# Chapter 7

## Review of the evidence: intelligence

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## Background

7.1 The first tests that aimed to measure intelligence were developed at the start of the twentieth century. The Simon–Binet test was commissioned by the French government to identify children who would not benefit from ordinary schooling because of low intelligence. It was subsequently adapted by researchers in the US to measure average and above-average intelligence as well. Other tests have been developed in different contexts than education, for example in military recruitment. The use of such tests has often aroused controversy and criticism, particularly when combined with claims about the biological basis of variation in test scores. There have been several prominent examples of claims that differences in IQ between racial groups are due to genetic factors rather than social or environmental ones and, further, that this ought to inform social policy. While it is often claimed that on average, black individuals score slightly lower on IQ tests than white individuals, who in turn score lower than people from East Asia, there are also studies which show that, if black individuals and white individuals are closely matched on socioeconomic status, the differences in IQ are substantially reduced.[2] The potential abuse of information about genetic influences on behaviour is discussed further in Chapters 13-15. Here, it suffices to observe that research into genetic influences on intelligence has been associated, historically, with significant concerns about misuse of the information and unfair discrimination.

## Trait definition and measurement

7.2 Psychologists measure intelligence using a range of tests called IQ (Intelligence Quotient) tests. However, there is considerable disagreement about whether these tests do in fact measure intelligence, and even whether intelligence can be measured by a test at all. Many critics have suggested that intelligence is too complex to be measured by such tests:

> 'IQ psychologists … like to think that intelligence can be measured as if it were … a simple scalar quantity … Unfortunately for IQ psychologists this is not so … Intelligence … is a complicated and many-sided business. Among its elements are speed and span of *grasp*, the ability to see implications and conversely to discern a *non sequitur* and other fallacies, to discern analogies and formal parallels between outwardly dissimilar phenomena or thought structures, and much else besides. One number will not do for all these.'[3]

7.3 However, IQ tests come in a variety of forms. Some require an individual to engage in reasoning in order to solve novel problems, which may be presented in verbal, numerical or diagrammatical form. Others test general knowledge or the extent of an individual's

[1] The material in this chapter is taken from a paper commissioned by the Nuffield Council on Bioethics from Professor N. J. Mackintosh, Department of Experimental Psychology, University of Cambridge. The paper is available on the Council's website: www.nuffieldbioethics.org.

[2] See, for example, Nichols, P. L. & Anderson, V. E. (1973). Intellectual performance, race and socioeconomic status. *Soc. Biol*. **20**, 367–74. The authors conclude that 'socioeconomic differences are largely responsible for the usually reported differences in intellectual performance'.

[3] Medawar, P. (1982). *Pluto's Republic*. Oxford: Oxford University Press. Another common criticism of IQ tests arises from the 'Flynn effect', first noted by Professor James Flynn in 1987 (*Psychol. Bull*. **101**, 171) that the average IQ of individuals has been rising steadily since the measurement was first introduced. In January 2002 he reported that the Flynn Effect is particularly great in Britain, which has seen a 27 point increase in average IQ since World War II, compared to a 24 point rise in the US.

vocabulary. Yet others measure how quickly an individual can solve a series of very simple problems, as well as whether he or she is capable of solving seriously difficult problems regardless of time pressure. The very diversity of questions asked in the various IQ tests makes it hard to accept that *none* of them succeeds in measuring any aspect of intelligence. But the important observation is that scores on all these different kinds of test are positively correlated. In general, people who score highly on tests of general knowledge or vocabulary will also tend to obtain high scores on tests of abstract reasoning or numerical series-completion tasks. Similarly, those who are poor at memorising a series of rapidly presented numbers will also be poor at seeing whether two three-dimensional diagrams are really views of the same object viewed from different angles and slow to delete all the 'X's in a list of random letters of the alphabet.

7.4 There are two implications of this observation. One, first noted by Spearman[4] but now accepted by most testers of IQ, is that the statistical technique of factor analysis,[5] when applied to people's scores on a variety of IQ tests, will always yield a substantial general factor, which accounts for much of the variation in their scores.[6] Spearman labelled this factor '*g*', for general intelligence, and argued that the reason why different IQ tests correlate with one another is because they all measure, to a greater or lesser extent, a single underlying psychological or even neurological, process. The second implication is that if IQ tests fail completely to measure intelligence, it should be possible to produce a different test, or set of tests, that does measure intelligence, but does not correlate with existing IQ tests. Given the diversity of existing tests that do correlate with one another, the challenge is not a trivial one, and has not yet been met.

7.5 If performance on every kind of IQ test correlates with performance on every other kind of test, it clearly follows that the score a person obtains on one test will be similar, but not identical, to the score they obtain on another. Correlations between different kinds of test range from about 0.35 to about 0.85. It must equally follow, therefore, that a single, short test will not tell us all that we might want to know about a person's IQ.

7.6 Different types of IQ test may all be partly measuring a factor of general intelligence. But they are also measuring partially distinct cognitive abilities. Factor analysis of scores on a large range of tests invariably reveals not only a general factor, but also a number of more specific 'group factors', caused by the fact that clusters of sub-tests show high correlations within the cluster, but lower correlations with sub-tests in other clusters. The general consensus is that one can distinguish between at least the following kinds of test:

- measures of abstract reasoning or 'fluid' intelligence (Gf)
- vocabulary and general knowledge, or 'crystallised intelligence' (Gc)

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4 Spearman, C. (1927). *The Abilities of Man*. London: Macmillan.

5 Factor analysis refers to a group of statistical procedures, based on correlation, which attempt to reduce a large amount of data to the smallest number of factors which can adequately account for the variance between individuals on the measures in question. Factor analysis is an important tool for areas of behavioural genetics where the underlying components are difficult to discern (e.g. personality assessment). Strictly speaking, factors are not traits as they merely represent regularity in the available data. The establishment of a valid trait from factor analysis requires additional inferences to be made.

6 See paragraphs 4.5 - 4.8 for a definition of heritability. Carroll, J. B. (1993). *Human Cognitive Abilities*. Cambridge: Cambridge University Press; Gould, S. J. (1996). *The Mismeasure of Man*. New York: Norton.

- visuo-spatial ability (Gv)
- retrieval or memory (Gr)
- speed of processing (Gs).

7.7 It has been argued that there are important aspects of human intelligence that IQ tests fail to measure, such as creativity, practical intelligence, social intelligence and emotional intelligence. Some of these constructs are more securely grounded than others, and not all of them are wholly independent of IQ. However, those who support IQ tests require only that their tests should measure some reasonably important aspects of intelligence. They can readily allow that their tests leave some aspects unmeasured.

7.8 The claim of those who support IQ tests must be, however, that the tests do measure some important aspects of intelligence. They have attempted to prove this by showing that people's IQ scores are correlated with, or predict, many other things about them: how well they are now doing and will do later at school, how long they will stay in full-time education, the kind of job they will obtain and how well they will perform that job. Schoolchildren's IQ scores correlate in the range 0.50 to 0.70 with their current and subsequent educational attainment: for example, the correlation between 11-year-olds' IQ scores and their GCSE grades at age 16 is over 0.50.[7] Studies in the US have shown that the correlation between children's IQ scores and their occupational status as adults is also about 0.50. Moreover, these correlations cannot simply be attributed to the pervasive influence of family background. Although there is a correlation of around 0.30 between IQ scores and socioeconomic status, Herrnstein and Murray showed that children's IQ scores were substantially more powerful predictors of their subsequent educational and occupational attainments than was their family background.[8] Their analyses have been vehemently criticised, and some of these criticisms require some qualification of their arguments.[9] But their central conclusion stands: IQ scores do predict, independent of family background, significant things about people's lives. The prediction is far from perfect: even correlations of 0.50 leave much unexplained. Moreover, many of these correlations, for example, between IQ and measures of actual performance of a job are usually substantially lower than this. This is hardly surprising. No one could sensibly doubt that success, whether at school or in the adult world, depends on many other things besides intelligence, including hard work, ambition, social skills and plain luck. But IQ is also a significant factor.

## Current findings: quantitative genetics

7.9 Both testers of IQ and researchers in behavioural genetics agree that the heritability of IQ is relatively high.[10] That there is a genetic influence on IQ is suggested by two findings:

(i) Monozygotic (MZ) twins resemble one another more closely than dizygotic (DZ) twins or siblings, and full siblings resemble one another more closely than half siblings.

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[7] Brody, N. (1992). *Intelligence*. New York: Academic Press; Jensen, A. R. (1998). *The g Factor*. Westport, CT: Praeger.

[8] Herrnstein, R. J. & Murray, C. (1994). *The Bell Curve*. New York: Free Press.

[9] Devlin, B. *et al*., editors. (1997). *Intelligence, Genes and Success*. New York: Springer-Verlag.

[10] See the following for summaries of research in this field: Devlin, B., Daniels, M. & Roeder, K. (1997). The heritability of IQ. *Nature* **388**, 468–71; Plomin, R., DeFries, J. C., McClearn, G. E. & McGuffin, P. (2000). *Behavioral Genetics*. 4th ed. New York: Worth; Sternberg, R. J., editor. (2000). *Handbook of Intelligence*. Cambridge: Cambridge University Press; Chipuer, H. M., RoVine, M. & Plomin, R. (1990). LISREL modeling: Genetic and environmental influences on IQ revisited. *Intelligence* **14**, 11–29.

(ii) Individuals who are genetically-related continue to resemble one another even when living apart.

Two other observations suggest that environmental factors have an effect:

(i) For all kinship categories, those living together resemble one another more closely than those living apart.

(ii) Unrelated people living together, adoptive parents and their adopted children or two adopted children living in the same family, show a modest correlation in IQ.

The data suggest, therefore, that both genetic and environmental sources of variation contribute to variations in IQ. This may not seem a startling conclusion, but it is still disputed by some critics, including those who question the validity of estimates of heritability and the methodologies of quantitative genetics.[11]

7.10 Adoption studies have also provided evidence for genetic influences on IQ. Children given up for adoption before the age of 6 months continue to resemble their biological mother in IQ. Critics have appealed to 'selective placement' to explain this, arguing that such children live in adoptive homes carefully selected by adoption agencies to match their biological parents' circumstances. If this were a sufficient explanation, it would follow that the resemblance between adopted children and their adoptive parents in IQ should be *at least* as high as that between these children and their biological parents. However, research suggests that this is not true, and in two recent American studies, the correlation with the biological parents has been considerably higher than with the adoptive parents.[12]

7.11 DZ twins resemble one another in IQ somewhat more than other siblings. An obvious explanation is that, being the same age, they spend more time together and share more experiences than siblings of different ages. In one small study, separated DZ twins were found to resemble one another more closely than separated siblings. This suggests that the shared prenatal environment may also be important.[13] An alternative explanation is that some children classified as full siblings may in fact have different biological fathers. Both blood group and DNA tests suggest that not all putative fathers are the actual biological fathers of their children.

7.12 The evidence from research in quantitative genetics strongly suggests that a significant part of the observed variation in IQ is genetic in origin: the heritability of IQ is substantially greater than zero. How much greater? A sufficiently accurate answer is that in modern Western societies it is probably about 0.50, with a range of possible values from, say, 0.35 to 0.75. For some time, this has been the consensus of virtually all researchers in behavioural genetics.[14] However, this finding does not provide any information about

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11 See Chapter 4 (paragraphs 4.7-4.8). How, M. J. A. (1997). *IQ in Question*. London: Sage; Wahlsten, D. & Gottlieb, G. The invalid separation of effects of nature and nurture: Lessons from animal experimentation. In Sternberg, R. J. & Grigorenko, E. L., editors. (1997). *Intelligence, Heredity and Environment*. Cambridge: Cambridge University Press. pp. 163–92.

12 Loehlin, J. C. *et al*. Heredity, environment, and IQ in the Texas Adoption Project. In Sternberg, R. J. & Grigorenko, E. L., editors. (1997). *Intelligence, Heredity and Environment*. Cambridge: Cambridge University Press. pp. 163–92; Plomin, R., Fulker, D. W., Corley, R. & DeFries, J. C. (1997). Nature, nurture, and cognitive development from 1 to 6 years: A parent–offspring adoption study. *Psychol Sci* **8**, 442–7.

13 Devlin, B., Daniels, M. & Roeder, K. (1997). The heritability of IQ. *Nature* **388**, 468–71

14 Plomin, R., DeFries, J. C., McClearn, G. E. & McGuffin, P. (2000). *Behavioral Genetics*. 4th ed. New York: Worth.

which genes influence intelligence, how many genes might be involved, or how the genes have their effect.

7.13 Interestingly, there is some evidence that the heritability of IQ increases with age. Although it might seem more plausible to suppose that an infant's or young child's intelligence is affected by their genetic make-up, and that the cumulative effect of environmental experience should become more important as children grow older, it is possible that some of the genes associated with variations in IQ are not 'switched on' until adolescence. Another possibility is that the genetic effects on IQ are mediated by the environment as we develop, in other words, that we actively select environments that complement our genotypes, and that the environment responds to us differently depending on our genotypes. If this is true, it could mean that the effects of our genes are reinforced over time and thus appear to be more important as we get older.

## Current findings: molecular genetics

7.14 Some progress has been made in identifying genes linked to instances of mental retardation. One example is Fragile X syndrome, a disease caused by a small section of base pairs on the X chromosome being repeated too many times. However, as one commentator has noted: 'Not a single gene involved in the development of mental retardation has been shown to be associated with normal variation in IQ'.[15] This is consistent with the general belief that mild 'familial' retardation is the lower end of normal variation in IQ, but serious retardation is usually due to quite specific, relatively rare causes – whether genetic or environmental in origin.

7.15 If this is true, it will be necessary to search specifically for individual genes associated with normal variation in IQ. The behavioural geneticist Robert Plomin and his colleagues have been engaged in just such a search for the past ten years. The difficulties should not be underestimated. Normal variations in IQ are expected to be influenced by the combined action of a number of genes, rather than by any one 'major' gene.[16] As we have already noted, although factor analysis yields a general factor *g*, IQ is not a unitary construct, and must therefore be influenced by many different genes. Suppose, for the sake of argument, that the heritability of IQ is 0.50 in today's Western populations. This means that half the observed phenotypic variation in IQ can be ascribed to genetic differences between members of those populations. Suppose also that there are 25 genes associated with this variation in IQ, and that each has an equal, additive effect. Then each will be associated with 2% of the observed variation in IQ. That is a small effect, not easily distinguished from chance fluctuation.

7.16 The history of the search for genes that influence such characteristics as schizophrenia or manic depression provides ample warning of some likely problems. It is all too easy to find some genetic differences between two groups of people selected for their difference in some phenotypic trait. Chance alone is almost bound to produce some small differences. They are not worthy of serious consideration unless replicated in further independent samples. With some false starts, Plomin's group does appear to have

[15] Grigorenko, E. Heritability and intelligence. In Sternberg, R. J., editor. (2000). *Handbook of Intelligence*. Cambridge: Cambridge University Press.

[16] Weiss, V. (1992). Major genes of general intelligence. *Pers. Individ. Dif*. **13**, 1115–34, has argued for a 'major gene' account of variation in IQ, but does not suppose that only one gene is involved.

satisfied this minimum requirement. One study compared two groups of about 50 children, between 6 and 15 years old, one of average IQ (a mean of 103), a second of high IQ (a mean of 136).[17] A systematic search of the long arm of chromosome 6 found a significant difference between them in the frequency of different alleles of the IGF2R gene.[18] This difference was replicated in a second sample of 12-year-old children, 50 with an average IQ (a mean of 101) and another 50 with an estimated IQ of at least 160. The probability of the difference arising by chance in both groups was less than 1 in 1,000. The same four groups of children were also used in a second study that employed a different technique (DNA pooling across participants) to perform a systematic search of chromosome 4.[19] Eleven differences were found between the initial pair of high and average groups, and three of these were confirmed in the second pair of groups. A more recent and perhaps more stringent study, however, has been less successful. The initial pair of high and average IQ groups was formed by combining the two pairs of groups from the earlier studies. A large number of differences in the frequency distribution of microsatellite alleles were found between these two groups (each comprising 101 individuals). However, very few of these differences were replicated in a second pair of groups, and none in a third sample.[20]

7.17 At present, the most one can say is that some differences in the frequencies of particular alleles at particular loci have been found between high and average IQ groups, and that some of these differences have been replicated in new samples. It will be important to see if independent groups of researchers, studying quite different populations (all the participants in these studies were white, non-Hispanic Americans, most of them living in the Midwest), can replicate these differences. It is, moreover, important to note that the effects observed, even if statistically significant, are very small. The critical allele 5 was found in less than half of the high-IQ children in the initial study, and in nearly one quarter of the average IQ group. As the authors properly acknowledge: 'IGF2R is not *the gene* for *g* but may be one of many genes responsible for the high IQ heritability of *g*.'

7.18 Finding genes associated with variations in IQ is not really surprising. If the heritability of IQ is approximately 0.50, there must be such genes. The importance of the research is that it may make it possible to work out *how* genetic differences lead to differences in IQ. That endeavour has barely started. IGF2R is an insulin growth factor gene. There is some, rather contentious, evidence implicating defective glucose metabolism in Alzheimer's disease, and some equally contentious animal studies have suggested that insulin may be involved in learning and memory.[21] However, this is a great distance from ascertaining the way in which variation in the IGF2R gene influences variation in IQ.

7.19 It is extremely unlikely that researchers will find one or two genes that have a sizeable impact on variation in IQ within the normal range. The discovery of genes with small effects will be very much harder than the discovery of mutations associated with serious mental

17 Chorney, M. J. *et al.* (1998). A qualitative trait locus associated with cognitive ability in children. *Psychol. Sci.* **9**, 159–66.

18 IGF2R (insulin-like growth factor II receptor).

19 Fisher, P. J. *et al.* (1999). DNA pooling identifies QTLs on chromosome 4 for general cognitive ability in children. *Hum. Mol. Genet.* **8**, 915–22.

20 Plomin, R. *et al.* (2001). A genome-wide scan of 1842 DNA markers for allelic associations with general cognitive ability: a five-stage design using DNA pooling and extreme selected groups. *Behav. Genet.* **31**, 497–509.

21 Wickelgren, I. (1998). Tracking insulin to the mind. *Science* **280**, 517–19.

retardation. It may also be very much more difficult to uncover their mode of action. It seems reasonable to suggest that there may be some readily detectable differences between the brains of those with an IQ below 50 and those with an IQ of 100 or more. Indeed, some such differences have already been observed. It seems rather less likely that a gene associated with a 1% to 2% variation in IQ in the normal range will have such easily discernible effects on brain function. Indeed, the search for correlations between any measure of the brain and variations in IQ in the normal range has been long and remarkably unproductive.

7.20 The only *securely* replicated correlation is that between IQ and the overall volume of the brain – where the correlation is about 0.40.[22] But we do not know whether that effect is genetic: improved nutrition and a more stimulating environment will both cause a significant increase in the volume of rats' brains and improve their learning ability, and it is entirely possible that these and other environmental variables have a similar impact on the human brain.[23] One recent study assessed the heritability of brain structure rather than cognitive ability.[24] The researchers compared the density of grey matter (brain cell bodies) at specific regions in the brains of twins and other individuals. Their findings suggest that grey matter density is much more clearly correlated with intelligence at some cortical sites than at others. This area of genetic research requires considerably more detailed studies before firm conclusions can be drawn.

7.21 The search for genes associated with variation in IQ will be made more difficult, to the extent that genetic effects on IQ are not additive. We used earlier the illustrative possibility that IQ was affected by 25 genes, each with an equal, additive effect (paragraph 7.15). But some genetic effects, dominance and epistasis, are not additive. A recessive allele at a particular locus will have one effect on the phenotype if it is accompanied by a dominant allele at that locus, and a quite different effect if accompanied by the same recessive allele. Many harmful recessive genes are maintained in the population because, although harmful or even lethal when two copies are present, they may be beneficial if they are accompanied by a dominant allele which blocks the harmful consequence. Epistasis refers to the possibility that phenotypic characteristics are affected by particular combinations of alleles at different loci. For example, it might be the case that allele 5 of the IGF2R gene is associated with high IQ only if it is accompanied by particular alleles at other loci. In their absence, it is accompanied by normal or even low IQ. If that were true, it would clearly be difficult to detect, and replicate, substantial effects.

7.22 Is the genetic variance underlying variation in IQ mostly additive? We noted in Chapter 4 that much research in behavioural genetics assumes this to be the case. But two relatively sophisticated attempts to model IQ variation, while both concluding that the overall broad-sense heritability of IQ is about 0.50, also argue that additive genetic variance accounted for no more than about 30% of the overall variation in IQ, while non-additive effects accounted for some 20%.[25]

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[22] Vernon, P. A. et al. The neuropsychology and psychophysiology of human intelligence. In Sternberg, R. J., editor. (2000). *Handbook of Intelligence*. Cambridge: Cambridge University Press; Deary, I. J. (2000). *Looking Down on Human Intelligence*. Oxford: Oxford University Press.

[23] Renna, J. M. & Rosenzweig, M. R. (1987). *Enriched and Impoverished Environments*. New York: Springer-Verlag.

[24] Thompson, P. M. et al. (2001). Genetic influences on brain structure. *Nat. Neurosci*. **4**, 1253–8.

[25] Devlin, B., Daniels, M. & Roeder, K. (1997). The heritability of IQ. *Nature* **388**, 468–71; Chipuer, H. M., RoVine, M., & Plomin, R. (1990). LISREL modeling: Genetic and environmental influences on IQ revisited. *Intelligence* **14**, 11–29.

7.23 Although we observed in paragraph 7.3 that performance on one kind of IQ test is often positively correlated with performance on others, thus ensuring that factor analysis will find a sizeable general factor, this *g* is certainly not the entire answer to the question of IQ. The cognitive abilities measured by tests of Gf, Gc, Gv and so on are partially independent of one another. This is particularly true at higher levels of IQ: scores on different types of IQ test are more strongly correlated in people of below average IQ, than in those of above average IQ.[26] Thus a high-IQ group may contain some people with much higher scores on one kind of test, and other people with higher scores on another kind of test. If the genes associated with variations in scores on these different tests are different, there will be that much less chance of finding genes consistently associated with a high IQ score. To that extent, the strategy of comparing a high-IQ group with an average-IQ group may be problematic.

7.24 There is evidence for the heritability of different cognitive abilities, independent of any general factor.[27] However, Plomin and others have argued that multivariate genetic analysis[28] establishes that, to a significant extent, the same genes affect different cognitive abilities.[29] To the extent that scores on tests of different cognitive abilities are all positively correlated, it is indeed possible that all cognitive abilities depend on a common underlying process – the substrate of *g*, and that genetic effects on *g* are common to all tests. But that is certainly not a necessary conclusion. It is true that tests of different cognitive abilities are all correlated: but the reason for the correlations between various pairs of tests may be different. The general factor extracted by factor analysis is no more than a mathematical representation of the fact that all these tests correlate with one another: it does not prove that there is a single reason why they should do so, in other words, that there is any process or processes common to all tests. It is entirely possible that the genes associated with what one pair of tests shares in common are different from those genes associated with what is common to other pairs of tests.

## Directions for future research

7.25 The strategy of the research programme of Plomin and his colleagues has been to identify alleles associated with high, as opposed to average, IQ. A different strategy might be able to locate genes associated with below average IQ, in the range 80 to 100. As noted earlier, since scores on tests of different cognitive abilities are more highly correlated in those of below-average, rather than above-average, IQ, there would seem to be more chance of such research finding genes associated with variations in *g* or any general factor of intelligence. There is, however, a growing belief that the genetic variance in IQ in the lower range of scores may be due to mildly deleterious mutations rather than genes that are associated with variation in IQ scores in the normal range.[30] Recent evidence suggests that the number of such mutations which all people carry and the rate at which new mutations

[26] Detterman, D. K. & Daniel, M. H. (1989). Correlations of mental tests with each other and with cognitive variables are highest for low IQ groups. *Intelligence* **13**, 349–59.

[27] Alarcon, M. *et al*. (1998). Multivariate path analysis of specific cognitive abilities data at 12 years of age in the Colorado Adoption Project. *Behav. Genet*. **28**, 255–64.

[28] Multivariate genetic analysis involves the simultaneous analysis of a number of phenotypes, which allows for the covariance between phenotypes to be broken down into genetic and environmental sources. This attempts to establish how well the genetic or environmental values of one phenotype predict the genetic or environmental values of another phenotype.

[29] Petrill S. A. (1997). *Current Directions in Psychological Science* **6**, 96–9.

[30] Alarcon, M. *et al*. (1998). Multivariate path analysis of specific cognitive abilities data at 12 years of age in the Colorado Adoption Project. *Behav. Genet*. **28**, 255–64.

occur in each generation are much higher than previously supposed.[31] If such mutations act to increase susceptibility to pathogens or other environmental factors, or decrease in any way the overall efficiency of the individual, one would expect them to contribute to a below-average IQ, and that variation in IQ in this range may be caused by variation in the number and nature of such mutations. This would help to explain why there is a significant correlation, after controlling for social class, between IQ and such physical factors as overall health and bodily symmetry.[32] If all this is true, it will be very difficult to identify particular alleles associated with below-average IQ in the population as a whole: a whole range of different genotypes, with quite different mildly deleterious mutations, may be implicated.

[31] See Kondrashov, A. S. (1995). Contamination of the genome by very slightly deleterious mutations: why have we not died 100 times over? *J. Theor. Biol*. **175**, 583–94 and Sunyzev, S. *et al.* (2001). Prediction of deleterious human alleles. *Hum. Mol. Genet*. **10**, 591–7. The latter comes to the conclusion that 'the average human genotype carries approximately $10^3$ damaging non-synonymous SNPs that together cause a substantial reduction in fitness'. In other words, every one of us is genetically defective to some extent.

[32] Lubinski, D. & Humphreys, L. G. (1992). Some bodily and medical correlates of mathematical giftedness and commensurate levels of socioeconomic status. *Intelligence* **16**, 99–115; Furlow, B. F., Armijo-Prewitt, T., Gangestad, S. W. & Thornhill, R. (1997). Fluctuating asymmetry and psychometric intelligence. *Proceedings of the Royal Society of London B*. **264**, 823–9.