General cognitive ability and the interplay between genes and environment

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Chapter 1

General introduction

GENERAL INTRODUCTION

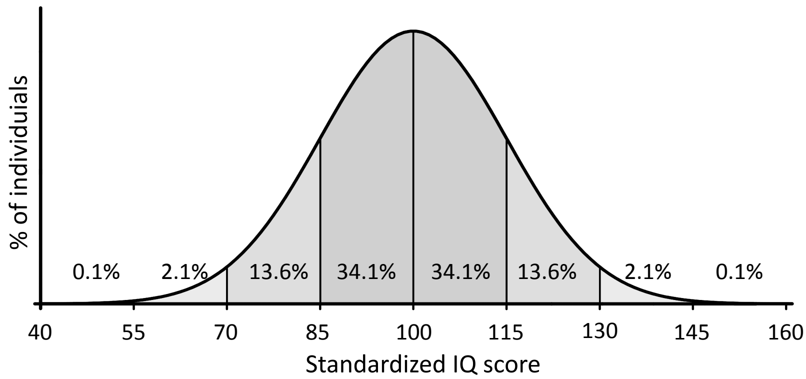
General cognitive ability, or *intelligence,* has fascinated scientists for more than a century. Its definition, however, differs widely across disciplines, time and places. In 1904, Spearman introduced the term *g* to explain the concept of intelligence. The general factor *g* is based on the observation that individuals who score high on one test of cognitive ability, also tend to score high on other tests of cognitive ability. According to Spearman, *g* explains a large part of the variance in performance on diverse tests of cognitive ability. The concept of *g* is however highly debated in the 20th century; scientists focused more on a multifactorial concept rather than a unitary concept of cognitive ability. For example, Thurstone (1938) focused on several primary mental abilities, such as verbal comprehension, memory and number facility, rather than a general factor of intelligence. In 1986, Sternberg and Detterman (1986) summarized the views of 52 scientists, collected on a symposium on intelligence (Gottfredson, 1997):

> *"Intelligence is a very general mental capability that, among other things, involves the ability to reason, plan, solve problems, think abstractly, comprehend complex ideas, learn quickly and learn from experience. It is not merely book learning, a narrow academic skill, or test-taking smarts. Rather, it reflects a broader and deeper capability for comprehending our surroundings-, 'catching on,' 'making sense' of things, or 'figuring out' what to do."*

For pragmatic reasons, the term *general cognitive ability* will be used throughout this thesis, to refer to intelligence such as it is measured with a psychometric intelligence test ("Intelligence as the tests test it"; Boring, 1923).

General cognitive ability is commonly assessed using psychometric tests that cover cognitive domains such as verbal comprehension, perceptual organization, processing speed, and working memory. Psychometric tests of intelligence show high reliability and validity. Outcomes of such tests are often transformed into standardized IQ scores such that the mean is 100 and the standard deviation is 15. IQ scores follow a normal distribution within a population (see Figure 1.1). About 68% of the population has IQ scores between 85 and 115 (i.e., one standard deviation from the mean), ~95% of a population has IQ scores between 70 and 130 (i.e., two standard deviations from the mean), and ~99% has IQ scores between 55 and 145 (i.e., three standard deviations from the mean).

Figure 1.1 Theoretical normal distribution for general cognitive ability within a general population.



Causes of Individual Differences in General Cognitive Ability

As general cognitive ability is strongly related to e.g. educational performance, occupational status, socio-economic status, social competences, and mortality risk (Gottfredson, 1997; Huisman et al., 2005; Johnson et al., 2006; Batty et al., 2007), causes of individual differences in general cognitive ability are considered of great practical and social importance. The question *why* individuals differ has been subject of research and philosophical reasoning for many centuries. Galton (1822-1911) attributed causes of individual differences in general cognitive ability to 'heritable factors' as well as 'environmental factors'. In his book *Hereditary Genius (1869)*, Galton declared that the closer the familial relatedness of two individuals, the more these people are thought to resemble each other for general cognitive ability. Based on this assumption, genetically informative designs, such as adoption studies, twin studies, and family studies have been used to estimate the relative influence of genetic and environmental factors on total trait variation. The most widely used design is the classical twin design (See Appendix I for an extensive description).

In the second half of the 20th century, a wealth of classical twin studies showed considerable evidence that individual differences observed in general cognitive ability were to a large extent due to individual differences at a genetic level (Bouchard, Jr. & McGue, 1981; Plomin, 1999). In addition, it has been reported that the relative contribution of genetic factors increases from childhood (41%) to adolescence (55%), to young adulthood (66%), and to middle and late adulthood (85%) (Posthuma et al., 2001a; Haworth et al., 2009).

Genetics of general cognitive ability, knowns and unknowns

Most of the reported heritability estimates for general cognitive ability are based on classical twin studies. Although such studies have provided a wealth of information on causes of individual differences in general cognitve ability, they are also known to rely on several assumptions, some of these assumptions do not necessarily hold for general cognitive ability.

First, in the classical twin design it is assumed that genes and environment act in an additive manner. It is however conceivable that more complex processes are operating. For example, individuals who have a genetic predisposition for e.g. attaining high cognitive ability, may select (passively, reactively, or actively) environmental conditions in which their genetic disposition can prosper and become manifest (Plomin et al., 1977). The environment is then selected based on a genetic propensity. In this situation, genetic and environmental factors do not act in an additive manner anymore, but are correlated (i.e., gene-environment correlation: $r_{(GE)}$).

Second, environmental factors (e.g., education, parental rearing style) may have different impact in individuals with a different genetic makeup, or vice versa, expression of genes may be dependent on an individual's exposure to a particular environment. In this situation, genetic and environmental factors interact such that genes control an individual's sensitivity to environmental factors, or environmental factors control the expression of the genes (i.e., gene-environment interaction: GEI).

A third assumption of the classical twin design is that the phenotypes of the parents of the twins are uncorrelated. It has however been reported that mates select each other on the basis of similar levels of general cognitive ability, also known as positive assortment (Jencks et al., 1972; Loehlin, 1978; Mascie-Taylor, 1989).

Fourth, in classical twin models, trait related environmental factors that are transmitted form parents to offspring (i.e., cultural transmission) cannot be distinguished from genetic transmission from parents to offspring.

Fifth, genetic influences due to dominance deviation (i.e., genetic non-additivity) and environmental factors that are shared between twins cannot be estimated simultaneously within the classical twin design. Consequently, either dominance deviation, or the contribution of shared environmental factors is assumed to be absent in the classical twin design, such that true effects of these factors can be underestimated.

When any of these assumptions is violated, estimates of the relative importance of genetic and environmental influences will be biased in classical twin studies (Jinks & Fulker, 1970; Eaves et al., 1977; Plomin et al., 1977; Purcell, 2002).

The classical twin design is the predominant design in heritability studies, however, little is known about the effects of the processes discussed above with respect to individual differences in many traits, including general cognitive ability. At the start of this PhD project only few studies, mainly in children and adolescents, considered $r_{(GE)}$, GEI, assortative mating, cultural transmission, and simultaneously modeling of genetic dominance deviation and shared environmental factors. More research on these topics, particularly in adults, is essential for a better understanding of genetic and environmental influences on individual differences in general cognitive ability.

Aims and outline of this thesis

The main aim of this thesis is to study the interplay between genetic and environmental factors (i.e., $r_{(GE)}$ and GEI) as well as assortative mating and cultural transmission in the context of general cognitive ability in adults. The hypothesis is that the high heritability estimates that have frequently been reported for cognitive ability in adults partly reflect these complex processes and that considering these processes will help us to understand the etiology of the individual differences that are observed in general cognitive ability. A clear understanding of the sources of individual differences in general cognitive ability may eventually facilitate gene finding studies, which have so far been less successful than expected (as discussed in Plomin & Davis, 2009; Posthuma et al., 2009; Deary et al., 2010). To this end, we extended the classical twin design to an extended twin family design and besides measuring cognitive ability, we measured a set of carefully selected environmental moderators.

In Chapter 2, characteristics and implications of $r_{(GE)}$, GEI, assortative mating, and cultural transmission are discussed in more detail. In addition, this chapter contains a description of the sample on which most of the studies reported on in this thesis are based, as well as a description of the measures of cognitive ability and environmental indices on which the studies in Chapters 3 to 8 are based. In Chapter 3, genetic and environmental influences on individual differences in cognitive ability are studied in an extended twin-family design, taking into account the effects of assortative mating, cultural transmission, and $r_{(GE)}$. In Chapter 4, the contribution of genetic influences to presumed 'environmental' factors such as childhood environment, social environment and behavior, leisure time activities, and life events is examined. A study on sex differences in academic and general achievement motivation is described in Chapter 5. In Chapter 6, moderation effects of achievement motivation and general cognitive ability on the variance decomposition of educational attainment are studied. Moderation effects of influential life events and experience seeking behavior on the variance decomposition of general cognitive ability are described in Chapters 7 and 8, respectively. The heritability of aptitude and exceptional talent across different domains is the topic of Chapter 9. Finally, the results of these studies are summarized and discussed in Chapter 10, together with a view on future studies on elucidating the role of genes and environment in general cognitive ability.