Standing, left to right:
J. Asendorpf, M. Kinsbourne, D. Fulker, N.G. Martin, C.G.N. Mascie-Taylor, L.A. Baker, C. R. Brand

Seated, left to right:
U. Lindenberger, D. Bishop, T.J. Bouchard, Jr., D.I. Boomsma, H. Gardner

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Group Report: Intelligence and Its Inheritance—A Diversity of Views

L.A. BAKER, Rapporteur

J. ASENDORPF, D. BISHOP, D.I. BOOMSMA, T.J. BOUCHARD, Jr., C.R. BRAND, D. FULKER, H. GARDNER, M. KINSBOURNE, U. LINDENBERGER, N.G. MARTIN, C.G.N. MASCIE-TAYLOR

INTRODUCTION

What does the study of twins tell us about the structure and origins of intelligent behavior in humans? Agreement on an explicit definition of "intelligence" would seem a reasonable starting point. As history would predict, however, little consensus was reached by a group of scientists whose opinions were surely as diverse as their individual hereditary constitutions and environmental histories. A clash of paradigms was evident in these attempts to define what we set out to explain, and there was little fundamental resolution after days of fervent deliberations.

We agreed that behavioral genetic research, especially the biometrical analysis of twin data, can be extremely useful in helping to understand complex psychological variables, and even in defining them. This research has helped validate existing measures of intellectual ability and has provided support for both general and specific dimensions of these abilities. Moreover, methods of structural equation modeling in twin designs allow evaluation of measurement properties. Researchers have been able to propose and test statistical models that uncover processes underlying cognitive development. As illuminated in the background papers by Boomsma and by Fulker and Cardon (both this volume), recent statistical advancements in the analysis of longitudinal twin and adoption data have proved particularly informative about the nature and development of intelligence.

Twins as a Tool of Behavioral Genetics
Edited by T.J. Bouchard, Jr. and P. Propping

BRIEF PRELUDE

The usefulness of biometrical analysis of covariance structures using twin data is highlighted first in this report. How do such methods address the validation of existing measures or the development of alternative measures of intelligence? The majority of twin and adoption studies of cognition have relied on traditional measures of intelligence (IQ tests and psychometric batteries of abilities). Recent studies, however, are beginning to consider more process-oriented models of cognition, such as those that refer to the basis of information-processing abilities.

The positions of various proponents of how to characterize abilities are then described. These range from the longstanding view that a general ability factor, as defined through psychometric tests, is still of prime importance in explaining individual differences in various aspects of success in humans, to the more radical perspective that current measures are of limited validity and that intelligence measures of greatest social significance are yet to be developed.

An evolutionary framework for considering both the social and biological significance of intellectual abilities is then discussed from two points of view: biometrical genetics and evolutionary psychology. The two approaches differ primarily in their level of analysis (phenotypic vs. latent genetic and environmental), although efforts to combine these approaches may prove useful in understanding the evolution of intellectual abilities.

Other issues reviewed include (a) the conceptualization and empirical study of the environment, specifying the nature of genetic effects by incorporating molecular genetics into biometrical twin analyses, (b) the secular rise in average IQ test performance and its relevance to behavioral genetic research, and (c) the role of speed of processing in cognition.

BIOMETRICAL ANALYSES OF COVARIANCE STRUCTURES IN COGNITION

Heritability of Intelligence

Early research on the origins of individual differences in human intelligence focused on single (univariate) measures of ability, and the primary question of interest was on the relative importance of genetic and environmental sources of variance (i.e., heritability and environmentality of IQ test variation).

Even in the study of specific cognitive abilities, reflected by subscales of IQ tests or other psychometric tasks, questions about heritability predominated. It was thought that through such univariate analyses of various abilities, it would be determined whether general and/or specific abilities existed. Some cognitive variables would show little genetic variance, some almost exclusively genetic influence, some gene-environment (GE) correlations, and so forth. If each ability had its own "psychogenetic story," this might reveal the structure of human abilities (e.g., see Horn and Cattell 1966).

The issue of whether or not cognitive abilities are heritable and the magnitude of the effects of environment and genes are today of much less interest than they were in the past. Most participants agreed that the majority of existing (reliable) measures of cognitive performance show some genetic variance, with heritability for a general ability factor being around 50–60%, although some estimates, based on adult samples, may be slightly higher (e.g., Bouchard et al. 1990; Pedersen et al. 1992; Tambs et al. 1984). Yet most agree that there are more interesting questions to be addressed than the magnitude of heritability of any particular aspect of intelligence measured at a given age.

Genetic and Environmental Architecture of Intelligence: Support for Both *g* and Specific Abilities

Fulker and Cardon, and Boomsma (both this volume) provide a sampling of the more interesting questions about cognition being addressed today. Beyond a simple partitioning of variance into genetic and environmental sources, more sophisticated analyses allow the study of *factorial structures* of genetic and environmental influences across a group of ability tests. Moreover, continuities and changes in genetic and environmental influences over time may also be determined from longitudinal and cross-sectional age comparisons of twin data.

These questions stem from multivariate biometrical analyses (see Martin and Eaves 1977; Fulker and Eysenck 1979; Heath et al. 1989), which focus on the sources of *covariation* among abilities rather than on the sources of variation of any one ability. This approach allows the examination of relationships among traits (e.g., between IQ and educational attainment, or among several specific cognitive ability tests) and the partitioning of covariance into genetic and environmental sources. The new question becomes one of what drives the correlation between two variables. For example, one may determine the importance of correlated genetic effects across different abilities, which may stem either from pleiotropy or linkage disequilibrium.

Twin studies have provided support for both general and specific abilities by examining factor structures of genetic effects and environmental effects for several tests of ability, as reviewed by Fulker and Cardon (this volume; see also Vandenberg 1965; Eaves and Gale 1974; Martin and Eaves 1977; Loehlin and Nichols 1976). Genetic influences for many different cognitive abilities are highly correlated (suggesting a general factor of genetic influences), which lends support to the notion of a general ability factor. The additional finding of independent, specific genetic variation for separate abilities, however, simultaneously validates the existence of specific factors of intelligence beyond this general factor.

Longitudinal data on twins and adoptees provide additional insights into developmental processes and give further support for the existence of both general and specific abilities, as illustrated in Fulker and Cardon's analyses. The considerable stability throughout childhood of genetic effects specific to each cognitive ability (and independent of genetic effects on a general ability factor) suggest that developmental processes are driven largely by heritable factors.

Although the value of biometrical analyses of twin data was undisputed, a number of methodological issues arose. These are discussed below.

Studying Development: Longitudinal and Cross-sectional Designs

The usefulness of longitudinal twin and adoption designs is made apparent by the background papers from Fulker and Cardon and from Boomsma, as well as other papers in this book. They allow the examination of intraindividual change and its genetic and environmental bases. A more limited set of questions about development may still be addressed through cross-sectional age comparisons, such as the extent to which relative effects of genes and environment change over time. There are, however, some instances where the most informative designs include both longitudinal and cross-sectional comparisons.

In psychometric research on adult intellectual development and cognitive aging, for example, researchers now agree that the combined use of evidence from cross-sectional and longitudinal data leads to a more veridical estimate of age-related changes in cognitive abilities than the use of one of the two types of data sets alone (cf. Kruse et al. 1993). On the one hand, later cohorts tend to score at a higher level than earlier cohorts on some cognitive ability measures. In these instances, cross-sectional comparisons result in an overestimation of negative age trends. On the other hand, the effects of repeated testing and of nonrandom sample attrition limit the generalizability of longitudinal studies. In the field of cognitive aging, dropout is not random but reflects conditions that may be closely related to the dependent variable (i.e., ill health or death). For this reason, longitudinal data tend to underestimate negative age trends in cognitive abilities.

Recent analyses of adult age changes in cognitive abilities (Hertzog and Schaie 1986, 1988; Hertzog 1989; Schaie 1983) combined cross-sectional and longitudinal evidence and used latent structural modeling as well as hierarchical regressions to arrive at a better description and understanding of age-related change. The reanalysis of the Seattle Longitudinal Study (Schaie 1983) by Hertzog and Schaie (1986, 1988) was particularly instructive because the cohort-sequential design of this study allows for the estimation of age trends based on both longitudinal and cross-sectional comparisons. The following picture has emerged from this reanalysis and related work:

1. Interindividual differences in intellectual abilities are highly stable over the adult years (i.e., with seven-year interval stability coefficients greater than 0.90).
2. Between the ages of 57 and 63, most individuals begin to show significant decrements in intellectual performance.

3. Negative age trends in measures of perceptual speed seem to mediate most of the negative age trends in other cognitive abilities (Hertzog 1989; Schaie 1989).

These findings with normal (i.e., genetically noninformative) samples are well in agreement with the high heritability estimates found for intellectual functioning among older adults (Jarvik et al. 1972; Kallmann et al. 1951; Pedersen et al. 1992; Swan et al. 1990). The high stability of interindividual differences in adult cognition may reflect, to a large degree, the continuous influence of genetic factors. The analysis of longitudinal data sets of aging twins will help to clarify the extent to which interindividual differences in the onset and course of age-associated cognitive decline are also under genetic control. Recent findings reporting relatively high heritability estimates for measures of perceptual speed (Pedersen et al. 1992; Swan et al. 1990) are important in this regard. If perceptual speed is at least as heritable as other cognitive abilities, and if decline reflected in measures of speed drives the decline in other cognitive abilities, as suggested by recent evidence (Hertzog 1989; Schaie 1989), then genetic influence is likely to explain a major portion of the interindividual variability in age-related decline. Thus, longitudinal studies of aging twins are of prime importance to determine sources of interindividual differences in the onset and course of age-related cognitive decline during late adulthood.

GE CORRELATION AND G × E INTERACTION

Those not totally familiar with the mechanics of biometrical analyses often criticize these models as being invalid for not routinely including terms for GE correlation and G × E interaction. Several papers by behavioral geneticists (Plomin et al. 1977; Scarr and McCartney 1983; Loehlin and DeFries 1987), which point to the importance of these effects have been criticized by other behavioral geneticists (i.e., those employing rigorous model-fitting techniques) because their approach is often misrepresented.

Nonetheless, some developmental psychologists continue to find that these papers provide an attractive way to think about how both genetic and environmental factors may work together in shaping individual intelligence in that they try to side-step variance estimations by focusing on (so far psychological) mechanisms that contribute to GE correlation: selection, evocation, and manipulation of specific environments ("active" social interaction); a partner's responses to one's personality ("reactive" selection); evocation and manipulation of one's rearing environment by one's parents. This process-oriented point of view is highly attractive both to personality psychologists and to developmental psychologists because both fields view people as active producers of their own environment and development. The empirical implementation of this approach is solely concerned with the study of person-environment (PE) correlations and their changes over time. The fact that P depends in part on G is theoretically recognized but not empirically studied. There may be two advantages of this approach. First, it can specify psychological mechanisms that may explain GE covariance to some extent. Second, the notion that genetic and environmental differences can covary at the population level due to a continuous genotype-environment transaction at the individual level overcomes the pitting of genetic versus environmental influences and thereby helps developmental psychologists to accept that genetic differences must be considered in any study of individual differences.

Others, however, regard this as mostly wordy sophistry, largely intractable to experimental investigation. They point to a considerable body of rigorous theoretical and empirical work in this area (e.g., Baker 1989; Carey 1986; Eaves 1976; Eaves, Last, Martin et al. 1977; Eaves, Last, Young et al. 1977; Jinks and Fulker 1970), the sum total of which is that some, but not all, forms of G × E interaction and GE correlation *can* be detected in principle, but that few good replicated examples exist in the literature, even from studies that have had the power to detect these effects if they were there. This literature is largely ignored by developmentalists.

It was agreed, finally, that GE correlations and G × E interactions may be studied more explicitly by incorporating molecular genetic technology into classical twin designs, as discussed below more fully in this report.

DEFINITION AND CHARACTERIZATION OF HUMAN INTELLIGENCE

The standard claim that there *exists* a general ability factor (*g*), at least as traditionally defined through psychometric tests, was generally accepted by all discussants within this group. Disagreement was apparent, however, as to whether such a general factor is broad enough to capture the richness of intelligent behavior in humans. Some even argued vehemently that *g* is so narrow a concept that it should not be referred to as intelligence, per se. Others viewed the question of whether general and specific abilities exist as moot, and considered *g* itself to be an outmoded concept that has outlived its practical utility. Finally, some pragmatists emphasized that most researchers study what is already well-defined and measurable. Thus, *g* has considerable practical utility in behavioral genetic research and will continue to be used until alternative measuring instruments are available.

The major positions taken during the discussion are summarized below, along with reactions and criticisms from advocates of other positions. It must be realized, however, that some of these positions were already well-stated in the background papers (especially by Brand and by Fulker and Cardon) and are not emphasized in this chapter in proportion to the amount of time spent discussing them. Other positions not stated in those papers are given greater emphasis here.

The Existence and Importance of *g*

Brand (this volume) provides an overview of this position, which is representative of the "London School" of thought. In short, this position states that if a general factor can explain so much variation and covariation among test scores and other measures of success in life[1], then *g* must be important and worth studying in its own right.

Brand's argument for considering general intelligence (*g*) was that virtually all reliable measures of cognitive abilities show substantial positive intercorrelation. This pattern of relationships among tests was originally referred to by Spearman as a "positive manifold." Despite many twentieth-century efforts to identify independent dimensions of intellectual variation (e.g., by Thurstone, Guilford, Hudson, Gardner), *g*-factors continue to account for some 50% of the variance in matrices of correlations between abilities. Beyond *g*, other independent dimensions each typically account for less than 10% of the variance of abilities. From this perspective, *g* may be to cognitive psychology what carbon is to organic chemistry.

Many psychologists have tried to invent mental assessments that reflect features going beyond the "narrow, scholastic" assessments provided by *g*-loaded tests. J.P. Guilford proposed and tried to develop no less than 150 different ability measures, including assessments of "social intelligence" and divergent thinking. Today, R.J. Sternberg proposes hundreds of distinct mental processes (and their interaction effects) that might be tapped, and H. Gardner (see below) more modestly proposes seven mental abilities, akin to Thurstone's (ca. 1935). Yet none of these theorists has so far produced a battery of reliable and valid tests that are empirically independent of each other and of *g*. Some assert that most recent proposals (e.g., by Gardner) to develop elaborate observational methods for studying sources of variation would be expensive in terms of time, effort, and research monies, and would not yield any construct different than those already tapped by traditional IQ mental ability tests.

Although most agreed on the importance of *g* from both pragmatic and theoretical perspectives, some argued strongly for the importance of ability-specific variance in addition. Using confirmatory factor analyses with a hierarchical solution, one may explicitly *test* (i.e., via nested comparisons) whether the first-order (specific ability) factors capture any reliable variance that is not represented at the second-order (*g*) level. (This is precisely the logic underlying the Fulker and Cardon developmental model [see chapter 4, this volume]). Based on this approach, Horn and Cattell (1966), for example, have unambiguously demonstrated that there is reliable ability-specific variance.

Alternative Definitions of Intelligence and Cognition

It was strongly argued that the view of cognition and intelligence put forth by the London School is so widely accepted in its broad outlines that it is difficult for many people to envision an alternative position. Critics of this view assert that the concept of intelligence and the instrument of the intelligence test were the results of a particular

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[1] O'Toole and Stankov (1992) show that IQ is a significant predictor of mid-life mortality, giving this statement literal meaning.

history and set of circumstances obtained a century ago. Researchers in England and France, in particular, were searching for ways of predicting failure in a specific institution: the turn-of-the-century school. These schools were said to stress the kinds of literacies that were important for administrators or bureaucrats in large organizations and particularly in far-flung empires.

How might intelligence—or cognate concepts—be defined or assessed in a very different kind of culture, for example, one without schooling at all or one in which the skills of the hunter, sailor, shaman, orator, mystic, or trader might be at a premium? How might such skills be assessed if paper-and-pencil or other short-answer instruments had not been invented or were for some reason proscribed?

Theory of Multiple Intelligences (MI)

In the last decade, in response to new work in the cognitive sciences and as a result of growing dissatisfaction with the limitations of traditional instruments, psychologists have put forth quite different views of intelligence (Baron 1985; Ceci 1990; Gardner 1983; Olson and Bruner 1974; Pea 1992). These views incorporate greater attention to the particular operations involved in problem-solving and product-making, the differences in skills across different domains, the role of cultural expectations and reward systems, and the social context of much intellectual activity. While standard psychometric activities continue, and sometimes incorporate new technologies, there is a tension between the London School and these new, broader, and more contextualized views of intelligence (Sternberg 1985, 1988; Sternberg and Detterman 1986).

One influential theory has been put forth by Gardner (1983, 1992). Rejecting psychometric techniques altogether, Gardner bases his theories principally on two lines of evidence: (a) the diverse roles or "end-states" that are valued in cultures around the world; (b) knowledge about the evolution and current organization of the cerebral cortex. Gardner defines *an* intelligence as the capacity to solve problems or fashion products that are valued in at least one culture. Drawing on eight distinct lines of evidence, Gardner proposes that human beings as a species have evolved to be able to carry out at least seven forms of information-processing or "intelligences"; in addition to the linguistic and logical faculties highlighted in schools and in most standardized measures of intelligence, Gardner proposes spatial intelligence, musical intelligence, bodily kinesthetic intelligence, interpersonal intelligence, and intrapersonal intelligence.

Gardner and his colleagues have attempted to develop techniques for assessing these intelligences in "intelligence-fair" ways. Among the most promising ways are the creation of new environments—resembling children's museums, in some respects—in which individuals reveal their intellectual proclivities and strengths by their patterns of interaction with various materials, puzzles, etc. It is possible to create reliable systems for scoring the intelligences of participating young children. Other methods for assessing intelligences include teaching new languages or games, with appropriate scaffolding, in order to determine potential in different intellectual domains, or the opportunity for subjects to engage in various simulations, which might be delivered by computer technology.

Misconceptions Regarding MI Theory

Contrary to the implications of Brand's paper (this volume), MI theory makes no claim about the hereditary or nonhereditary nature of the several intelligences. Nor are the intelligences related to social class, except insofar as lack of exposure to, say, music, will prevent the development of musical intelligence. Neither is MI theory committed to the independence or nonindependence of the several intelligences; their relation (or lack of relation) is an empirical matter to be determined by intelligence-fair instruments.

At the workshop, much discussion focused on the relationship between *g* and MI theory. Gardner did not dispute the existence of substantial estimates of heritability for *g*. With other participants, he believes that the nature of psychometric *g* has yet to be understood and may be, to some extent, an artifact of the kinds of instrumentation used and of the background of testing as we know it today. Critics pointed out that once MI theory is fully instrumented, it may well turn out that scores on the various intelligences will yield a "positive manifold." Gardner argued that were "tests" of intelligence to be constituted quite differently, or to be used in very different environments (e.g., non-schooled environments), *g* might either loom much less important, or a new *g*, only loosely related to the current scholastically oriented *g*, might emerge through a suitable kind of factorial analysis. Critics of MI theory pointed out that many new kinds of tests have been tried and have fallen by the wayside, and that tests with good reliability and validity yield a substantial *g*.

Gardner argued that one implication of the "*g* perspective" is that individuals can be aligned in terms of a single general ability and that education should be carried out differently for various individuals, based on the intellectual potential assessed by the IQ test. He argued for an aptitude-by-trait interaction view but acknowledged lack of evidence for this view. He also argued that the belief that an educational approach will be effective can itself be very powerful (Dweck and Licht 1980). The Japanese Suzuki Talent Education is able to evoke powerful—even prodigious—musical performances from youngsters, independent of assessed intellectual level or potential. Critics of his view maintained that claims of potentially powerful interventions seldom stand the test of time and rigorous evaluation.

Multiple Views on the Meaning and/or Causes of *g*

There was considerable discussion of what mechanisms *g* might represent. A common view among psychologists is that *g* represents the general problem-solving capacity of the brain. Its existence is supported substantially through statistical analyses at the phenotypic level (see Brand, this volume). Quantitative geneticists view *g* as a phenotypic trait that is to a considerable degree under the influence of many genes.

This *g*, however, may be, in whole or in part, an evolutionary "artifact" of cross-character assortative mating for many specific cognitive abilities (see Eaves et al. 1984) that have separate adaptive functions.

An alternative view, from a neurological perspective advocated by Kinsbourne, is that *g* simply reflects the overall effectiveness of a well-formed brain not subjected to any disruption pre- or postnatally and which has had sufficient opportunity to acquire skills necessary to score well on an IQ test. This view expressly denies that *g* can be attributed to any particular location or module of the brain and is highly consistent with the argument that evolution selects for specialized rather than general purpose mechanism (see below). The existence of mentally retarded individuals with special abilities (idiot savants) shows that specific mental capacities or skills can exist even in individuals who do not have well-formed brains and have quite low IQs.

THE EVOLUTIONARY FRAMEWORK OF COGNITION

There was a great diversity of opinion regarding how evolutionary issues in human cognition should be addressed. Biometrical analyses address the issue via the genetic and environmental architecture of the trait(s). Information is gained about gene action (e.g., genetic dominance, epistasis), the effects of different mating systems (e.g., assortative mating, inbreeding). These analyses suggest that both social and biological significance attach to traditional measures of intelligence. Evolutionary psychology takes an entirely different approach and analyzes the adaptive significance of various aspects of mental abilities. This approach rejects, on broad evolutionary grounds, the possibility that evolution would have generated a general purpose problem-solving mechanism.

Biometrical Analyses and Inbreeding Studies: Evidence for Directional Dominance in Intelligence

The evolutionary significance of cognitive abilities can be illuminated through the partitioning of variances and covariances in biometrical analyses. In addition, some predictions can be tested through inbreeding studies. Fitness characters have predictable patterns of genetic architecture, which can be revealed through quantitative genetic designs. According to Fisher's fundamental theorem, if intelligence has been subjected to constant natural selection throughout evolutionary history, additive genetic variance for cognition should have vanished by now and only nonadditive genetic variance should remain. In fact, this extreme case is not found in nature; considerable additive genetic variance is always detected for a wide range of important fitness characters in both animals and plants. One reason why Fisher's asymptote is not attained may be that the environment never stays constant long enough for all additive variance to be fixed. Thus, the interesting criticism of *g* that some might be tempted to assert, i.e., that *g* cannot be important because there is too much additive variance, does not hold up when examined in the context of a broad array of empirical evidence.

Studies of inbreeding do suggest directional dominance (or epistatic) effects, whereby children of cousin marriages (who are partially inbred) show a depression in mean IQ of about 2–3 points compared to non-inbred children (Bashi 1977; Jensen 1983). In addition, children from incestuous matings not only show a variety of physical defects but also evidence for cognitive deficits (Bouchard 1993). Inbreeding reveals recessive alleles in homozygous combinations (and directly reveals effects of directional dominance). The phenomenon of inbreeding depression is common in many species and is a clear indication that we are dealing with a fitness characteristic. It suggests that recessive alleles are associated with low rather than high IQ, and Fisher's theory of the evolution of dominance, supported by evidence from plant and animal experiments, suggests that there has indeed been selection for high IQ through much of human evolution. Thus, whatever the views of educational psychologists about the importance of IQ, it is clear that it has been an important trait in evolution (Mather 1974).

Do we find evidence for directional dominance in areas other than inbreeding studies? Bouchard and McGue's (1981) data for twins do not suggest dominance, but only additive genetic variance and common environmental effects. However, twin studies alone have very low power to detect dominance (Martin et al. 1978), so this is not surprising. Even worse, dominance and shared environmental variance are completely negatively confounded in the classical twin study and, if both are acting, it is impossible to estimate the relative importance of either. However, with the inclusion of other relationships, such as parents and offspring, half siblings, or biological and adopted siblings, the presence of dominance could be inferred. Unfortunately, the power to detect dominance as a variance component is much less in these designs than as a mean effect in inbreeding studies, provided that it has a directional component.

An extra complication is that any dominance effects may be masked by developmental trends in genetic influences on IQ (which make the parent-offspring correlation lower than the sibling correlation, and the sib correlation lower than the DZ twin correlation) and by the effects of assortative mating (which mimic shared environment and are thus negatively confounded with dominance unless there are spousal data). Assortative mating increases additive genetic variation between families and may accentuate social stratification—if IQ is socially important. The analysis of dominance effects depends to a large extent (except for inbreeding studies) on resemblance among relatives who are not of the same age (e.g., parent-offspring). This highlights the need to consider developmental issues in modeling research. The background papers concerned with the modeling of development clearly show the conditional nature of genetic variation at different age points. Genetic and environmental variations are not fixed; the patterns may change over time and, more importantly, the organization of cognitive abilities may change with time due to developmental processes. The only way to address these important issues is to use a multivariate longitudinal design.

Evolutionary Psychology

Taking the functional approach of evolutionary psychology, Buss argued for greater significance of specific cognitive abilities, as opposed to a "*g*-factor," in adaptation of humans (see also Buss, this volume). Consistent with this view, it was pointed out by the population geneticists that the highly correlated genetic influences across many diverse cognitive abilities may be simply an artifact of cross-character assortative mating for these specific abilities (see Eaves et al. 1984).

Because of the numerous complex and specialized adaptive problems that humans have faced over evolutionary history, evolutionary psychologists expect human cognitive abilities to be numerous, specialized, complex, and domain-specific (Tooby and Cosmides 1990, 1992). By analogy, the body has a heart to pump blood, a liver to filter impurities, and sweat glands for thermal regulation—numerous, specialized mechanisms, each tailored to perform different functions and solve different adaptive problems, yet all working together within the organism.

A heuristic set of evolutionary psychological criteria for validating the existence of different intellectual or cognitive mechanisms was proposed by Buss:

1. Are there different mechanisms activated by different input (i.e., different adaptive problems confronted)?
2. Do different information-processing rules apply?
3. Do the outputs solve different adaptive problems?
4. Are different parts of the brain more active when solving different problems (e.g., as shown through PET scans)?
5. Do the sexes differ in observed ability in ways that correspond to the different adaptive problems each sex has presumably faced?

These criteria are merely heuristic and provisional, but do suggest a set of nonarbitrary standards for identifying specialized cognitive mechanisms.

Buss also advanced the possibility that there may be specialized cognitive mechanisms, each of which is uniquely configured to process information about different adaptive problems. These adaptive problems could include gathering and scavenging (spatial location memory) (Silverman and Eals 1992); hunting (spatial rotation) (Silverman and Eals 1992); cheater detection in social exchange (Cosmides 1989); reciprocal alliance formation (Buss 1986); hierarchy negotiation (Buss 1986); coalition formation and maintenance (Tooby and Cosmides 1990); infidelity detection (Buss et al. 1992); identification of beliefs and desires in others (concepts of mind) (Wellman 1989). Evolutionary psychology provides a heuristic for identifying what many of these adaptive problems are and hence a guide to uncover the possibly numerous cognitive mechanisms and abilities that humans possess.

Should these cognitive mechanisms be considered as "modules"? The neuroscientists argue that the term "modularity" is ill-conceived when applied to complex behaviors. Focal brain lesions do not selectively eliminate capabilities such as lie detecting or hierarchy negotiation. Such activities result from the coordinated use of more primitive underlying mental operations. Only the latter are selectively eliminated by focal lesions. Modularity reduces to the differential coordination of various parts of the brain to accomplish different cognitive operations. Phrased differently, complex activities are generated by neural "software" that coordinates particular subsets of primitive operations. Whether such software itself is differentially available to the two genders or is a genetically determined individual variable is an issue that deserves further study.

THE ROLE OF TWIN STUDIES IN ADDRESSING THESE ISSUES

What do these positions on the definition and nature of intelligence have to offer each other? Can their differences be resolved through the use of behavioral genetic studies? Here, the extent to which biometrical analyses of twin and adoption data can address these issues is summarized.

The lack of well-defined measuring instruments available to assess Gardner's constructs was a major criticism of his position. Thus, *g*, especially if it is defined as a higher-order factor of intercorrelated cognitive abilities, maintains great usefulness in genetic designs: it is well measured and shows importance in predicting various kinds of success in life (Barrett and Depinet 1991; Behrman et al. 1980). It remains to be seen whether Gardner's alternative measures, when they appear, will be useful in our study of individual differences.

Those who advocate alternative measures of intelligence might find genetically informative designs to be of some use in the actual development of such new constructs and their operational measures. They might conceptualize their variables somewhat differently if their observations were made on MZ and DZ twins rather than on nongenetically informative individuals. For example, if the hypothesis states that musical intelligence has a core of abilities, the best way to find that out is through the study of MZ twins reared apart. Certain pairs of abilities may have a genetic correlation, as opposed to being independent factors. This is just to say that definitions of intelligence might be *different* (not necessarily *better*) if developed with information about genes, environment, and evolutionary significance.

Some behavioral genetic studies of more contemporary measures of cognitive abilities have already begun. For example, a wide range of information-processing tasks are being investigated in twins, in an effort to study more closely the component processes involved in complex mental functioning (e.g., Baker et al. 1991; McGue and Bouchard 1989; Vernon 1989). These studies may possibly help to identify just what are the specific "core operations" within a general area like verbal or spatial performance. Extensions of these studies may also prove useful in understanding basic operations related to musical talent or mathematical ability. Presumably these "core operations" are most likely to be linked to specific gene complexes. Educational interventions are most likely to be effective if the structure of these complex faculties is better understood and if one has the options of "supplementing" operations that are impaired.

We might also consider how biometrical analyses of genetic and environmental architecture might enter into the evolutionary psychology perspective. It is incumbent upon evolutionary psychologists to show that there is specific variation for these abilities not explained by *g*, and that there is genetic variation for these specifics with nonadditive variation acting in the predicted direction.

OTHER ISSUES: PAST AND FUTURE

Studying the Environment

Twin studies are usually thought of as providing information about genetic influences. They can, however, with equal validity be used to examine environmental influences on the phenotype. First, a twin study can demonstrate that an environmental influence exists, and the variance can be partitioned into shared and nonshared environmental influences.

Mascie-Taylor (this volume) documents the numerous correlations between what are commonly, but erroneously, called "environmental" factors with respect to intelligence. These correlations are difficult to interpret, however, because of the inevitable confusion between genetics and environment in nuclear families and the covariation between the environmental factors. The same pregnant woman may, for example, abuse alcohol, continue to smoke, use illicit drugs, suffer from poor nutrition, and have inadequate hygiene and medical care during pregnancy. An adverse outcome for her child is not immediately interpretable in terms of environmental factors because these characteristics may be more frequent in women with a genetic predisposition to low intelligence and maladaptive behaviors such as an undue sensation-seeking tendency. Thus, the fetal outcome may consequently reflect, in part, those antecedent genetic conditions as opposed solely to the intervening environmental variables.

The importance of both prenatal and postnatal factors in the study of environment is discussed elsewhere in this volume (see Macdonald et al.). In our own discussions, there was particular concern that prenatal factors may not entirely be considered as shared environmental effects. Although prenatal factors that are typically classifiable under shared environment may include maternal nutrition, fetal oxygenation, and the effects of circulating toxins, there may be a differential placental vasculature, particularly in MZ twins (e.g., the MZ twin transfusion syndrome), that produces large differences between co-twins (e.g., in birthweight) (see also Bryan, this volume).

Genetic variance may appear as environmental if an environmental effect arises from a genetically controlled risk factor. The following (hypothetical) sequence of events is illustrative: An immune-dysfunctional mother becomes sensitized to a fetal antigen. The resulting immune reaction damages fetal brain development (Adinolfi

1976). (Neuromigrative and synaptic pruning impairments in dyslexics may be a case in point.) So the product—dyslexia, though arising from an adverse intrauterine event—may result from a maternal effect based on a genetically transmitted variable, immune dysfunction.

Bishop was concerned with the polarization between genetics and environment implicit in Brand's paper (this volume). As Rutter (1991) pointed out, it is a common misconception that if a trait shows strong heritability, then environmental factors are unimportant. High heritability indicates that genetic factors account for a high proportion of variance within the population, but it does *not* imply that the trait cannot be altered by environmental manipulations. Estimates of heritability will depend on the range of environments in the population: as environments become more uniform within a population, genetically based individual differences will account for a greater proportion of the variance. To take an extreme example, one can demonstrate high heritability for spelling ability in Western societies (e.g., Stevenson et al. 1987). However, one might expect to find lower heritability in a society such as rural Papua New Guinea, where access to schooling is much more haphazard. Environmental factors that are common to all individuals in a society (e.g., schooling in a Western society) may have an impact on the mean level of a trait, without opposing findings from studies demonstrating secular changes in the average level of a strongly heritable trait (Rutter uses the example of height, although IQ is also relevant here). One would expect this to occur if the whole population was exposed to a change in environment. Clearly, it is naive to assume that affording everyone comparable environmental opportunity and support will eliminate individual differences in intelligence. However, we should beware of concluding that a highly heritable trait is nonmodifiable. Rutter (1991) points to the example of phenylketonuria as a genetically determined form of mental retardation that can be treated by imposing dietary restrictions outside the normal range of environmental variation. Far from being irrelevant, modification of the environment may be especially important for children with a genetic predisposition to low ability.

The same kinds of issues raised with respect to the conceptualization and measurement of cognition were also raised by Gardner with respect to the environment. He urged caution with respect to the sampling and range of environments studied by behavioral geneticists, and emphasized a need to take into account what is known about radically different cultures (Geertz 1973). In addition to a focus on the home and school, it may be useful to observe and measure personality and social features in unfamiliar environments (like a new city), in rich environments (like a "hands-on" museum), and across environments (how consistent is behavior at home and in school?). Behaviors between siblings, or between siblings and parents, may also vary substantially across situations (Mischel 1968), and need to be regarded in more than an unequivocal way.

These criticisms suggest the possibility of interactions between *persons* and *situations*. Critics of these ideas, however, argued that it remains incumbent on those who insist on the importance of *person* × *situation* interactions to show that the interaction variance is large relative to the main effect, and that it is adaptively important. Failing this, whatever the range of tasks and environments proposed in speculations of Gardner and others, *g* remains the best single predictor of success, provided the latter is defined within a moderately sensible Darwinian framework.

Gardner also raised the issue of reliance on self-reports and other short-answer measures of environmental factors, which often show low reliability and validity (see Nisbett and Ross 1980; Kahneman et al. 1982, concerning criticisms of introspective reports). Systematic and reliable obervations of sibling-sibling and parent-child relations, however, have showed considerable consensus among family members and have been used successfully in exploring the nature of environment effects in genetically informative designs (see Baker and Daniels 1990; Plomin and Daniels 1987).

One conclusion that received consensus was that environmental effects can be studied most appropriately in biometrical designs. By including measured indices of the environment in model-fitting analyses of twin and adoption data, one can evaluate the full extent of latent sources of their variation and covariation with cognitive outcomes.

Speed of Processing

A particularly unlikely correlate of IQ is inspection time (discovered by Nettlebeck in Australian retarded individuals; see Nettlebeck 1987). The shortest exposure for which an individual can make a judgment of difference in lines correlates moderately with scores on IQ tests (see Vernon 1987). Simple measures of information-processing speed deserve further attention in twin research.

Arguably, individual differences in basic information processing speed underlie surface differences in psychometric *g*. One theoretical model is provided by Anderson (1992), where *g* is akin to a tape recorder, and specific abilities (e.g., verbal, spatial, memory) are akin to tapes: a good tape recorder allows differences between the quality of tapes to be detected, and relatively high *g* is similarly envisaged to allow the differentiation of specific abilities to be observed. Anderson's model accords with Detterman and Daniel's (1989) observation that, in psychometric data, *g* factors appear stronger (i.e., *s*-factors emerge less clearly and strongly) in testees ranging across lower values of *g*. Thus, perhaps we can reconcile the general omnipresence and explanatory power of *g* with the apparent differentiation of specific abilities in people with higher levels of *g*. Might Spearman's *g* thus be partly reconciled with Gardner's MIs?

Some argued against such optimism, however, in explaining IQ differences as a function of inspection time. Working memory (Baddeley 1986, 1992) was mentioned as another possible candidate for explaining individual differences in IQ (see Kyllonen and Christal 1990).

Kinsbourne argued that such diverse procedures as reasoning, discriminative reaction time, estimates of working memory, stability of the configuration of the evoked potential and even peripheral nerve conduction time all exhibit high correlations with psychometric *g*, making it unlikely that *g* represents a separate mental domain, like speed of processing. Rather, it could represent the general integrity or well-formedness of the nervous system, just as the presence or absence of minor congenital abnormalities may index the well-formedness of the body. A better-developed brain better houses specialized processors (such as those listed by Gardner).

Deviations from well-formedness can be local in the brain and impact differentially on differential mental skills. Thus, an uneven skill profile could arise from selective deficit, as readily as from selective ability development. Neither origin can simply be assumed. They may, however, converge. Differences in neural synaptic organization may characterize genetically disparate brains as well as distinguish damaged from undamaged brains.

Secular Rise in Average IQ

The worldwide rise in IQ test raw scores has been documented by Flynn (1987). Based primarily on military sources of young men tested in the 1950s to 1970s in 14 advanced Western countries, Flynn claimed there was a massive IQ rise of 5 to 25 points in a single generation. In his review, Flynn therefore criticized IQ tests as not highly scholastic, but being limited to abstract rather than real-world problem-solving ability. Flynn claimed, thus, that intelligence must be a socially unimportant characteristic. Perhaps teachers do not take notice of individual abilities, and educational attainment is based on hard work rather than individual intelligence.

Alternative explanations for the secular change in IQ performance were discussed:

1. Intelligence and educational levels might have risen due to twentieth-century improvements in schooling. There are, however, no undisputed educational improvements, and pupil-teacher ratios are uncorrelated with pupils' success; Flynn himself rejects this explanation outright and calls attention to the loss in SAT scores over the same time period.
2. The rise may only have occurred on some types of IQ tests, especially those involving multiple-choice format, time-limited administration, no guessing correction, and built-in penalties for persistence in trying to solve hard items (see Brand 1990). Flynn believes that the very slight rise in Scottish IQ subtest scores since 1962 hides, because of methodological errors, a large increase in real IQ (which Flynn holds, however, to reflect "mere problem-solving ability").
3. Improved nutrition is another explanation provided by Schoenthaler (1991; see also Blinkhorn 1990). However, this involves a marked shift from previous hereditarian positions allowing nutritional effects on IQ only at very low levels of either nutrition, IQ, or both.
4. Better maternal and infant health in recent years leads to a more well-formed brain.

Can twin and adoption research shed light on the causes of these secular changes in IQ test performance? The conventional wisdom in behavioral genetics is that group means and individual differences represent two different realms of variation so that inferences about the etiology of group differences have no implications for inferences about individual differences. Rowe argued that this is false. There are two realms of variance—between and within groups—but only one realm of developmental process. A similar point has recently been made by Turkheimer (1991). Thus, developmental process should affect both group means and individual differences, and findings for group differences are relevant for individual differences and vice versa. This is true except in certain specialized conditions, such as when there is restricted sampling or the introduction of new influences. The outcomes for group and individual variation may be different, but exceptions to a rule do not falsify it. For example, lead exposure influence on IQ can be detected in a study of unrelated siblings reared together if some pairs are lead exposed and some are not. It will also be detected in a comparison of group means when one group has more lead exposure than another. Hard scientific questions, such as race differences in IQ, cannot be avoided by claiming that group means and individual differences are intrinsically different. They are not, because there is only one seamless process of development.

Several attempts have been undertaken to arrive at models allowing the simultaneous analysis of mean variation and individual differences (Dolan et al. 1992; Turkheimer 1991). These models represent steps towards the empirical study of the possible relationship between group means and individual differences.

The Role of Molecular Genetics in Quantitative Genetic Designs

What will be the future of the twin method in light of rapid developments in molecular genetics and its application to studying continuous traits like cognitive abilities? Some biologists believe that the rapid advances in molecular genetics will soon render obsolete biometrical studies of twins, families, and adoptions. There was a general consensus that nothing could be further from the truth, for as soon as a single gene effect has been found, one will want to estimate the proportion of variance, or risk, that it accounts for. While this can be done on a sample of unrelated individuals, traditional twin or family design will allow a much richer range of hypotheses to be tested, as well as help to avoid some of the pitfalls of artifactual associations produced, for example, by population stratification. We may ask how much of the remaining variance is genetic (Martin et al. 1987). Is there evidence of epistatic interaction with the polygenic background and, if so, what kind (Martin et al. 1987)? Comparing the intrapair variance of MZ twins of different measured genotypes allows one to test whether environmental sensitivity is under genetic control ($G \times E$ interaction). For example, MZ twins of blood group M have lower intrapair variance in serum lipid levels than those of blood group N (Martin et al. 1983). This suggests that environmental factors (e.g., diet) may play a more important role in N than M individuals. In searching for "IQ genes" in the framework of a twin study, it would be just as important to look for genes with effects on environmental sensitivity using this technique, as effects on the mean. Of course, since the former relies on a variance ratio test (Martin et al. 1983), it has much less power than tests for mean differences.

With respect to the effects of a measured genotype on a phenotype such as IQ, even while this can be done on unrelated individuals, the use of twins is very attractive because of the possibility to partition the phenotype into a genetic and a nongenetic part at the level of the individual. Attention was drawn to the work of Boomsma, Molenaar, and Orlebeke (1990) and Boomsma, Molenaar, and Dolan (1991), who extended the genetic analysis of covariance structure to the estimation of individual environmental and genetic factor scores. In principle, and under favorable circumstances in the context of twin studies, it should be possible to assign each individual twin both a genetic and an environmental factor score. In this case, it might prove more powerful to look for measured gene effects on estimated genetic factor scores than on phenotypic measurements.

Analysis of Extremes

Alternative approaches to genetic analyses of normal variation in cognition were also highlighted. Examination of extremes of talent using the Fulker and DeFries (1985) regression method, tetrachoric correlations (e.g., Baker 1986), or ordinal regression techniques could prove particularly useful in understanding sources of abnormal variation. These might also prove particularly useful in exploratory analyses of alternative measures of intelligence, as one does not even need well-validated constructs to work with genetically informative designs. Those of Gardner's persuasion could use ratings or ordered variables or a "cafeteria of opportunity" measurement system in twin design, e.g., as a preliminary, exploratory analysis.

CONCLUSIONS AND SUGGESTIONS FOR FUTURE RESEARCH

Our discussions reflected communication among, and challenges offered to, several different research traditions and schools of thought. It is hoped that developmental psychologists, neuropsychologists, evolutionary psychologists, and cognitive psychologists will soon recognize that behavioral geneticists are keenly aware of many theoretical issues they allegedly ignore (e.g., G $\times$ E covariation, effects of the environment, developmental processes). More importantly, behavioral genetic methods are actually the most appropriate methods to study such issues.

Several suggestions for future research are apparent in this report. These are briefly reiterated below.

1. Study the decline in aging and its relationship to speed of processing.
2. Use biometrical models to study "environmental" variables, such as presented by Mascie-Taylor (this volume).

3. Use twin and adoption methods to develop and evaluate new measures of intelligence.
4. Examine abnormal variation by analyzing extremes of talent, e.g., using the Fulker and DeFries (1985) regression method for twin data.
5. Use linkage and candidate gene approaches to study the nature of genetic influences on specific abilities. This will also allow more detailed study of GE correlation and interaction (e.g., see Martin et al. 1987a,b).
6. Study differences between MZ twins as a means of specifying environmental effects. This has been nicely illustrated by Kinsbourne's examples, as a means to explicate neurological mechanisms (which could be genetic or environmental in origin) related to cognitive development.
7. Continue use of longitudinal twin and adoption studies (illustrated by Fulker and Cardon and by Boomsma, this volume) to examine whether stability in genetic factor scores at the level of *g* is better predicted by *g* itself or by cognitive abilities underlying *g*; that is, is stability higher for first-order abilities than for *g*?

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