
LIFE COURSE EPIDEMIOLOGY

Social origin, schooling and individual change in intelligence during childhood influence long-term mortality: a 68-year follow-up study

Anton CJ Lager,^{1,2*} Bitte E Modin,¹ Bianca L De Stavola³ and Denny H Vågerö¹

¹CHES, Centre for Health Equity Studies, Stockholm University/Karolinska Institutet, Stockholm, Sweden, ²Department of Public Health Sciences, Karolinska Institutet, Stockholm, Sweden and ³Department of Medical Statistics, London School of Hygiene and Tropical Medicine, London, UK

*Corresponding author. CHES, Centre for Health Equity Studies, Stockholm University, 106 91 Stockholm, Sweden.
E-mail: anton.lager@chess.su.se

Accepted 15 August 2011

Background Intelligence at a single time-point has been linked to health outcomes. An individual's IQ increases with longer schooling, but the validity of such increase is unclear. In this study, we assess the hypothesis that individual change in the performance on IQ tests between ages 10 and 20 years is associated with mortality later in life.

Methods The analyses are based on a cohort of Swedish boys born in 1928 ($n = 610$) for whom social background data were collected in 1937, IQ tests were carried out in 1938 and 1948 and own education and mortality were recorded up to 2006. Structural equation models were used to estimate the extent to which two latent intelligence scores, at ages 10 and 20 years, manifested by results on the IQ tests, are related to paternal and own education, and how all these variables are linked to all-cause mortality.

Results Intelligence at the age of 20 years was associated with lower mortality in adulthood, after controlling for intelligence at the age of 10 years. The increases in intelligence partly mediated the link between longer schooling and lower mortality. Social background differences in adult intelligence (and consequently in mortality) were partly explained by the tendency for sons of more educated fathers to receive longer schooling, even when initial intelligence levels had been accounted for.

Conclusions The results are consistent with a causal link from change in intelligence to mortality, and further, that schooling-induced changes in IQ scores are true and bring about lasting changes in intelligence. In addition, if both these interpretations are correct, social differences in access to longer schooling have consequences for social differences in both adult intelligence and adult health.

Keywords Intelligence, socioeconomic factors, public health, mortality, child, adolescent, child development, parents

Introduction

A rapidly growing literature shows strong associations between early cognitive ability and later health.¹⁻⁶ In this article, we test the hypothesis that individual 'change' in the performance on IQ tests between ages 10 and 20 years is associated with mortality later in life. We base this on the assumption that such changes, observed, for example, when children are exposed to longer schooling,⁷⁻¹⁰ are true and valid changes of underlying intelligence, rather than artefactual and/or transient changes. If correct, such a framework might help us to better understand the observed link between people's IQ and health outcomes,^{1-6,11,12} the validity of schooling-induced increases in individual IQ,⁷⁻¹⁰ and the causes of social stratification in intelligence¹³ and health.^{14,15}

An association between mortality rates and 'change' in IQ, rather than an IQ score at a single time-point, would support the idea that life can be prolonged through the promotion of cognitive ability, especially if this change is linked to the physical or social environment. One good candidate for such an environmental factor is regular schooling: a vast amount of literature suggests that an extra year in school increases an individual's IQ by approximately two points.^{9,10} Presumably, not all of this effect is causal. Social background might, for example, be a confounder and since initial intelligence is strongly related to educational attainment, there is also a risk of residual confounding by early abilities. Still, a number of studies based on a variety of natural experiments suggest that a true effect of schooling on IQ exists as well.⁹

However, whether or not a change in 'IQ scores' between two points in time reflects a real change in 'the underlying intelligence' or not can be questioned. Higher IQ after more intense schooling can be interpreted as merely artefactual, reflecting an improvement in the individual's ability to perform IQ tests and/or transient changes, rather than real improvements of the underlying intelligence.

Here, we approach these issues empirically. If changes in IQ are artefactual or transient, we would expect them to be unrelated to mortality rates, given a certain baseline IQ. However, if the changes are real, we could expect an association with mortality, given the ample new research linking a single measurement of IQ to later life health and mortality.¹⁻⁶ Further, if IQ changes are artefactual, we would expect any initial association between IQ change and mortality to be confounded by attained education, given that attained education has been shown to be related to both a decrease in mortality risk¹⁴ and an increase in IQ score.^{9,10} However, if the change in intelligence is real and at least partly driven by schooling, we would instead expect intelligence change to act as a mediator in the association between attained education and mortality. Finally, the social status of

the child's family may influence schooling, intelligence and mortality, and should therefore be accounted for.

In the Malmö Longitudinal Study (MLS), we have the opportunity to assess the effect of IQ change between ages 10 and 20 years on all-cause mortality across the life course (up to the age of 78 years), as well as the contribution to this association of accumulated number of years in school between ages 10 and 20 years, initial intelligence (at the age of 10 years) and social background (at the age of 9 years) measured by the father's attained education. The analyses are based on information about all boys who attended third grade in Malmö, Sweden, in 1938, for whom complete information on these variables exists. In the conceptual model underpinning our study, all factors are expected to predict those that follow in time (but not the preceding ones). This conceptual model is shown in [Figure 1](#).

Methods

The MLS cohort

The MLS recruited all third grade children (aged ~10 years) in the Swedish city of Malmö in early February 1938, when they were expected to undergo IQ testing ($n=1542$). In 1938, Sweden's GDP was comparable with those of today's mid-income countries and Malmö was an industrialized city of approximately 150 000 citizens. On the day of testing, ~90% of children were present.¹⁶ Information on fathers' education was collected beforehand from population, tax and school registers. Years of schooling before the age of 20 years was collected via a questionnaire and linkage to educational registers, and IQ at the age of 20 years from military conscript registers (see below). Due to the use of conscript data, the analyses are restricted to male MLS members ($n=834$). Of the 834 individuals, 610 (73%) had complete data on the variables used in these analyses. The main reason for exclusion from the main analyses was missing information on the results of the IQ tests at the age of 20 years.

Follow-up

Data on date of death were obtained via linkage to the Swedish Cause of Death Register, covering deaths until the end of 2006 when participants were ~78-years old. Among the 610 with complete data, 315 died during follow-up. Only three individuals were right-censored due to migration or loss to follow-up.

Explanatory variables

Four predictors were used in the analyses: intelligence scores at ages 10 and 20 years, years of schooling between these ages and paternal education.

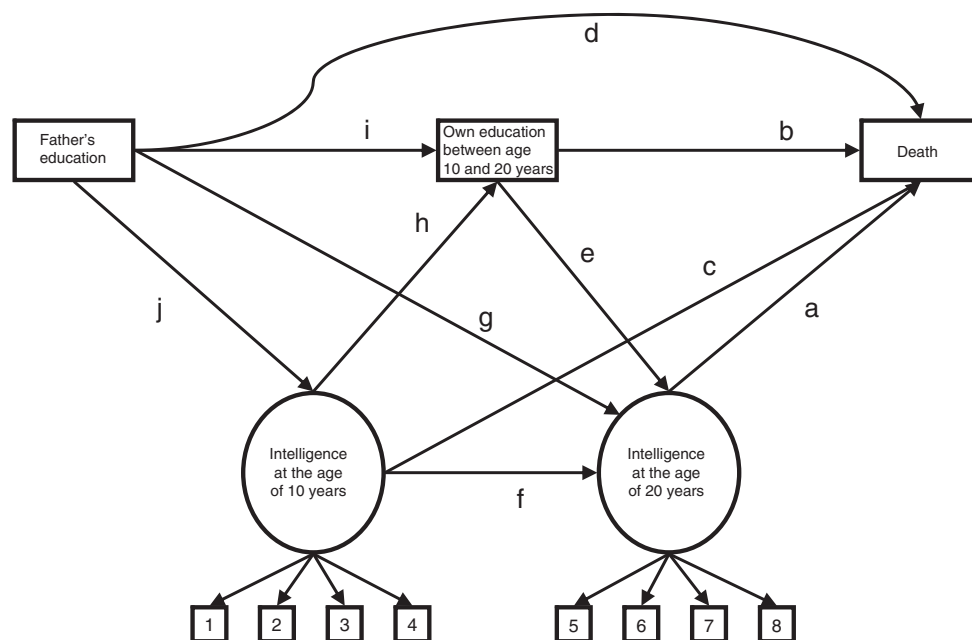


Figure 1 Theoretical associations (a–j) between fathers' education, sons' intelligence at the age of 10 years manifested by results on subtests 1–4, intelligence at age 20 manifested by subtests 5–8, sons' education between the ages 10 and 20 years and mortality until the age of 78 years

Intelligence tests at ages 10 and 20 years in the Malmö study

The MLS was initiated in the late 1930s by Siver Hallgren, a school teacher who was interested in the association between children's social environment, their general intelligence and schooling.¹⁷ Hallgren realized that testing all children individually was not feasible and since Alfred Binet had sparked the field of group intelligence testing, some 35 years earlier,¹⁸ there had been much development in this area. At least three group tests for children aged ~10 years existed in Sweden when Hallgren initiated his research, but after having reviewed the international theoretical and empirical literature on these tests, Hallgren judged them to be too unreliable.¹⁷

Therefore, Hallgren designed a new test, influenced by empirical findings by William Stern and others.^{19–21} He developed and piloted the test among 860 children in six cities surrounding Malmö in 1937 trying to ensure that: (i) items were not too influenced by learned information, (ii) the questions were neither too simple nor too difficult, (iii) the average scores did not improve with time, (iv) the level of reading and writing difficulty was suitable for the age and (v) the children enjoyed taking the test.¹⁷

The final test consisted of four subtests: antonyms (measuring the ability to bring up and use words in the vocabulary; 16 items with words familiar to a third-grader), missing words in a story (measuring the ability to put together parts to a meaningful whole; 16 items), a picture test (measuring the ability to differentiate among many stimuli and use the most important; 16 items comprising 8 pictures each, two

of which were identical) and rearranged sentences (measuring logical ability, as well as the ability to resist the suggestive form that characterized some of the rearranged sentences; 8 items with sentences that had their words in the wrong order, each sentence written on two lines to increase complexity). The children had 65 min to complete the test. For validation, a sample of the children also underwent an individual intelligence test.²²

The IQ test at the age of 20 years taken by male conscripts comprised four subtests as well: synonyms (40 items), concept discrimination (40 items), number series (40 items) and matrices (40 items).²³ The test was one of the first in a series of modern intelligence tests still used today in Swedish conscription.²⁴ A subsample of the boys ($n=99$) took a previous version of the military test. This test consisted of eight subtests.²⁴ These participants' subtest scores have been lost, but their standardized overall score (mean 100, standard deviation 15) is still available.

Education between ages 10 and 20 years

Four data sources were used to collect information on the participants' own educational attainment: central school registers with information about completion of elementary school and transfers to junior secondary school, a questionnaire mailed to the principals of the secondary schools, the national register of students at universities and equivalent institutions and, finally, a questionnaire mailed to the MLS participants themselves.²³ These were combined to construct a variable for education between ages 10 and 20 years that had

six levels: dropouts from elementary school 1 year in advance (corresponding to 3.5 years following the first IQ test, $n=51$), passed elementary school (4.5 years, $n=232$), vocational school attendants and dropouts from junior secondary school (6 years, $n=165$), completed junior secondary school (8 years, $n=72$), completed senior secondary school or its equivalent (10 years, $n=60$) and attended university (10.5 years, $n=30$); and was used in its metric form in the analyses.

Paternal education

In 1937, Hallgren collected data on social standing and occupation in registers from four different sources: the population/census office, the tax office, the parishes' civil registration offices (several registers) and the schools (which provided comprehensive class registers as well as a social register for those eligible for free material and support in each school). In our study, there were three major reasons to use paternal education over class or income as the indicator of social origin. First, education is known to be relatively strongly related to intelligence and thus, sharpens the assessment of our hypotheses. Secondly, it is relatively stable over the life course. Thirdly, education precedes occupation and income in time and is an important determinant of the latter two. The paternal education variable was constructed in the 1970s based on the register data and grouped into six categories:²⁵ basic (elementary school for 6 or 7 years, coded as 6.5 years, $n=140$), on-the-job training (coded as 7 years, $n=149$), apprenticeship (coded as 7.5 years, $n=234$), vocational school (coded as 8 years, $n=53$), junior secondary school (coded as 9.5 years, $n=22$) and senior secondary school or higher (coded as 13 years, $n=12$); and used as a metric variable in the analysis.

Statistical analyses

Structural equation models (SEMs) were used to estimate the joint distribution of the two latent intelligence scores measured by IQ testing at ages 10 and 20 years of own education, and time to death as functions of all temporally earlier variables including paternal education (Figure 1). Each of the two latent intelligence measures was identified via measurement models defined by their respective subtests. Equivalent models were also considered where the latent dimension 'intelligence at age 20' was replaced by 'change in (latent) intelligence between age 10 and 20'. Note, however, that the effect of 'intelligence at age 20' and of 'change between age 10 and 20' is exactly the same when conditional on 'intelligence at age 10', as shown by Lucas *et al.*²⁶ in the context of childhood growth data.

Years of education and latent intelligence scores were modelled assuming their distribution was normal, whereas time to death was modelled using Cox proportional hazard regression, with the proportional hazard

assumption checked via the Schoenfeld's test.²⁷ Maximum likelihood estimation with robust standard errors (MLR) was used, with the expectation maximization algorithm²⁸ to deal with missing data, assuming that missingness was random.²⁹ The Akaike information criteria³⁰ were used to compare alternative specifications of the model, as discussed below.

Results

The hypothesized model depicted in Figure 1 corresponds to an SEM with four dependent variables: intelligence at the age of 10 years, accumulated years of schooling between ages 10 and 20 years, intelligence at the age of 20 years, and (time to) death. In the more general specification of this SEM, each of these variables was expressed in terms of all their (temporally) earlier variables plus interactions. The best fitting model according to the Akaike Information criterion was the one with an interaction between years of schooling and intelligence change in relation to mortality and no direct link between paternal education and mortality. There was also no statistical evidence of a direct effect of intelligence at the age of 10 years, but this was kept in the model because of the interest in the change in intelligence. The final estimates are presented in Table 1.

The results suggest that change in intelligence was in itself important for later life mortality, even if this effect weakened with longer education as identified by the interaction term. For illustration of this interaction, we refitted the model without the interactions term but stratifying the analyses by two levels of own education: <6 years and ≥ 6 years. The effect of a (standardized) unit change in intelligence at the age of 20 years was then estimated to be -0.288 [95% confidence interval (CI) -0.654 to 0.032 ; $P=0.123$] in the first stratum and -0.155 (95% CI -0.560 to 0.249 ; $P=0.452$) in the second. As these are log hazard ratios, they imply that increased intelligence is associated with lower mortality rates, with the relative advantage being stronger among the less educated.

The association between own education and mortality was mediated by intelligence change, as there was a clear association between education and intelligence at the age of 20 years, as well as an association between intelligence at 20 years and death. In the analyses stratified for educational level (see above), the effect of a (standardized) unit in education was -0.046 (95% CI -0.207 to 0.115 ; $P=0.577$) in the first stratum and 0.017 (95% CI -0.215 to 0.249 ; $P=0.885$) in the second stratum. There was no clear suggestion of differential effects of education in different strata of intelligence at the age of 20 years.

There was no evidence of a direct path between paternal education and mortality once the mediating effects of the boys' own initial intelligence and length of education had been taken into account (and this direct path was in fact removed from the model). Further, higher paternal education was associated

Table 1 Final model; estimates, 95% CIs and *P* values

Parameter (letter in Figure 1)	Estimate (95% CI)	<i>P</i> value
Outcome: time to death ^a		
Intelligence at the age of 20 years (a)	−0.073 (−0.129 to −0.018)	0.009
Years of own education (b)	−0.163 (−0.328 to 0.003)	0.055
Interaction term between years of own education and intelligence at the age of 20 years (a*b, not in Figure 1)	0.006 (0.001 to 0.012)	0.030
Intelligence at the age of 10 years (c)	0.003 (−0.090 to 0.096)	0.946
Father's years of education (d) ^b	<i>n/a</i> ^b	<i>n/a</i> ^b
Outcome: intelligence at the age of 20 years		
Years of education between ages 10 and 20 years (e)	1.467 (1.126 to 1.809)	<0.0005
Intelligence at the age of 10 years (f)	1.761 (1.528 to 1.994)	<0.0005
Father's years of education (g)	0.355 (−0.052 to 0.763)	0.087
Outcome: years of own education		
Intelligence at the age of 10 years (h)	0.299 (0.248 to 0.350)	<0.0005
Father's years of education (i)	0.623 (0.491 to 0.755)	<0.0005
Outcome: intelligence at the age of 10 years		
Father's years of education (j)	0.667 (0.421 to 0.913)	<0.0005

^aNote that the reported parameters are log-standardized hazard ratios when the outcome is time to death, whereas they are regression parameters for the other outcomes.

^bNot applicable, the direct link between father's education and death was dropped from the model.

with the sons' educational duration both indirectly, via the sons' higher initial intelligence, and directly, by increasing the probability of longer studies even when differences in early intelligence were accounted for. Since the boys' education increased intelligence change, school in this way increased differences in adult intelligence. Since intelligence change was associated with mortality, extended schooling contributed to overall increased social differences in mortality—even if the interaction between education and intelligence change in relation to mortality described above somewhat counteracted this effect.

Robustness of the results

To assess whether the results were affected by selection bias, we refitted the final model (equivalent to Table 1) on all participants who had complete information on father's and own education ($n=742$) assuming missingness for the other variables was random. Earlier results were confirmed with one exception: there was no longer any clear support for an interaction between intelligence change and years of own education (0.003, 95% CI −0.002 to 0.009, $P=0.279$).

To assess whether the data were compatible with an alternative structural assumption, we considered a model where the direction of the association between 'years of own schooling' and 'change in intelligence' (the path 'e' in Figure 1) was reversed, capturing the possible effect that greater intelligence change leads to longer schooling. Naturally, this new model had the same goodness-of-fit as our original final model,

because all other links were kept as before. This model produced a clear association between intelligence at the age of 20 years and education (0.185, 95% CI 0.136–0.234; $P<0.0005$) and one other estimated coefficient changes interpretation: the link between intelligence at the age of 10 years and education becomes reversed (−0.109, 95% CI −0.232 to 0.014; $P=0.081$).

Discussion

In this study, intelligence at the age of 20 years was found to be important for survival even after controlling for own education and intelligence at 10 years. The finding is in line with results from a previous study showing associations between cognitive decline in middle-aged and older individuals and mortality,³¹ but is to our knowledge, the first focused on intelligence changes in early ages.

One possible concern with this finding is that the observed associations could have arisen if the test at the age of 20 years was simply a better measure of 'stable' intelligence than the test at the age of 10 years or, alternatively, if change in intelligence arose for reasons other than schooling, whereas at the same time, change in intelligence directly affected the duration of schooling. These are valid concerns since we are not presenting an experiment where the educational exposure was manipulated by us—even if results from ample research, including natural experiments in this area have been reported previously.^{7–10} To address this concern, we fitted an alternative

model to our data where intelligence at the age of 20 years was allowed to predict the amount of schooling (i.e. reversing the direction of the link 'e' in our original conceptual model). In this way, we allowed something measured later in time to predict something occurring earlier, and the interpretation of the link between initial intelligence and education changed (it was reversed). Still, our data are not sufficient to completely separate the two pathways—and most likely there are effects in both directions.

A second finding was that the schooling–mortality association was partly accounted for by the changes in intelligence. This is consistent with the interpretation that schooling has the strongest effect on mortality when it succeeds in increasing intelligence, or at the very least, that repeated intelligence tests are crucial for future investigations of educational differences in health.

Thirdly, our results showed that social origin, here measured by fathers' education, was linked to mortality, primarily through the association with the sons' initial intelligence and duration of schooling. Highly educated fathers tended to have brighter children, who therefore studied longer—and at the same time, children of more highly educated fathers studied longer irrespective of their initial intelligence. This is similar to what sociologists call the primary and secondary effect of parental education. Interestingly, if our conceptual model is correct, these effects increased social inequality in both adult intelligence and mortality, given the effect of education on the two latter.

This study is of relatively small size and it has local rather than national representativeness. However, it does provide an unselected sample of all boys in the third grade of one of the major cities in Sweden. The proportion of boys with missing data at the age of 20 years is substantial (27%), but not extreme for a study with a 10-year interval between the data collections. The proportion censored due to emigration or loss to follow-up thereafter is practically non-existent (three individuals), thanks to the quality of Swedish population registers. For the purpose of generalizability, the main limitation of this study is the absence of women, since some evidence suggests that the role of intelligence, as measured by IQ tests, is different for men and women.²

In summary, this study tries to link two separate research fields: one repeatedly showing that IQ is increased by schooling,^{9,10} and another linking IQ to health and mortality¹ but where the causal ordering of IQ and health is in question. Our findings are consistent with the interpretation that there is a causal link from intelligence to mortality. In addition, they are consistent with the idea that schooling-induced changes in IQ scores are real changes of underlying intelligence. If both these interpretations are correct, we should expect the social gradient in access to longer education to reproduce the association between social background and intelligence, as well as that between social background and mortality in each new generation. Additional to these processes, family influences before school starts, e.g. via parenting style,³² may have similar consequences. It is possible that efforts to promote intelligence via schooling may prove to be as important for public health, and contribute to elucidating the understanding of the role of intelligence, just as much as the genetic and brain imaging studies presently dominating the intelligence discussion.³³

Funding

Swedish National Institute of Public Health, Östersund, Sweden (to A.L.). Swedish Council for Working Life and Social Research (FAS 2005-1733 to CHESS, FAS 2006-1637 to B.M., FAS 2006-1276 to B.D.S. and FAS 2005-1723 to D.V).

Acknowledgements

The funding agencies had no role in design or conduct of the study; collection, management, analysis or interpretation of the data; preparation, review or approval of the article. A.L. had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis. This article was based on ideas by A.L., B.M. and D.V. The data analyses were conducted by A.L. with contributions from B.M. and B.D.S. All versions of the article were drafted by A.L. and critically revised by B.M., B.D.S. and D.V.

Conflict of interest: None declared.

KEY MESSAGES

- We assessed the hypothesis that individual change in intelligence between ages 10 and 20 years is related to mortality later in life, based on data from a cohort of Swedish boys born in 1928.
- The results suggested that increases in intelligence between ages 10 and 20 years, partly predicted by amount of schooling received, was associated with lower mortality in adulthood independently of intelligence at the age of 10 years.
- Adult differences in intelligence (and consequently in mortality) were partly explained by the tendency for sons of more educated fathers to receive longer schooling, irrespective of their initial intelligence level.

References

- ¹ Batty GD, Deary IJ, Gottfredson LS. Premorbid (early life) IQ and later mortality risk: systematic review. *Ann Epidemiol* 2007;**17**:278–88.
- ² Lager A, Bremberg S, Vågerö D. The association of early IQ and education with mortality: 65 year longitudinal study in Malmö, Sweden. *BMJ* 2009;**339**:b5282.
- ³ Batty GD, Mortensen LH, Gale CR, Shipley MJ, Roberts BA, Deary IJ. IQ in late adolescence/early adulthood, risk factors in middle age, and later cancer mortality in men: the Vietnam Experience Study. *Psychosomatics* 2009;**18**:1122–26.
- ⁴ Moran P, Klinteberg BA, Batty GD, Vågerö D. Brief report: childhood intelligence predicts hospitalization with personality disorder in adulthood: evidence from a population-based study in Sweden. *J Personal Disord* 2009;**23**:535–40.
- ⁵ Koenen KC, Moffitt TE, Roberts AL *et al.* Childhood IQ and adult mental disorders: a test of the cognitive reserve hypothesis. *Am J Psychiatry* 2009;**166**:50–57.
- ⁶ Der G, Batty GD, Deary IJ. The association between IQ in adolescence and a range of health outcomes at 40 in the 1979 US National Longitudinal Study of Youth. *Intelligence* 2009;**37**:573–80.
- ⁷ Cliffordson C, Gustafsson J-E. Effects of age and schooling on intellectual performance: Estimates obtained from analysis of continuous variation in age and length of schooling. *Intelligence* 2008;**36**:143–52.
- ⁸ Husén T. The influence of schooling upon IQ. *Theoria* 1951;**17**:61–88.
- ⁹ Ceci SJ. How much does schooling influence general intelligence and its cognitive components? A reassessment of the evidence. *Dev Psychol* 1991;**27**:703–22.
- ¹⁰ Gustafsson J. Schooling and intelligence: Effects of track of study on level and profile of cognitive abilities. *Int Edu J* 2001;**2**:166.
- ¹¹ Batty GD, Kivimäki M, Deary IJ. Intelligence, education, and mortality. *BMJ* 2010;**340**:c563.
- ¹² Lager A, Bremberg S, Vågerö D. Intelligence and mortality. Only ignorance stops progress. *BMJ* 2010;**340**:c2765.
- ¹³ Neisser U, Boodoo G, Thomas J *et al.* Intelligence: knowns and unknowns. *Am Psychol* 1996;**51**:77–101.
- ¹⁴ Mackenbach JP, Stirbu I, Roskam AJ *et al.* Socioeconomic inequalities in health in 22 European countries. *N Engl J Med* 2008;**358**:2468–81.
- ¹⁵ Geyer S, Hemstrom O, Peter R, Vågerö D. Education, income, and occupational class cannot be used interchangeably in social epidemiology. Empirical evidence against a common practice. *J Epidemiol Community Health* 2006;**60**:804–10.
- ¹⁶ Husén T. *Testresultatens prognosvärde [Prognostic value of the test results]* (Swedish). Stockholm: Geber, 1950.
- ¹⁷ Hallgren S. *Intelligens och miljö samt en del därmed sammanhängande problem: En experimentell undersökning av barn i tredje skolåret vid Malmö folkskolor och privata skolor, I-II [Intelligence, environment and related Problems]* (in Swedish) [unpublished licentiate thesis]. Malmö, 1939.
- ¹⁸ Binet A, Simon TA. Méthode nouvelle pour le diagnostic du niveau intellectuel des anormaux [New method for the diagnosis of the intellectual level of subnormals] (French). *L'Année Psychologique* 1905;**11**:191–244.
- ¹⁹ Stern LW. *Die Intelligenz der Kinder und Jugendlichen und Methoden ihrer Untersuchung [The intelligence of children and adolescents, and methods of its investigation]* (German). Leipzig: Barth, 1920.
- ²⁰ Lämmermann H. Bericht über die Eichung einer Serie von Gruppentests für Acht- bis Vierzehnjährige Volksschüler [Report about the gauging of a series of group tests for eight- to fourteen-year-old elementary school students] (German). *Zeitschrift für angewandte Psychologie* 1926;**27**:1–47.
- ²¹ Koskeniemi M, Grenquist P. Kokeita suomalaisilla joukkotesteillä I; [Experiment with Group Tests I] (in Finnish). *Kasvatus ja Koulu* 1934.
- ²² Anderberg R. *Experimentell intelligensundersökning [Experimental intelligence testing]* (Swedish). 3rd edn. Uppsala: Lindblad, 1944.
- ²³ Husén T, Emanuelsson I. *Talent, opportunity and career: A twenty-six year follow-up of 1500 individuals*. Stockholm: Almqvist and Wiksell, 1969.
- ²⁴ Carlstedt B. *Cognitive abilities – aspects of structure, process and measurement*. Göteborg: Acta Universitatis Gothoburgensis, 2000.
- ²⁵ Fägerlind I. *Formal education and adult earnings: A longitudinal study on the economic benefits of education*. Stockholm: Almqvist and Wiksell International, 1975.
- ²⁶ Lucas A, Fewtrell MS, Cole TJ. Fetal origins of adult disease – the hypothesis revisited. *BMJ* 1999;**319**:245–49.
- ²⁷ Ng'andu NH. An empirical comparison of statistical tests for assessing the proportional hazards assumption of Cox's model. *Stat Med* 1997;**16**:611–26.
- ²⁸ Dempster AP, Laird NM, Rubin DB. Maximum likelihood from incomplete data via EM algorithm. *J R Stat Soc Ser B* 1977;**39**:1–38.
- ²⁹ Little RJA, Rubin DB. The analysis of social-science data with missing values. *Sociol Methods Res* 1989;**18**:292–326.
- ³⁰ Akaike H. New look at statistical-model identification. *IEEE Trans Autom Control* 1974;**19**:716–23.
- ³¹ Shipley BA, Der G, Taylor MD, Deary IJ. Association between mortality and cognitive change over 7 years in a large representative sample of UK residents. *Psychosom Med* 2007;**69**:640–50.
- ³² Guo G, Harris KM. The mechanisms mediating the effects of poverty on children's intellectual development. *Demography* 2000;**37**:431–47.
- ³³ Deary IJ, Penke L, Johnson W. The neuroscience of human intelligence differences. *Nat Rev Neurosci* 2010;**11**:201–11.