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Intelligence and Achievement: A Behavioral Genetic Perspective

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Understanding the etiology and relationship between standardized intelligence and academic achievement tests is essential, given their ever-increasing role in American education. Behavioral genetic studies have examined the genetic and environmental etiology of intelligence, academic achievement, and their relationship. Results suggest that genetic, shared environmental, and nonshared environmental influences have an impact on intelligence and academic achievement. Behavioral genetic studies also suggest that the importance of genes may vary as a function of age. Other studies suggest that genes drive the correlation and that the nonshared environment drives the discrepancy between measures of intelligence and achievement. Implications for the identification of intellectually and academically relevant environmental influences are discussed.

KEY WORDS: behavioral genetics; intelligence; academic achievement.

Why do children perform so differently from one another on standardized tests of intelligence and achievement? Why is it that some students possess standardized intelligence test scores that correspond with their achievement test scores, whereas other students show wide discrepancies between intelligence and achievement? Given the ever-increasing role of standardized tests of intelligence and academic achievement in American education, it is important to continually strive to better understand the relationship among these constructs. The purpose of this paper is to examine

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this issue from a behavioral genetic perspective. First, we describe the measures of intelligence and achievement typically used by behavioral genetic studies. We then discuss behavioral genetic methods and examine research examining intelligence, academic achievement, and their relationship. Finally, we discuss how behavioral genetics can be used to identify the genetic and environmental factors that shape intelligence and achievement.

THE MEASUREMENT OF INTELLIGENCE AND ACADEMIC ACHIEVEMENT

Although many have attempted to develop general theories of intelligence (e.g., Gardner, 1983; Spearman, 1904; Sternberg, 1985; Thurstone, 1938), the standardized tests used in most educational settings and employed historically in most empirical research are derived from the Binét–Simon scales of intelligence (1905). The Binét scales were designed for the pragmatic purpose of identifying special needs children in the Parisian public school system. The Stanford–Binét scale was standardized by Terman (1916) and extended by Wechsler (1939). As the 20th century progressed, standardized tests of intelligence became commonplace in schools. Most group and individually administered intelligence tests are direct descendents, modifications of, or reactions to these measures.

Almost all of these standardized tests of intelligence measure specific dimensions of cognitive functioning, often called *group factors.* Examples of these group factors are verbal ability, spatial ability, perceptual speed, and memory. These dimensions of cognitive functioning, although distinct, have been shown to correlate with one another, yielding a *general intelligence,* or *g factor* that accounts for a large portion, but not all, of the individual differences in the group factors (see Carroll, 1993). Although these standardized measures of intelligence certainly do not account for all types of intelligent behavior, they are highly reliable and predict later intellectual performance, educational attainment, and occupational status (Brody, 1992).

Understanding the important dimensions of academic achievement has also been a focus of intense research. Many studies have used *standardized achievement tests* (see Sattler, 1988) that attempt to measure specific types of academic performance (e.g., reading comprehension, mathematics computation). Others have argued that standardized achievement tests are nearly identical to measures of intelligence, opting instead for measures of *classroom performance,* such as teacher evaluations or cumulative grade point average (see McCall, Evahn, and Kratzer, 1992).

BEHAVIORAL GENETIC STUDIES OF INTELLIGENCE AND ACHIEVEMENT

One of the major misconceptions about behavioral genetics is that the method describes whether nature *or* nurture is operating. Instead, behavioral genetic methods assume that differences in measured behavior (in this case measures of intelligence or academic achievement) can be shaped by both genetic *and* environmental factors. The question is not *whether* genes or environments are operating, but *how much* impact do genes and environments have on intelligence and achievement, and *how* do genes influence the similarity and differences between these constructs. Heritability (h^2) is the proportion of differences in measured behavior (e.g., academic achievement) that can be explained by genetic differences in the population. For example, the similarity in reading ability between family members may be influenced by shared genes important to reading. In addition, behavioral genetic methods also provide a powerful tool to separate the environment into those influences that operate between families and those that operate within families. Shared environment (c^2) measures differences in behavior that can be explained by environmental influences that make family members similar. For example, the similarity in reading ability between family members may also be influenced by the fact that family members went to the same schools and had the same teachers. Nonshared environment (e^2) measures the extent to which differences in behavior are influenced by differences within family environments. Thus, nonshared environment measures environmental differences within families (one child may be a better reader because he/she has read more books that than his/her sibling). In addition, e^2 measures error and any other factor that makes family members different. These estimates are obtained by examining twins or families with adoptive children.

Genetic influences on intelligence are statistically significant, averaging around 50% when collapsing across all available twin and adoption studies (Bouchard and McGue, 1981; Chipuer, Rovine, and Plomin, 1990; Plomin and Petrill, 1997). Interestingly, heritability appears to vary with age, starting around 40% in early childhood, rising to 60% in early adulthood, and rising to 80% in later life (McGue, Bouchard, Iacono, and Lykken, 1993; Plomin, 1986; Plomin, Fulker, Corley, and DeFries, 1997). Evidence suggests that the heritability of intelligence may decline to around $h^2 = .60$ in old-old populations (Finkel, Pedersen, Plomin, and McClearn, 1998; McClearn *et al.,* 1997). In contrast, shared family environmental influences are significant in early and middle childhood but decrease to zero by adolescence and early adulthood. Nonshared environmental influences are significant throughout the lifespan. These results are found not only for general intelligence (e.g., a Full Scale IQ Score), but also for specific cognitive abilities, especially Verbal Ability, Spatial Ability, and Perceptual Speed (Plomin, 1988).

In contrast to the hundreds of studies examining the heritability of intelligence, there are fewer studies examining academic achievement. Interestingly, the heritability of academic achievement is almost as high as the heritability of intelligence. Achievement also displays a similar pattern of increasing heritability and decreasing shared environment with the age of the sample. In elementary school, the shared environment accounts for around 60% of the differences in standardized tests of reading, spelling, and math achievement, whereas genetic influences account for roughly 30% (Brooks, Fulker, and DeFries, 1990; Thompson, Detterman, and Plomin, 1991). During the school years, genetic influences increase whereas shared environment decreases. For example, Husen (1959) suggests that the heritabilities for report card grades in a sample of 13-year-old Swedish twins ranged from 30% to 60%, with shared environment accounting for roughly 25% of the differences in achievement. Loehlin and Nichols (1976) conducted a study of 1300 identical and 864 same-sex fraternal twin pairs. Again the heritability of performance on the National Merit Scholarship Qualifying Test was about 40%, and the shared environment was about 30%. Similarly, Gill, Jardine, and Martin (1985) conducted a study of 264 identical and fraternal twins taking the Tertiary Admissions Examination Test and the Australian Scholastic Aptitude Test (both measures are used as college entrance exams). Heritability estimates were roughly 44% and shared environment roughly 43%. In a related study, Baker, Treloar, Reynolds, Health, and Martin (1996) suggested that the heritability of educational attainment (highest educational level attained) is 57% and the shared environment is 24%. Similarly, Lichtenstein and Pedersen (1997) examined genetic influences on educational attainment (highest educational level attained) in a sample of 91 pairs of male Swedish twins ranging in age from 27 to 80 years (mean age 52.6 years). The heritability of education attainment was 42%; shared environmental influences accounted for 21%, and nonshared environment (and error) explained 31% of the differences in educational attainment.

Thus, like measures of intelligence, heritability is significant in academic achievement, and appears to vary with age. Measures of intelligence and academic achievement are positively correlated with one another, most likely in a reciprocal relationship (see Brody, 1997). Intelligence test scores are correlated with later academic achievement (Butler, Marsh, Sheppard, and Sheppard, 1985) and final educational attainment (Jencks, 1979). At the same time, IQ scores change in response to educational opportunities available to individuals (Ceci and Williams, 1997). Whatever the causal pathways, the correlation between intelligence and achievement is substantial and consistent, averaging around .50. Thus, the correlation between intelligence and achievement may be influenced by genetic and/or environmental overlap.

So how might behavioral genetics help us understand the correlation between standardized tests of intelligence and academic achievement? There are several possibilities. An environment-only position hypothesizes that intelligence and achievement correlate due to overlap in the environments that shape both constructs (Fig. 1). In other words, both intelligence and achievement have genetic and environmental components, but the environment (such as schooling) drives the correlation between intelligence and achievement. These environmental influences could either be due to shared environment (both children in the home experience environments that shape their intelligence and achievement equally) or nonshared (each child experiences a separate environment, but this unique environmental experience has an effect on that child's IQ as well as on his/her achievement).

Second, a gene + environment hypothesis suggests that the correlation between intelligence and achievement is due to both genetic and environmental overlap (Fig. 2). In this case, there are genes in common across both constructs, but there are also shared and/or nonshared environmental influences that affect both intelligence and achievement.

Finally, a gene-only hypothesis suggests that the correlation between intelligence and achievement is due solely to genetic influences (Fig. 3). Environmental influences cause intelligence and achievement to be differ-

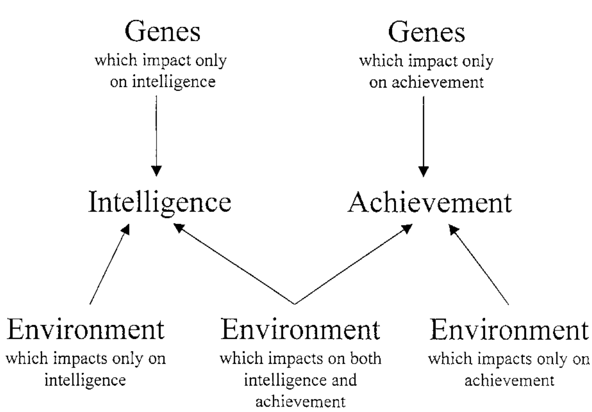

Fig. 1. The environment influences the correlation between measures of intelligence and achievement.

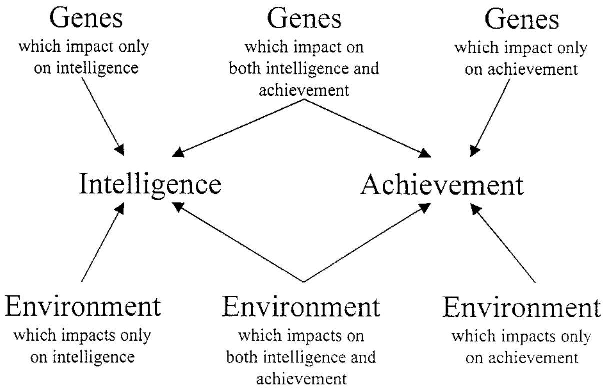

Fig. 2. Both genes and the environment influence the correlation between measures of intelligence and achievement.

ent from one another. A correlation of .50 between intelligence and achievement scores means that 75% of the variance ($1 - r^2$) in achievement is not shared with IQ. Thus, the environment (and some genes specific to intelligence and achievement) may cause achievement scores to diverge from what would be predicted by intelligence scores.

Making this issue more complex is the fact that different models may be functioning at different ages. Because shared environmental influences are more important prior to adolescence, we might expect that the environment plays a greater role in the correlation between intelligence and

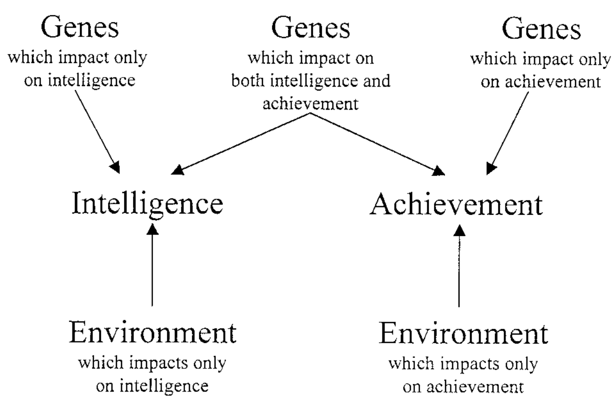

Fig. 3. Genes influence the correlation between measures of intelligence and achievement.

achievement in elementary school and that genetics plays a more important role in later school years and adulthood. This shift to a gene-only model makes intuitive sense because children are engaged in school—an environmental influence affecting both achievement test scores and cognitive ability that stops about when the biggest decrease in shared environment in IQ and achievement occurs.

When examining the data, the gene-only model appears to be operating at all points in the lifespan. In other words, although intelligence and achievement themselves are influenced by *both* genetic and environmental factors, the correlation between intelligence and achievement appears to be driven mostly by shared genetic influences (see Fig. 3). The discrepancy between intelligence and achievement is influenced primarily by the non-shared environment (with small independent genetic influences in achievement and intelligence). Thompson, Detterman, and Plomin (1991) examined a sample of 278 pairs of identical and fraternal twins ranging in age from 6 to 12 years. Each twin was given an extensive battery of standardized cognitive and achievement tests. Multivariate results suggested that the correlation between the cognitive tests (broken down into Verbal Ability, Spatial Ability, Perceptual Speed, and Memory) and achievement tests (i.e., Reading, Spelling, and Math) was driven largely by genetic factors. These results have since been replicated in an adoption study examining roughly 500 adoptive and nonadoptive 7-year-old children (Wadsworth, 1994). In addition, the gene-only theory appears to operate in late adulthood as well. Lichtenstein and Pedersen (1997) demonstrated that 75% of the correlation between intelligence and educational attainment in a sample of older adult twins is due to genetic overlap between these constructs.

Thus, the behavioral genetic data paints a picture of intelligence and achievement that is contrary to conventional wisdom. Genetic influences appear to vary in importance across the lifespan, and they are primarily responsible for the correlation between measures of intelligence and achievement. Shared environment is important in childhood but declines in adolescence. The nonshared environment (the environment unique to each child in a family) appears to be the most pervasive environmental influence across the lifespan, and is also responsible for the discrepancy between measures of intelligence and achievement.

How might we begin to explain these results? One direction has been to identify the genes that are associated with cognitive ability and academic achievement. Although these methods are described in greater detail elsewhere (see Plomin, DeFries, McClearn, and Rutter, 1997), molecular genetic techniques look for differences in DNA sequences that are related to differences in a measured behavior. With respect to intelligence, Chorney *et al.* (1998) report a DNA marker associated with IGF2R (found on chromosome 6) that explains a small but statistically significant proportion of the variance in intelligence. It is important to mention that, although Chorney *et al.* (1998) found this association between IGF2R and intelligence in two independent samples, attempts by others to replicate this result have not yet been reported.

Similarly, other research has described a possible link between another marker on chromosome 6 and reading disability, as defined as a clinically significant discrepancy between measures of intelligence and reading (Cardon *et al.,* 1994). Grigorenko and her colleagues (1997) replicated these results, suggesting that that phonologic awareness may be partially responsible for the linkage between DNA markers on chromosome 6 and reading disability. The validity of these findings is very much in a state of uncertainty. Some researchers have not only replicated (Gayan *et al.,* 1999) but extended (Fisher *et al.,* 1999) these findings. Other researchers, however, have failed to replicate these findings (Field and Kaplan, 1998). Although finding a set of DNA markers relating to intelligence and achievement is very much a "work in progress," this search constitutes an important step in understanding the developmental neurobiological pathways that influence individual differences in the development of complex cognitive functioning.

In addition, we must also reexamine our assumptions concerning the environment. Harris (1995) argued provocatively that the family environment is ultimately unimportant as children move from middle childhood to adolescence where peer and individual influences become more pervasive. At first glance, the behavioral genetic data presented so far seem to support this conclusion: Shared environmental influences are negligible after adolescence, whereas the nonshared environment (and error) remains significant. However, the behavioral genetic results do *not* necessarily imply that the family environment is unimportant, as suggested by Harris (1995). The shared environment can occur both at home, at school, or in any situation in which two members of a family experience an environment in the same manner. Similarly, the nonshared environmental can occur in the home (e.g., differential parenting targeted to the strengths and weakness of each child) or outside of the home. The interesting finding is that within these familial, peer, or academic contexts, the most important environmental influences appear to shift from those that are shared by members of a family to those that are unique to each child within the family.

So how can we identify the shared and nonshared environmental factors that are associated with intelligence and academic achievement? Typically, studies have examined the environment using two general approaches. In the first approach, a measure of some "environmental" influence is developed (such as number of books in the home) and then correlated with some outcome (such as intelligence or academic achievement). For example, research has suggested that oral language development is associated with the way in which (as opposed to how much) parents and teachers read to children (Mason, 1992; Moon and Wells, 1979; Lonigan, 1993; Whitehurst *et al.,* 1988), availability of books in the home (Scarborough, 1998; Mason, 1992), and parental attitudes/expectations (Briggs and Elkind, 1977; Dunn, 1981; Scarborough and Dobrich, 1994).

A second approach has involved attempts to raise intelligence and/or academic achievement test scores in at-risk populations. Since the 1970s, researchers have attempted to develop early educational interventions that raise the intellectual and academic level of disadvantaged economic groups. Spitz (1986) reviewed several well-known projects such as Head Start and the Consortium for Longitudinal Studies. He suggests that early intervention studies have a positive effect on intelligence, but these gains disappear when the intervention is terminated. In contrast, the Abecedarian Project (Ramey and Campbell, 1991) involved an intensive daycare program for children judged to be at risk for academic failure (e.g., median family income reported was zero). Average age at entry was 4.4 months. In addition to an intensive daycare program, the Abecedarian Project endeavored to involve families in the preschool program and performed a support service to improve communication between parents and teachers once the children reached elementary school. Campbell and Ramey (1994) then reexamined these children at 12 years of age, suggesting one-third standard deviation gains in IQ persisted.

Although these two approaches are different in terms of their aims, subject populations, and methodologies, behavioral genetic findings may shed additional light on their findings. First, most studies that examine the relationship between environmental measures and cognitive outcomes employ designs that cannot separate genetic from environmental influences. In other words, these studies assume that "environmental" interventions are free from genetic measurement error. A growing body of behavioral genetic research calls this assumption into question (Plomin and Bergeman, 1991; Rowe, 1994; Rowe and Rodgers, 1997; Scarr and McCartney, 1983; van den Oord and Rowe, 1997). These studies suggest that measures of the environment possess a significant genetic component. Practically speaking, these results mean that the correlation between identical twins' scores on these environmental measures is greater than the correlation between fraternal twins' scores. Because identical twins are more similar genetically, it is assumed that the greater similarity in identical twins' scores is due to genetic influences.

More importantly, the nonshared environment becomes the most important environmental variable as the population ages and is most responsible for discrepancies in IQ and achievement scores. However, both approaches typically employ methods that cannot separate shared from nonshared environmental effects. Attempts to bring about a lifespan increase in intelligence or achievement ought to identify and examine these nonshared effects. For example, one may examine the number of books a particular child in the home reads in a given period as opposed to the number of books the entire family possesses.

Currently, behavioral genetic studies are beginning to examine the environment using genetically sensitive designs. For example, Pike, McGuire, Hetherington, Reiss, and Plomin (1996) decomposed the relationship between measures of the environment and behavioral outcomes into genetic, shared environmental, and nonshared environment components. These analyses were virtually identical to the approach discussed earlier when examining the overlap between intelligence and achievement. The difference is that a measure of the environment was employed as one of the variables. Other approaches have been employed to examine the nonshared environment directly by studying differences between identical twins (Pike, Reiss, Hetherington, and Plomin, 1996). Because identical twins living in the same home share 100% of the same genes and the shared environment, any difference between identical twins has to be due to nonshared environmental differences and error. Thus, if one calculates the difference between identical twins' environments and outcomes, the correlation between these difference scores provides an index of nonshared environmental mediation between the environment and the outcome in question. Although these approaches have been used when examining social and emotional development (see Hetherington, Reiss, and Plomin, 1994), this approach is only beginning to be used to examine cognitive ability and achievement.

Although genes and environments are often conceptualized as independent or parallel processes, numerous theoretical models have also been developed to explain how genes and environments can correlate or interact with one another. Scarr and McCartney (1983) describe three types of gene-environment (GE) correlations. In *passive* GE correlation, both genes and environments derive from the same source: the parents. For example, number of books in the home is related to parents' cognitive ability, which is determined, in part, by genetic influences. Because biological parents provide genes to their children and obtain the books that are in the home, the child's environment is indirectly correlated with their genes.

In contrast, other types of GE correlations are the result of genes directly influencing the environment that the child experiences. *Reactive* GE correlation occurs when the environment experienced by an individual changes as a reaction to his or her genotype. Evidence for reactive GE correlation has been found in the behavior problems literature, which suggests that antisocial behavior in adopted children, related to biological parents behavior, is predictive of more negative parenting from adoptive parents (Ge *et al.,* 1996). Similarly, reactive GE correlation can be posited for academic achievement. For example, parents might read to their children as a function of a child's interest in reading, which, in turn, could be a function of genetic variance relating to reading ability (Scarborough, 1991). Another possible but untested example may the tracking that is found in many schools that is based on children's performance on tests of cognitive ability and achievement.

Finally, active GE occurs when a child's genes make them more likely to seek out certain environments. For example, sociable children may select more sociable environments, which, in turn, amplify their sociability. In the case of academic achievement or intelligence, then, it may be that more academically oriented children seek out more academically enriched environments. Finally, Scarr and McCartney (1983) posit that GE interaction occurs when a nonlinear relationship exists between genetic and environmental influences. For example, environmental influences on academic achievement may vary nonlinearly as a function of the child's genotype.

The purpose of presenting these GE models is not to suggest that all environmental influences can be boiled down to indirect genetic expression. Genes do not code environments such as number of books in the home. However, genes may mediate the extent to which children seek out academically related environments or have more highly enriched environments provided for them. Thus, genes may affect not only how efficiently children learn information but also the likelihood of children being exposed to enriching environments. Although some have begun to examine the GE correlation and interaction in cognitive ability (e.g., van den Oord and Rowe, 1997), many more studies are needed.

Finally, a significant heritability estimate or a genetic correlation between intelligence and achievement does not mean that intelligence and achievement cannot be modified by the environment. For one, the environment is an important determinant of individual differences in achievement and intelligence, especially in childhood. More importantly, heritability describes why individuals differ within a group, but it does not examine average increases in ability or average differences in ability between groups. Although genetic influences account for 90% of the individual differences in height, for example, the height of the average person has increased, presumably due to an average improvement in the environment. Similarly, although the heritability of IQ has remained stable across the 80+ years that twin studies have been conducted, the measures used to measure IQ have been restandardized numerous times. The average IQ, although set to be 100 on a particular test, increases over time. Put another way, if a random sample of children in 1999 were given an intelligence test standardized in 1920, the average IQ would be significantly greater than 100 (Flynn, 1998). Thus, behavioral genetic methods tell us "what is," not "what will be" or "what should be" (Plomin and Petrill, 1997).

SUMMARY AND CONCLUSIONS

The major contribution of behavioral genetic studies is that they provide a more comprehensive picture of the factors that influence intelligence and achievement. Genetic differences are important to understanding intelligence, achievement, and their relationship. However, the environment is also important. Intelligence tests are not a veridical window into genetic potential nor are measures of academic achievement indices of environmentally driven learning. Both are measures of behavior, and thus are potentially subject to genetic and environmental effects.

Behavioral genetic studies also suggest an important distinction between the shared and the nonshared environment. Shared environmental influences on intelligence and achievement decrease throughout the lifespan, leaving the nonshared environment as a more important source of environmental influence. Coupled with research suggesting that genes and environments are correlated with one another, it appears that we need to rethink our assumptions about how children are exposed to and seek out different environments. Far from passively receiving an educational program, children may be actively seeking out and receiving enriched environments based, in part, on genetic influences. Not only should our research begin to identify these multiple influences on intelligence and achievement, but our educational practices should also be more sensitive to these sources of individual differences.

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