcohol. Women showed less age-related decline in grip strength.

***Discussion*.** Physical and mental ‘grips’ declined in the ninth decade of life. Their levels were significantly correlated; their slopes were not. There was no evidence for reciprocal dynamic influences, nor for shared associations.

***Key words*.** Aging—Intelligence—Reasoning—Grip strength—Longitudinal cohort study—Growth curve modeling.

Introduction

Grasping the world physically and cognitively is important for an independent and high-quality life (Foresight mental capital and wellbeing project, 2008; Stern & Carstensen, 2000). Physical grip strength is an easy-to-apply and important indicator of the health of the musculature and health status more generally, especially in old age (Carmeli, Patish, & Coleman, 2003; Bohannon, 2008). Poor physical grip strength is also a predictor of mortality, poor nutritional status, and loss of independence, among other outcomes (Cooper et al., 2010; Norman et al., 2011; Rantanen et al., 2003). Others have found that physical grip strength is a useful biomarker that can account for more variance than health measures in explaining people’s differences in reaction time (Anstey et al., 2005), which are in turn correlated with more general cognitive abilities (Deary et al., 2009). Cognitive ability is an important general indicator of life coping skills and ability to make sense of the environment (Gottfredson, 1997; Fiocco & Yaffe, 2010). A central component of cognitive ability in this sense is fluid intelligence, the ability to think things through in novel situations (Carroll, 1993; Salthouse, 2004; Salthouse & Ferrer-Caja, 2004), and non-verbal reasoning is a good marker of the general health of fluid intelligence. Both physical grip strength and fluid intelligence decline with age—even in people without physical or cognitive pathology (Carmeli, Patish, & Coleman, 2003; Salthouse, 2004; Salthouse & Ferrer-Caja, 2004; Frederiksen et al., 2006; Finkel et al., 2003). It is important to be mindful of variation in such mean age trends; that is, people of the same chronological age can vary in two respects. They can vary in their levels of grip strength and fluid intelligence at any given age; and they can vary in the rates at which these change as they grow older.

There are findings that grip strength and some cognitive abilities are correlated in old age (Christensen, MacKinnon, Korten, & Jorm, 2001; Deary, Whalley, Batty, & Starr, 2006): people who grip better, think better. Grip strength and tests of general mental ability share more than the fact that they are correlated at any given age and that they both decline with age: they also both have predictive validity for a range of health and wellbeing outcomes in old age, including mortality (Bohannon, 2008; Bäckman & MacDonald, 2006). Taking into account their importance as somatic and psychological functions, their correlation, and their predictive validity, it is of theoretical and practical interest to address two questions about age-related changes in grip strength and reasoning. First, it is important to identify contributors to age-specific levels and age-related rates of change in these key physical and cognitive functions (Kuh, Cooper, Hardy, Guralnik, & Richards, 2009), including finding whether some of these contributors are shared. The common cause hypothesis of aging (Lindenberger & Baltes, 1994; Baltes & Lindenberger, 1997) is relevant to this first question: i.e., it hypothesizes that there might be some set of underlying causes that brings about their association, reflected in the finding that cognitive, sensory and some physical capabilities show correlations among older people.

Second, it is important to discover whether and how the two functions of physical health and cognitive function influence each other; that is, it is important to explore longitudinally the dynamic, reciprocal associations between them. With regard to this second question, many studies to date have been cross-sectional and based on age-heterogeneous samples; both of these are factors that tend to over-estimate such associations (Hofer, Berg, & Era, 2003; Hofer & Piccinin, 2010). Indeed, Hofer et al. (2003) highlighted cognitive and muscle strength in this regard, and pointed out that correlations between such variables can and do arise from age-related mean trends—even when longitudinal data show no evidence of correlated slopes—and that narrow age cohorts followed up over time offer a way to test for correlations between rates of change. There is a lack of longitudinal studies, especially in the old-old, that might help to understand any mutual developmental influences in these two skills, and whether their age-related changes have common contributors. This is especially true in the ninth decade of life when physical frailty, cognitive decline, and dependency are common, and when retaining muscle strength and cognitive abilities is important for retaining independence and quality of life. Here, we examined the reciprocal influences on and contributors to reasoning and grip strength across eight years in a narrow age cohort of people in their ninth decade for whom there was information about intelligence level from childhood.

Method

Participants

The study sample is the Lothian Birth Cohort 1921 (LBC1921), all of whom were born in 1921. LBC1921 began as 550 (234 men, 316 women) relatively healthy, community-dwelling volunteers from the Edinburgh City area of Scotland, first recruited and tested between 1999 and 2001 (wave 1). Most had taken part in the Scottish Mental Survey of 1932 in which they were given validated test of general intelligence (Scottish Council for Research in Education, 1933; Deary, Whalley, & Starr, 2009). The recruitment and cognitive and medical testing in wave 1, when the age of the participants was *M* = 79.1 years (*SD* = 0.3), was described previously (Deary, Whiteman, Starr, Whalley, & Fox, 2004). Since wave 1, the surviving participants have been recalled and re-examined on two further occasions. At wave 2, after excluding withdrawals from the study and those who had died, 321 (145 men, 176 women) were re-examined at M_{age} = 83.4 years (*SD* = 0.5) (Gow et al., 2008). With similar exclusions, 207 (97 men, 110 women) participants were tested at wave 3 at M_{age} 86.6 years (*SD* = 0.4) (Starr et al., 2010; Gow et al., 2011). Hereinafter, the ages of the three waves will be referred to as 79, 83, and 87 years.

Participants were administered the Mini-Mental State Examination (MMSE) at each wave of testing (Folstein et al., 1975). This is a widely-used screening test for dementia. All had scores of 18 or above, and few had any indication of cognitive pathology. Considering only those who were able to provide both Raven's and grip strength data at each wave, the numbers with MMSE scores less than 24 (which is often used to indicate mild cognitive pathology) were as follows: 8 out of 539 at wave 1; 9 out of 317 at wave 2; and 11 out of 200 at wave 3. With regard to an indication of dementia in the medical history, there were two people in wave 1, three in wave 2, and one in wave 3. Therefore, there is little indication of cognitive pathology, and all data from all participants were used in the analysis. Moreover, repeating the analyses after excluding these participants generated nearly identical results. The study was conducted with permission from the Local Research Ethics Committee in NHS Lothian.

Measures and procedure

Raven's Standard Progressive Matrices (Raven, Court, & Raven, 1977). This test assesses non-verbal reasoning. It was devised to be a relatively pure test of inductive reasoning. The Raven test is often considered to be a good measure of the general factor of intelligence (Carroll, 1993). It was administered on a one-to-one basis on three occasions: at waves 1, 2 and 3. The test has 60 items, in which the participant examines an incomplete abstract pattern and chooses an answer to complete the pattern from a number of options. The score was the number of correct responses in 20 minutes.

Grip Strength. This was assessed using a Jamar Hydraulic Hand Dynamometer. It was administered on a one-to-one basis on three occasions: at waves 1, 2 and 3. At each assessment, it was tested three times in both hands, and the best recording (in kg) from the dominant hand was used.

Covariates. The covariates used here were similar to those used by Kuh et al. (2009) in their study of people born in 1946. Intelligence from childhood was included, based on the score obtained in the Scottish Mental Survey 1932. The test used was a version of the Moray House Test No. 12 which principally assesses verbal reasoning (Scottish Council for Research in Education, 1933; Deary et al., 2009). The information for the other covariates was gathered from the interviews at wave 1 (mean age 79). These were conducted by trained researchers, with psychology or nursing backgrounds. Sex and height (measured using a stadiometer without shoes) were included. Height was adjusted for sex prior to modeling. Self-reported mood state was assessed using the depression score from the Hospital Anxiety and Depression Scale (Zigmond & Snaith, 1983). The highest occupation-based socio-economic status was recorded using the classification provided by the UK’s 1951 Classification of Occupations (General Register Office, 1956), ranging from the most professional (I) to unskilled (V). Many women of this era did not have paid work, and so a woman’s occupational status was recorded as the higher of hers and her husband’s. Smoking status was recorded as current or non-smoker. Units of alcohol consumed per week were estimated from interview about the type, amount and frequency of alcohol consumed in a typical week. The interview information was converted into units of alcohol using the United Kingdom Government’s guidelines. A half pint of lager or beer = 1 unit (defined in the UK as 10 millilitres of alcohol); a standard glass of wine = 2 units; a standard glass of sherry or port = 1 unit; a public house measure of spirits or liqueurs = 1 unit. A medical interview recorded whether participants had a history of cardiovascular disease, hypertension, or diabetes. These items were part of a larger, structured interview in which the participants were asked about a number of specific conditions, were allowed to mention other conditions, and reported prescribed medications.

Statistical analyses

Descriptive statistics were calculated using SPSS version 16.0. Structural equation modeling was undertaken using Mplus. The maximum likelihood method was used to estimate parameters in the model, making possible the incorporation of the small number of cases with missing data on some of the variables, under the assumption, generally reasonable in this case, that missingness was not directly dependent on score level. The general approach was the multivariate growth curve model (e.g. see Gerstorf, Lovden, Rocke, Smith, & Lindenberger, 2007; McArdle & Hamagami, 2001). The key outcome variables—Raven and grip strength—were measured on three occasions. ‘Growth curve’ modeling refers to the fact that each person’s individual trajectory for each outcome across the period can be obtained from these repeated measures. The key aspects of this trajectory are the elements of a regression line: the intercept of the variable, capturing the level of performance at the start of the period of measurement; and the slope, describing rate of change across the period. The modeling process estimates latent factors for the intercept and slope of each variable, and the systematic variance around them. With three occasions of measurement it is possible to model linear and non-linear (quadratic) aspects of the slope as well as two different slopes linking the first and second and second and third assessments; however, single linear slopes provided the best fit in the present data set.

Under the model, the effects of covariates are modeled by testing whether they have significant associations with the intercept and slope factors; that is, whether the covariates influence the levels of the outcome variables, and/or their age-related changes. Bivariate refers to the fact that, in the present study, there were two variables measured repeatedly, in parallel. This afforded the opportunity to extract intercepts and slopes from both variables. More importantly, and at the heart of this analysis, the modeling allowed the estimation of the extent to which there were associations among the intercepts and slopes of the two variables. A significant between-intercept correlation would mean that the levels of the two variables were associated. A significant between-slope correlation would suggest that they tended to age in tandem; people who were declining more steeply in one variable would be declining more steeply in the other one too. A significant intercept-slope association within one of the variables would mean that a person’s level (or starting value) of a variable affected the rate of change in that variable with age. A significant association between the intercept of one variable and the slope of the other one would indicate that the starting value (level) of one variable affected the age-related changes in the other variable. The bivariate growth curve model can thus provide some indication of lead-lag effects between variables, and helps toward causal attributions. In this regard it is an improvement upon simpler cross-lagged models (Rogosa, 1980; Locasio, 1982), especially because it adjusts for unequal reliabilities of the repeated measures, and because it can use all the information provided by subjects including those who do not complete all waves of the study.

The bivariate growth curve method was used to derive individuals' intercepts and slopes of Raven scores (non-verbal reasoning) and grip strength from the age 79, 83 and 87 measurement waves. The aims of the analyses were: to test for any reciprocal, dynamic influences among the levels and slopes of reasoning and grip strength; and to discover whether there were other variables (covariates) which accounted for individual differences in these levels and slopes, especially whether there were variables which influenced those of both outcomes. To achieve this latter aim, all covariates were allowed to influence the intercepts and slopes of Raven and grip strength scores. Continuous variables were standardized ($M = 0$, $SD = 1$) prior to modeling. A number of recommended (Bentler, 2007) fit indices were used to assess the adequacy of the structural equation model, including: the significance of the residual covariation among the variables, using a chi square test; the overall amount of residual covariation among the variables after model fitting, using the standardized root mean square residual (SRMSR); and the overall model fit, using the root mean square error of approximation (RMSEA), the comparative fit index (CFI), and the Tucker-Lewis index (TLI).

Results

Descriptive statistics for the sample are shown in two forms. First, in Table 1, the untransformed descriptive statistics are given for the three waves. In addition to showing the whole sample at each wave, the variables' descriptive statistics are also given for those—79 year old at wave 1—subjects who did and did not return at subsequent waves of testing at mean ages of 83 and 87 years. The two outcome measures are Raven scores and grip strength. For the whole sample, on the three occasions, the mean Raven score decreased from *M* = 31.2 at age 79 (*N* = 543), to *M* = 29.7 at age 83 (*N* = 318), to *M* = 27.8 at age 87 (*N* = 201). This decline of 3.4 points underestimated the change that occurred in the sample who attended all three waves, in which the decline was 5.5 points, because the wave 2 and 3 returnees had higher wave 1 scores than non-returnees. There was a similar finding for grip strength: the mean scores declined across the three waves, but more so for those subjects who attended all three waves. The maximum likelihood-estimated means (Table 2), which take into account all information, including that from subjects with some missing data, show that Raven scores fell by over half a standard deviation from age 79 to age 87, and that grip strength fell by over three quarters of a standard deviation. The characteristics of the covariates are also described in Tables 1 and 2.

Figure 1 shows the bivariate growth curve model for Raven and grip strength scores and their covariates. The model fitted well: Chi square = 44.1, d.f. = 27, *p* = .020; RMSEA = .033, 90% C.I. = .013 to .051; SRMSR = .012, CFI = .992 and TLI = .977. Table 2 provides the maximum likelihood-estimated full correlation matrix (and the maximum likelihood-estimated means and variances) for the variables included. The correlations in Table 2 show the high stability of Raven and grip strength across the three testing waves, with coefficients ranging from *r* = .762 to almost *r* = .900. There were eight correlations between Raven and grip strength. The coefficients showed a highly consistent association, with a mean *r* of .254 (range of *r*s = .236 to .275). There was little indication of any association between intelligence from childhood and grip strength in old age, with correlations all *r*s ≤ .062 (previously reported for wave 1 data only; Deary et al., 2006).

In describing the model (see Figure 1) further, the Raven and grip strength intercepts and slopes will be described first, and then the influences of covariates.

The model (Figure 1) shows that both Raven and grip strength scores declined by just under 0.1 *SD* units per year. The Raven and grip strength intercepts showed a significant association (standardized path coefficient = .20), reflecting the contemporaneous correlations at each wave. There was no significant correlation between their slopes; that is, within the sample, a person’s rate of change in Raven was not predictable from their rate of change in grip strength. There was no significant association between Raven intercept and Raven slope: people with different initial Raven scores declined in parallel. Likewise, there was no significant intercept-slope association for grip strength; people with different initial grip strengths declined in parallel. Therefore, age was not kinder to the reasoning or grip slopes of the initially more able. Cross-trait, there were no significant associations between Raven intercept and grip strength slope, or between grip strength intercept and Raven slope: the starting value of either one of the two variables did not influence the amount of decline in the other one over the eight year period.

Higher Raven intercept was significantly associated with: higher IQ at age 11, more professional occupational status, lower depression at age 79, male sex, and height (Figure 1). There were no significant associations with Raven slope among the variables studied here. Especially notable was that IQ at age 11 did not contribute significantly to Raven slope. Stronger grip strength intercept was significantly associated with male sex, height, and drinking less alcohol. Shallower decline in grip strength was associated with female sex. It is clear from the standardized coefficients shown in Figure 1 (non-significant effects are not shown) that, apart from the effects of age 11 intelligence on Raven intercept and sex on grip strength intercept and slope, the effect sizes are small (less than 0.2).

Discussion

Effective reasoning and stronger hand grip are two valuable functions in old age, and it is important to know more about the extent and causes of their association through the lifecourse. Both variables declined across the period of observation in the present study. In this rare longitudinal study of people across most of their ninth decade, we found that non-verbal reasoning and grip strength were significantly associated at each wave, and had correlated intercepts (levels): better reasoners tended to have stronger grip strength. However, the trajectories of decline were not significantly correlated; whatever factors contributed to variation in age-related changes in these functions, they do not appear to be shared in the ninth decade. Sex and height contributed to both intercepts, but other covariates affected only one or other of the intercepts. The association between height and intelligence is well known, exists across the lifecourse, and we have discussed this association and its possible causes elsewhere (Starr et al., 2010). The only covariate related to slope among those assessed here was female sex, which conferred a protective effect against decline in grip strength.

Individual differences in grip strength were highly stable across eight years. There was also mean decline. The present study was consistent with two previous studies (Frederiksen et al., 2006; Finkel et al., 2003) in finding that grip strength's decline with age was shallower for women than for men. The amount of decline in grip strength per year was somewhat larger than that reported in a large cross-sectional and longitudinal study of Danes aged from

46 to 102 (Frederiksen et al., 2006). Because age trajectories were largely linear in both studies, this difference is unlikely to be due to the present sample's being at the upper end of the age range in the Danish sample. It is possible that the smaller (4-year) follow-up in the Danish sample accounts for the difference.

Can the association between reasoning and grip strength within old age be traced back to childhood? In the present study, childhood intelligence was associated with Raven score intercept, but there was no association between childhood intelligence and grip strength level. Therefore, in our narrow age cohort, although we did not find correlated slopes, we did find cognition-grip strength associations that were not merely due to trends based upon mean age effects (compare Hofer et al., 2003). The substantial correlation between intelligence at age 11 and Raven intercept in the ninth decade largely ruled out the possibility that the lack of an association between childhood intelligence and grip strength in old age might have been because the cognitive tasks in childhood and old age differed qualitatively. Moreover, we have shown elsewhere that there is strong continuity in the rank ordering of cognitive ability between age 11 and ages 79 and 87 (Deary et al., 2004; Gow et al., 2011).

Similar lack of significant association between childhood intelligence and grip strength at 53 years was reported in the National Survey of Health and Development (NSHD) in the United Kingdom (the British birth cohort born in 1946) (Kuh et al., 2009). However, some of the earlier NSHD studies did suggest some possible shared origins for the two variables. That is, they found significant positive contributions from timing of developmental milestones (age at standing and walking) to grip strength (Kuh et al., 2006) and to cognitive ability (Murray, Jones, Kuh, & Richards, 2007) in middle age. The relevance of this must be tempered by their finding only weak associations between grip strength and crystallized cognitive ability in middle age (Kuh et al., 2009), though they did not have a test of reasoning or a test of general fluid cognitive ability. Therefore, the causes of the significant association between reasoning and grip strength intercept might in part be sought in childhood influences, but this is not yet clear. Another testable source of the correlation between grip strength and reasoning in old age is shared genetic influence, because both show substantial heritability at that time (Finkel et al., 2003; Deary, Johnson, & Houlihan, 2009). In the Longitudinal Study of Aging Danish Twins, cognitive and self-reported physical functions (the latter was self-reported) had a genetic correlation of 0.56 (Johnson, Deary, McGue, & Christensen, 2009).

The present study had some strengths. There was a relatively large sample, especially for wave 1 at age 79. The method used included all available data, so even people who had dropped out after waves 1 and 2 contributed to the analyses. The very narrow age range of the sample was a particular strength because, otherwise, chronological age effects would be likely to have swamped other sources of variation (Hofer & Sliwinski, 2001). The three waves of testing across about eight years in the ninth decade made a useful addition to a rarely-studied, yet important, age group, about whom we shall need to know much more in an aging society (Fiocco & Yaffe, 2010).

The study also had limitations. In common with every other longitudinal study, there was selective attrition. When recruited at age 79 the sample was higher in cognitive ability and restricted in range with respect to the background population (Deary et al., 2004). Also, as may be seen from Table 1, attrition within old age was associated with lower Raven scores and grip strength at baseline, and was also affected by health. It is likely that this attrition resulted in some underestimation of the effect sizes in this study. However, we point out that the statistical modeling used all data, not just those data available from subjects who attended all waves of testing.

A specific limitation of the study’s analytical method was the limited power of single-indicator growth curve models to detect individual differences in change (Hertzog et al., 2008). This limited the model’s power to detect correlations in changes between slopes (Hertzog et al., 2006). It does not affect the power to measure other parameters in the model, but we cannot confidently conclude that Raven and grip strength slope are uncorrelated until the single-indicator limitation has been corrected. However, Hofer et al. (2003) also found no evidence for correlated slopes between cognitive function and grip strength despite multiple measures. Moreover, the amounts of variation in slopes across the eight-year period for the two outcome variables was not large, making a relatively small targets for which to find contributors. Possible remedies for this are to study samples for a longer time and to include people likely to incur a greater amount of decline in cognition and/or grip, though the potential problem with the latter strategy is the risk of including people with cognitive pathology who might be qualitatively different from the remainder of the healthily aging sample. It is also possible that the advanced age in this age-homogeneous sample has somewhat truncated the variance in slopes of cognition and grip strength.

The study has theoretical and practical relevance. Theoretically, it adds to our knowledge of the common cause theory of aging, with the finding that an association between reasoning and grip strength level does not mean that these factors are changing with age in concert (the slopes were not correlated; and the intercept of each did not affect the other’s slope), at least not from age 79 to age 87 in this sample at measurable levels. To the extent that an interpretation of the common cause hypothesis would predict this, our results do not support the hypothesis. With regard to ideas about cognitive reserve, and especially the specific notion within this hypothesis that prior intelligence might be protective against decline, we obtained a null result; there were various contributors to Raven mean intercept, but none to the slope—including from old-age-baseline or childhood intelligence—between 79 and 87 (Deary, Starr, & MacLennan, 1998; and see Gow et al., 2008 and Gow et al., 2011, in which two and three, respectively, waves of the LBC1921 data were modeled with respect to this question using other cognitive data). We have discussed this intercept-slope issue with respect to cognition in detail in these other publications, to which we refer interested readers.

In summary, at 79, 83 and 87, there was a persistent, similar and non-negligible association between grip strength and reasoning. The healthy body did tend to house a healthy mind, but their causal connections remain to be discovered.

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Table 1
Descriptive statistics for variables in the Lothian Birth Cohort 1921: Mean (*SD*; *N*) for continuous variables, and N (%[a]) for categorical variables. Variables in rows below 'Grip age 87' refer to those variables' values at age 79.

	Age 79 (Max. *N* = 550)	Age 83 Returnees (Max. *N* = 319)	Age 83 Non-returnees (Max. *N* = 231)	Age 87 Returnees (Max. *N* = 206)	Age 87 Non-returnees (Max. *N* = 344)
Raven age 79	31.2 (8.8; 543)	32.5 (8.4; 318)	29.3 (9.0; 225)	33.3 (8.3; 205)	29.8 (8.9; 338)
Raven age 83		29.7 (9.2; 318)		31.0 (8.3; 201)	27.5 (10.2; 114)
Raven age 87				27.8 (9.2; 201)	
Grip age 79	26.5 (9.1; 544)	27.4 (9.5; 319)	25.3 (8.4; 225)	28.0 (9.3; 206)	25.5 (8.9; 338)
Grip age 83		24.9 (9.1; 319)		25.8 (9.2; 204)	23.3 (8.9; 115)
Grip age 87				21.5 (8.7; 204)	
Sex					
Male	234 (42.5)	144 (45.1)	90 (39.0)	96 (46.6)	138 (40.1)
Female	316 (57.5)	175 (54.9)	141 (61.0)	110 (53.4)	206 (59.9)
Age at baseline	79.1 (0.58; 550)	79.0 (0.56; 319)	79.1 (0.60; 231)	79.0 (0.57; 206)	79.1 (0.58; 344)
Occupational Social class					
I	129 (23.5)	76 (23.8)	53 (22.9)	59 (28.6)	70 (20.3)
II	183 (33.3)	128 (40.1)	55 (23.8)	73 (35.4)	110 (32.0)
III	217 (39.5)	109 (34.2)	108 (46.8)	71 (34.5)	146 (42.4)

IV	12 (2.2)	3 (0.9)	9 (3.9)	1 (0.5)	11 (3.2)
V	7 (1.3)	3 (0.9)	4 (1.7)	2 (1.0)	5 (1.5)
Height	163.3 (9.3; 544)	163.9 (9.5; 319)	162.6 (9.0; 225)	164.1 (9.6; 206)	162.9 (9.1; 338)
Alcohol	5.7 (10.0; 550)	6.0 (10.0; 319)	5.2 (9.9; 231)	5.9 (9.3; 206)	5.5 (10.4; 344)
Smoking					
Yes	40 (7.3)	21 (6.6)	35 (15.2)	9 (4.4)	31 (9.0)
No	509 (92.5)	298 (93.4)	194 (84.0)	197 (95.6)	312 (90.7)
Moray House Test age 11 IQ	100 (15.0; 493)	101.0 (14.5; 292)	98.6 (15.6; 201)	102.1 (14.3; 183)	98.7 (15.3; 310)
HADS Depression	3.5 (2.3; 547)	3.4 (2.3; 318)	3.7 (2.4; 229)	3.2 (2.1; 205)	3.7 (2.4; 342)
Cardiovascular Disease					
Yes	88 (16.0)	53 (16.6)	35 (15.2)	31 (15.0)	57 (16.6)
No	456 (82.9)	262 (82.1)	194 (84.0)	171 (83.0)	285 (82.5)
High blood Pressure					
Yes	220 (40.0)	129 (40.4)	91 (39.4)	81 (39.3)	139 (40.4)
No	328 (59.6)	188 (58.9)	140 (60.6)	124 (60.2)	204 (59.3)
Diabetes					
Yes	28 (5.1)	12 (3.8)	16 (6.9)	6 (2.9)	22 (6.4)
No	522 (94.9)	307 (96.2)	215 (93.1)	200 (97.1)	322 (93.6)

[a] Because of occasional missing data, not all percentages sum to 100.

Table 2

Maximum likelihood estimated means and variances, and correlations among the measured variables.

	Raven 79	Raven 83	Raven 87	Grip 79	Grip 83	Grip 87	Height	Sex	Age 11 IQ	HADS Dep	SES	Alc	Smok	CVD	HBP	Mean (Variance)
Raven 79	-															-.013 (1.003)
Raven 83	.800	-														-.299 (1.155)
Raven 87	.762	.813	-													-.618 (1.271)
Grip 79	.236	.239	.229	-												-.006 (0.994)
Grip 83	.244	.275	.254	.880	-											-.267 (0.948)
Grip 87	.262	.251	.268	.845	.884	-										-.759 (0.869)
Height	.181	.213	.214	.188	.204	.169	-									-.004 (0.998)
Sex	-.136	-.122	-.081	-.767	-.709	-.687	.001	-								.582 (0.243)
Age 11 IQ	.462	.476	.392	.046	.059	.062	.145	.020	-							.028 (0.999)
HADS Dep	-.103	-.082	-.086	-.017	-.015	-.038	-.012	-.025	-.029	-						-.001 (0.985)
SES	-.299	-.285	-.168	-.128	-.119	-.139	-.139	.106	-.416	.076	-					.006 (1.001)
Alcohol	.035	.010	-.001	.148	.168	.093	.041	-.254	.037	-.009	-.152	-				-.016 (0.870)
Smoking	-.086	-.085	-.053	-.007	-.004	-.075	-.028	.029	-.030	.011	.093	.077	-			.073 (0.068)
CVD	.054	.052	.036	.087	.095	.130	.016	-.147	-.032	.076	.044	-.049	-.066	-		.161 (0.136)

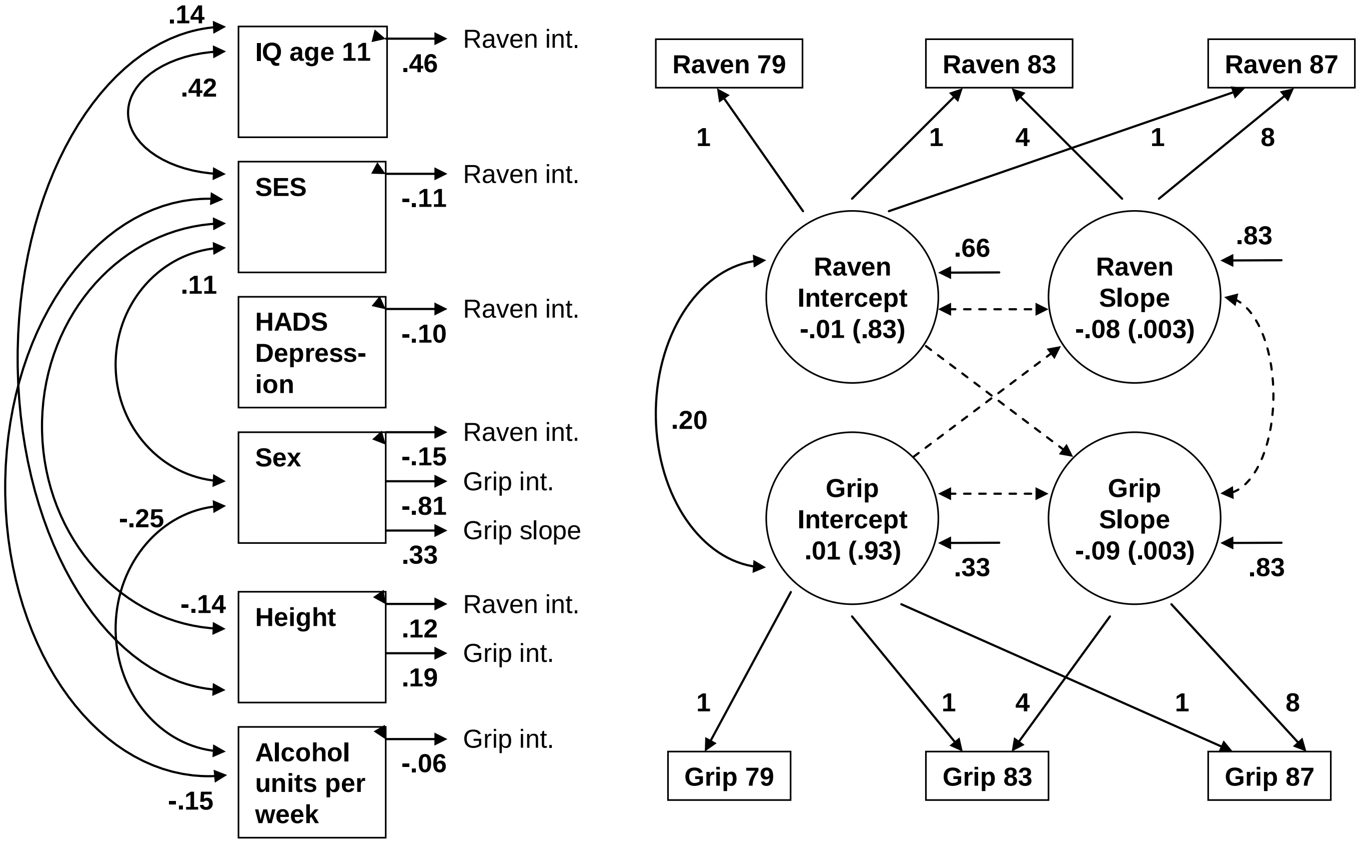
HBP	.038	.046	.028	-.048	-.079	-.108	-.040	.056	-.003	.003	-.003	-.056	-.066	-.030	-	.402 (0.240)
Diabetes	-.002	.067	.036	-.018	-.062	-.095	-.003	-.108	.005	.011	.011	-.029	-.065	.111	.064	.051 (0.048)

Note. Raven = Raven's Standard Progressive Matrices; Grip = Grip strength; 79, 83, 87 = mean age at testing in waves 1-3, respectively, of the Lothian Birth Cohort 1921; Age 11 IQ = result of Moray House Test in the Scottish Mental Survey 1932; HADS Dep = Hospital Anxiety and Depression Scale depression score; SES = occupation-based socio-economic status; Alcohol = mean number of units of alcohol consumed per week; Smoking = smoking status (current smoker or non-smoker); CVD = cardiovascular disease; HBP = hypertension. Correlations, means, and variances are estimated by maximum likelihood. Continuous variables were standardized. Height is adjusted for the effect of sex.

Figure legend

Bivariate growth curve (structural equation) model of the change in non-verbal reasoning (Raven) and grip strength across three waves of testing from age 79 to 87.

Note. Manifest (measured) variables appear as rectangles, latent traits as circles. Single-headed arrows indicate putative direction of influence. Double headed arrows indicate correlation. The principal outcome variables in the model are the intercepts and slopes of the Raven test and grip strength. Note that measured variables have fixed, unit-weighted contributions to intercepts. Note that the fixed contributions to slopes reflect the number of years since testing at age 79, and that the age 79 Raven and Grip measured variables make no contributions to their respective slopes (the path weights are fixed at zero). All numbers that have decimal points are standardized estimates of free parameters in the models. They may be treated like partial beta weights, and they may be squared to obtain the proportion of variance accounted for by adjacent variables in the model. The column of rectangles to the left are the covariates in the model, and the double-headed arrows that connect them are the significant correlations among them. Each of the covariates was examined for their contribution to Raven and grip strength intercept and slope, and only the significant ($P < .05$) contributions are shown. Non-significant associations among the latent traits are shown as dashed lines. Arrows pointing to the latent traits without origins represent the residual variation. Cardiovascular disease, hypertension and diabetes do not appear in the model as they made no significant contribution to the Raven of grip strength intercepts or slopes.


.14
IQ age 11
.46
Raven int.
.42
SES
-.11
Raven int.
.11
HADS Depress-ion
-.10
Raven int.
Sex
-.15
Raven int.
-.81
Grip int.
.33
Grip slope
-.25
-.14
Height
.12
Raven int.
.19
Grip int.
Alcohol units per week
-.06
Grip int.
-.15
Raven 79
Raven 83
Raven 87
1
1
4
1
8
Raven Intercept -.01 (.83)
.66
Raven Slope -.08 (.003)
.83
.20
Grip Intercept .01 (.93)
.33
Grip Slope -.09 (.003)
.83
1
1
4
1
8
Grip 79
Grip 83
Grip 87