Heritability of Intelligence

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This article discusses findings of two recent studies conducted in collaboration with the East Flanders Prospective Twin Survey in the field of cognitive ability. The first study examined the effect of chorion type on heritability estimates of intelligence in children. The second study investigated the causes of association between child psychopathology and lower cognitive ability. Findings of these studies are discussed in the light of the current view on cognitive ability (or 'g') and recommendations for future research are made.

Effect of Chorion Type on Heritability Estimates

Intelligence is one of the oldest topics in behavior genetics research and it is probably the most complex — and most controversial — of all complex traits. In spite of different theoretical views of intelligence (e.g., Catttells crystallized and fluid intelligence, Cattell, 1971; Sternberg's triarchic theory of intelligence, Sternberg, 1999; and Gardner's multiple intelligences, Gardner, 2000), the notion of 'general cognitive ability' as a basic general factor of mental ability, represented by the symbol 'g' (Spearman, 1927), is well accepted. In psychometric terms, 'g' is operationalized by the covariance among diverse tests of cognitive abilities such as abstract reasoning, spatial, verbal and memory abilities (Plomin, 2003) and most psychometric researchers agree that the 'g' factor is sensitive to individual differences in abilities to learn, reason and solve problems (Toga & Thompson, 2005). Since long, behavior genetic researchers are trying to explain these observed individual differences in 'g' in terms of nature (genetics) versus nurture (environment). The first twin study and adoption studies on 'g' were conducted in the 1920s and suggested substantial genetic influences. Since then, with the exception of personality assessed by self-report questionnaires, more research has addressed the genetics of 'g' than that of any other human characteristic. Heritability estimates vary from 40% to 80%, but meta-analyses yields estimates of about 50% and even higher in studies of adults (Craig & Plomin, 2006). However, none of these studies looked at the possible confounding effect of chorion type on the heritability estimates. After all, according to differences in the antenatal development, three types of monozygotic (MZ) twins can be distinguished: approximately 32% are dichorionic (DC, each fetus having its own chorion and amnion), nearly 66% are monochorinic–diamnionic (MC–DA, twins sharing a common chorion, but having their own amnion) and 2 to 3% of the MZ twins are monochorionic–monoamnionic (MC–MA, twins sharing one chorion and one amnion). As some studies suggested that chorion type may influence postnatal phenotypes such as intelligence (Spitz et al., 1996), this was investigated in a sample of 451 twins pairs aged 8 to 14 from the East Flanders Prospective Twin Survey (EFPTS) as this twin survey is unique in having reliable information about the chorionicity of the twins. Results of this study as reported by Jacobs at al. (2001) showed a small but significant effect of chorion type on the WISC-R subscales Arithmetic and Vocabulary: as expected, MC twins, who share the same placenta and have a common blood circulation, resembled each other more that DC–MZ twins (see also Table 1). In addition, high heritability estimates were found for almost all subscales as well as for total IQ scores such as verbal IQ (82%), performance IQ (73%) and total IQ (83%), which confirmed previous studies (Boomsma, 1993; Wright et al., 2001).

Genetic Association With Child Psychopathology

The topic of 'g' is without doubt an important one. After all, 'g' predicts important social outcomes such as scholastic achievement, employment, lifetime income and even health-related parameters such as life expectancy (Toga & Thompson, 2005). In addition, 'g' is specifically relevant to molecular psychiatry because mild mental retardation appears to be the low extreme of the normal distribution of 'g'. Moreover, at least 200 single-gene disorders include mental retardation among their symptoms (Inlow & Restifo, 2004). Lower cognitive ability is also found to covary with behavioral outcomes such as child psychopathology

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Table 1

Estimates and 95% Confidence Intervals of Genetic, Environmental and Chorion Parameters Under the Best Fitting Genetic Model

WISC—R subscale	Best-fitting model	*a*	95% CI	*c*	95% CI	ch	95% C.I.	*e*	95% C.I.
Information	AE	.72	.66–.77	—	—	—	—	.28	.23–.34
Similarities	AE	.48	.39–.87	—	—	—	—	.51	.43–.61
Arithmetic	AE–ch	.53	.4–.64	—	—	.14	.01–.29	.33	.26–.41
Vocabulary	AE–ch	.72	.63–.79	—	—	.10	.02–.19	.18	.14–.23
Comprehension	AE	.55	.47–.62	—	—	—	—	.45	.38–.53
Digit span	AE	.55	.47–.62	—	—	—	—	.45	.38–.53
Picture completion	AE	.29	.19–.39	—	—	—	—	.71	.61–.81
Picture arrangement	AE	.52	.43–.59	—	—	—	—	.48	.4–.57
Block design	AE	.7	.63–.75	—	—	—	—	.3	.25–.37
Object assembly	ACE	.24	0–.54	.27	0–.05	—	—	.49	.41–.58
Coding	AE	.67	.61–.73	—	—	—	—	.3	.27–.39
Mazes	AE	.37	.27–.46	—	—	—	—	.63	.54–.73
Total verbal IQ	AE	.82	.78–.85	—	—	—	—	.18	.15–.22
Total performance IQ	AE	.73	.68—.78	—	—	—	—	.27	.22–.32
Total IQ	AE	.83	.79–.86	—	—	—	—	.17	.14–.21

Note: Table adapted from Jacobs et al. (2001).

A indicates additive genetic factors; C, common environmental factors; E, individual–specific environmental factors.

(Goodman, 1995). In a study (Jacobs et al., 2002) conducted in a sample of 376 twin pairs aged 8 to 14 from the EFPTS, it was found that genetic factors accounted for 84% of this modest but significant phenotypic correlation (r = –.19; see Figure 1). It was concluded that in children three different genetic factors may exist: one that solely affects the liability to child psychopathology, one that had only an effect on 'g' and one that influences both phenotypes. This finding of a shared genetic factor influencing (the low end of) 'g' and child psychopathology, can help the search for specific genes in comorbid samples by increasing the power to detect a quantitative trait locus (QTL; Boomsma & Dolan, 1998), as illustrated by a recent study by DeYoung and colleagues in which an allelic variation in the dopamine D4 receptor gene was suggested as a genetic factor moderating the association between externalizing behavior and cognitive ability (DeYoung et al., 2006).

Discussion

General cognitive ability is one of the most inherited dimensions of human behavior, even after taking the possible confounding effect of chorionicity into account. It should be noted that a (partly) genetically determined 'g' does not necessarily imply that there is a single fundamental brain process that permeates all other brain processing, such as 'a speedy brain', neural plasticity or the quality and quantity of neurons. It has been proposed that 'g' exits in the brain in the sense that diverse brain processes are genetically correlated (Plomin, 2003). Our finding of a shared genetic factor influencing two correlated phenotypes may be a good illustration of this view. Genetic factors involved in 'g' were also found to be associated with child psychopathology.

Although the role of genes in cognition have been proven for a long time, it is only in the past few years, with the rapid evolution of molecular and computational technology for genetic analyses, together with data from the human genome project, that identification of these genes has become a viable challenge. Most promising genes implicated in neurocognitive function seem to be the dopamine receptor genes D1, D2 and D4, the COMT gene and the BDNF gene (Savitz et al., 2006), although recent genetic studies also reported interesting associations with genes such as the CHRM2 gene and the SNAP-25 gene. Variation in a single-nucleotide polymorphism in the CHRM2 gene (T-allele of rs324560) was found to be associated with an increase of 4.6 performance IQ points (Gosso et al., 2006) and the A-allele of the SNP rs363050 in the SNAP-25 gene was found to be associated with an increase of 2.84 performance IQ points, explaining 3.4% of the variance in PIQ (Gosso et al., 2006). So, genetic studies focusing on phenotype–gene associations seem to be a fruitful method of unravelling the genetics of intelligence. However, it must be noted that in most cases the reported associations are rather small, accounting for only a modest proportion of the phenotypic variation, and are not (yet) replicated. Therefore, it has been suggested that strategies focusing solely on identifying related genes might be not the whole story of 'g'. The heritability of 'g' has been found to increase with age suggesting genotype–environment correlation and genotype–environment interaction (Toga & Thompson, 2005). This leads to the current and well-accepted view that 'g' is a complex genetic trait caused by multiple genes of varying but small effect size, as well as multiple environmental factors. Therefore,

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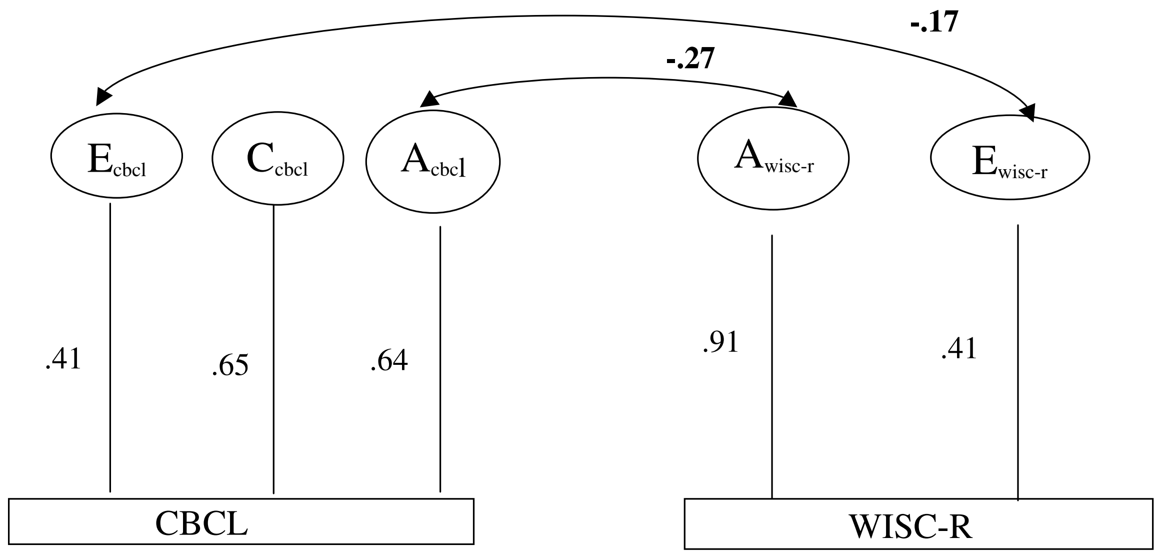

Figure 1

The genetic and environmental parameters estimates from the best fitting model, adapted from Jacobs et al. (2002).

Note: The variance in liability to each trait is divided into that due to additive genetic factors (A_{cbcl} and A_{wisc-r}), common environmental effects (C_{cbc}l and C_{wisc-r}) and individual-specific environmental factors (E_{cbcl} and E_{wisc-r}) whereby CBCL indicates Child Behavior Checklist and WISC-R, Wechsler Intelligence Scale for Children — Revised. Paths, which are the standardized regression coefficients, must be squared to equal the proportion of variance accounted for. The phenotypic correlation between Child psychopathology and Cognitive ability is decomposed into that due to the correlation of additive genes ($r_a = -.27$), the correlation of individual-specific environmental factors ($r_e = -.17$).

future molecular genetic research needs to incorporate environmental variables and to examine gene–gene interactions in powerful designs with large samples.

To conclude, 'g' is one of the most fascinating topics in psychology and for some time have been prompted to unravel the mystery of this complex trait. As described above, studies in collaboration with the EFPTS have made a significant contribution to this ongoing exploration of 'g', taking advantage of the unique features of this twin registry. Therefore, one may look forward to future EFPTS studies including environmental and genetic variables.

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