Behavior Genetics: What's New? What's Next?

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Abstract

What's new in behavior genetics? With widespread acceptance that nearly all behavioral variation reflects some genetic influence, current studies are investigating developmental changes in the nature and magnitude of genetic and environmental effects, the extent to which different behaviors are influenced by common genes, and different forms of gene-environment correlation and interaction. New designs, focused on assessment of unrelated children in the same households or neighborhood environments, and use of measured environmental variables within genetically informative designs, are yielding more incisive evidence of common environmental effects on behavior. What will be next? Behavior genetic techniques and analyses will be used to inform efforts to find genes altering susceptibility for disorder and dispositional genes affecting behavioral variation. The developing integration of behavioral and molecular genetics will identify genes influencing specific behavioral variation and enhance understanding of how they do so. Psychologists will play a pivotal role in communicating that understanding to the public and in facilitating consideration of the inevitable ethical issues then to be confronted.

Keywords

behavior genetics; molecular genetics; development; gene-environment interaction

Through most of its brief history, behavior genetics had a single and simple goal: to demonstrate that some of the variation in behavior is attributable to genetic variance. Now, a diverse array of behaviors has been investigated with twin and adoption designs, yielding evidence that genetic variation contributes to individual differences in virtually all behavioral domains (McGuffin, Riley, & Plomin, 2001). Is behavior genetics, then, a thing of the past, a field whose success makes it obsolete? Not at all: Never has behavior genetic research held more promise. Investigators now possess analytic tools to move from estimating latent, unmeasured sources of variance to specifying the genes and environments involved in behavioral development, and the ways in which they interact. Our modest aim in this essay is to describe the questions now asked by behavior geneticists and to sketch the role that the field will assume in the emerging era of behavioral genomics.

A DEVELOPMENTAL PERSPECTIVE

Traditional behavior genetic analyses divide observed behavioral variance into three unobserved (latent) sources: variance attributable to genetic effects, that due to environmental influences shared by siblings (e.g., family structure and status), and that arising in unshared environmental experience that makes siblings differ from one another. Estimates of the

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magnitude of these genetic and environmental effects are usually obtained from statistical path models that compare identical twins, who share all their genes, with fraternal twins, who like ordinary siblings, on average, share one half their genes. Behavior genetic research now identifies developmental changes in the importance of genetic dispositions and environmental contexts in accounting for individual differences in behavior. Such changes can be dramatic and rapid. For example, we assessed substance use in a sample of adolescent Finnish twins on three occasions from ages 16 to 18 1/2; we found that genetic contributions to individual differences in drinking frequency increased over time, accounting for only a third of the variation at age 16, but half of it just 30 months later (Rose, Dick, Viken, & Kaprio, 2001). Concurrently, the effects of sharing a common environment decreased in importance. Interestingly, parallel analyses of smoking found little change in the importance of genetic and environmental effects, illustrating the trait-specificity of gene-environment dynamics: Some effects are stable across a developmental period; others change.

DIFFERENT BEHAVIORS, SAME GENES?

It is well known that certain behaviors tend to co-occur, as do certain disorders, but the causes of such covariance are much less understood. Behavior genetic models assess the degree to which covariation of different disorders or behaviors is due to common genetic influences, common environmental influences, or both. An example can be found in the significant, albeit modest, correlations observed between perceptual speed (the minimum time required to make a perceptual discrimination, as assessed with computer display methods) and standard IQ test scores (Posthuma, de Geus, & Boomsma, in press); those correlations were found to be due entirely to a common genetic factor, hypothesized to reflect genetic influences on neural transmission. Another example is found in our study of behavioral covariance between smoking and drinking during adolescence. Genes contributing to the age when teens started smoking and drinking correlated nearly 1.0 (suggesting that the same genes influence an adolescent's decision to begin smoking and to begin drinking), but once smoking or drinking was initiated, genes influencing the frequency with which an adolescent smoked or drank were quite substance-specific, correlating only about .25.

GENE-ENVIRONMENT INTERACTION AND CORRELATION

The interaction of genes and environments has been difficult to demonstrate in human behavioral data, despite consensus that interaction must be ubiquitous. New behavior genetic methods are demonstrating what was long assumed. These methods use information from twins who vary in specified environmental exposure to test directly for the differential expression of genes across different environments. For example, genetic effects played a larger role in the use of alcohol among twin women who had been reared in nonreligious households than among those who had been reared in religious households (Koopmans, Slutske, van Baal, & Boomsma, 1999). Similarly, we found greater genetic effects on adolescent alcohol use among Finnish twins living in urban environments than among those living in rural environments (Rose, Dick, et al., 2001).

These demonstrations of gene-environment interaction used simple dichotomies of environmental measures. But subsequently, we explored underlying processes in the interaction effect of urban versus rural environments by employing new statistical techniques to accommodate more continuous measures of the characteristics of the municipalities in which the Finnish twins resided. We hypothesized that communities spending relatively more money on alcohol allow for greater access to it, and communities with proportionately more young adults offer more role models for adolescent twins, and that either kind of community enhances expression of individual differences in genetic predispositions. And that is what we found: up to a 5-fold difference in the importance of genetic effects among twins residing in communities at these environmental extremes (Dick, Rose, Viken, Kaprio, & Koskenvuo, 2001), suggesting that the influence of genetic dispositions can be altered dramatically by environmental variation across communities.

Analysis of gene-environment interaction is complemented by tests of gene-environment correlation. Individuals' genomes interact with the environmental contexts in which the individuals live their lives, but this process is not a passive one, for genetic dispositions lead a person to select, and indeed create, his or her environments. Perhaps the most salient environment for an adolescent is found in the adolescent's peer relationships. In a study of 1,150 sixth-grade Finnish twins, we (Rose, in press) obtained evidence that they actively selected their friends from among their classmates. This result is consistent with the inference that people's genetic dispositions play

some role in their selection of friends. People like other people who are like themselves, and genetically identical co-twins make highly similar friendship selections among their classmates.

MEASURING EFFECTS OF THE ENVIRONMENT IN GENETICALLY INFORMATIVE DESIGNS

In traditional behavior genetic designs, environmental influences were modeled, but not measured. Environmental effects were inferred from latent models fit to data. Such designs understandably received much criticism. Now, behavior geneticists can incorporate specific environmental measures into genetically informative designs and, by doing so, are demonstrating environmental effects that latent models failed to detect. Thus, we have studied effects of parental monitoring and home atmosphere on behavior problems in 11- to 12-year-old Finnish twins; both parental monitoring and home atmosphere contributed significantly to the development of the children's behavior problems, accounting for 2 to 5% of the total variation, and as much as 15% of the total common environmental effect. Recent research in the United Kingdom found neighborhood deprivation influenced behavior problems, too, accounting for about 5% of the effect of shared environment. Incorporation of specific, measured environments into genetically informative designs offers a powerful technique to study and specify environmental effects.

In other work, new research designs have been used to directly assess environmental effects in studies of unrelated children reared in a common neighborhood or within the same home. We have investigated neighborhood environmental effects on behavior in a large sample of 11- to 12-year-old same-sex Finnish twins. For each twin, we included a control classmate of the same gender and similar age, thus enabling us to compare three kinds of dyads: co-twins, each twin and his or her control classmate, and the two control classmates for each pair of co-twins. These twin-classmate dyads were sampled from more than 500 classrooms throughout Finland. The members of each dyad shared the same neighborhood, school, and classroom, but only the co-twin dyads shared genes and common household experience. For some behaviors, including early onset of smoking and drinking, we found significant correlations for both control-twin and control-control dyads; fitting models to the double-dyads formed by twins and their controls documented significant contributions to behavioral variation from nonfamilial environments—schools, neighborhoods, and communities (Rose, Viken, Dick, Pulkkinen, & Kaprio, 2001).

A complementary study examined genetically unrelated siblings who were no more than 9 months apart in age and who had been reared together from infancy in the same household. An IQ correlation of .29 was reported for 50 such dyads, and in another analysis, 40 of these dyads were only slightly less alike than fraternal co-twins on a variety of parent-rated behaviors (Segal, 1999). Clearly, appropriate research designs can demonstrate effects of familial and extrafamilial environmental variation for some behavioral outcomes at specific ages of development.

INTEGRATING BEHAVIOR AND MOLECULAR GENETICS[2]

Where do the statistical path models of behavior geneticists fit into the emerging era of behavioral genomics (the application of molecular genetics to behavior)? In the same way that specific, measured environments can be incorporated into behavior genetic models, specific information about genotypes can be included, as well, to test the importance of individual genes on behavior. Additionally, the kinds of behavior genetic analyses we have described can be informative in designing studies that maximize the power to detect susceptibility genes. Many efforts to replicate studies identifying genes that influence clinically defined diagnoses have failed. Those failures have stimulated the study of alternatives to diagnoses. When several traits are influenced by the same gene (or genes), that information can be used to redefine (or refine) alternatives to study, to enhance gene detection. For example, because heavy smoking and drinking frequently co-occurred in the Collaborative Study of the Genetics of Alcoholism sample, combined smoking and alcohol dependence was studied (Beirut et al., 2000). The combined dependency yielded greater evidence of linkage with a chromosomal region than did either tobacco dependence or alcohol dependence alone.

This approach is not limited to co-occurring behavioral disorders. It applies to normative behavioral differences, as well: A multidisciplinary international collaboration (Wright et al., 2001) has initiated a study of covariation among traditional and experimental measures of cognitive ability and will employ the correlated measures, once found, in subsequent molecular genetic analyses. And in a complementary way, behavior genetic methods can be useful to identify behavioral outcomes that are highly heritable, because these outcomes are most likely informative for genetic studies: When the definition of major depression was

broadened, genetic factors assumed a larger role in women's susceptibility to this disorder (Kendler, Gardner, Neale, & Prescott, 2001), and, interestingly, this broader definition of depression suggested that somewhat different genes may influence depression in men and women.

A second strategy to enhance the power of molecular genetic analyses is to more accurately characterize trait-relevant environmental factors and also incorporate them more accurately in the analyses. In searching for genes, traditional genetic research effectively ignored the interplay of genetic and environmental influences in behavioral and psychiatric traits. Now, new analytic methods are being developed to incorporate environmental information better (Mosley, Conti, Elston, & Witte, 2000). But which specific environmental information is pertinent to a particular disorder? And how does a specific risk-relevant environment interact with genetic dispositions? Behavioral scientists trained in the methods of behavior genetics will play a key role in answering these questions.

BEYOND FINDING GENES

The traditional endpoint for geneticists is finding the gene (or genes) involved in a behavior or disorder. At that point, psychologists should become instrumental in using this genetic information. Applying genetic research on complex disorders to clinical practice will be complicated, because gene-behavior correlations will be modest and nonspecific, altering risk, but rarely determining outcome. Genes confer dispositions, not destinies. Research examining how risk and protective factors interact with genetic predispositions is critical for understanding the development of disorders and for providing information to vulnerable individuals and their family members. Far from ousting traditional psychological intervention, advances in genetics offer opportunities to develop interventions tailored to individual risks in the context of individual lifestyles. Enhanced understanding of the interactions between genetic vulnerabilities and environmental variables may dispel public misconceptions about the nature of genetics and correct erroneous beliefs about genetic determinism. Informed psychologists can play a vital role in disseminating the benefits of genetic research to families whose members experience behavioral and psychiatric disorders, and to the public in general.

CONCLUSIONS

Research questions now addressed by behavior geneticists have grown dramatically in scope: The questions have expanded into developmental psychology and sociology, as researchers have employed measures of the home and community, and utilized longitudinal designs. And behavior geneticists now study the effect of measured genotypes, a study traditionally left to geneticists. These developments create new and compelling research questions and raise new challenges. One such challenge is in addressing the complexity of behavioral development despite current reliance on methods that largely assume additive, linear effects. People who appreciate the complex, interactive, and unsystematic effects underlying behavioral development may be skeptical that the genomic era will profoundly advance understanding of behavior. But there is a preliminary illustration that advance will occur, even within the constraints of additive models: the identification of a gene (ApoE) that increases risk for Alzheimer's disease, and the interaction of that gene with head trauma (Mayeux et al., 1995). Further, new analytic techniques are being developed to analyze simultaneously hundreds of genes and environments in attempts to understand how gene-gene and gene-environment interactions contribute to outcome (Moore & Hahn, 2000). These techniques are beginning to capture the systems-theory approach long advocated by many researchers as an alternative to linear additive models.

This is not to deny that unresolved problems remain. For example, we are enthusiastic about including measured environmental information in genetic research designs, but we note, with disappointment, that the magnitude of shared environmental effects detected to date has been modest. Equally disappointing are the results of recent research efforts to specify nonshared environmental effects (Turkheimer & Waldron, 2000). Such findings underscore a problem acutely evident in contemporary behavior genetics: an imperative need for better measures of trait-relevant environments. Now that researchers have tools to search for measured environmental effects, what aspects of the environment should they measure—and with what yardsticks? These are questions that psychologists are uniquely positioned to address.

Another set of challenging questions will arise from the ethical, legal, and social issues to be confronted once genes conferring susceptibility to disorders are identified. How should information about the nature and meaning of susceptibility genes be conveyed to the media, the public, and the courts? How can erroneous beliefs about genetic determinism be dis-

pelled effectively? Such issues will be even more salient once dispositional genes for normal behavioral variation are identified: Ethical issues surrounding prevention of behavioral disorders are undeniably complex, but surely they are less so than the ethical issues surrounding enhancement of selected behavioral traits.

Results from the first phase of behavior genetics research convincingly demonstrated that genes influence behavioral development. In the next phase, that of behavioral genomics, psychologists will begin to identify specific genes that exert such influence, seek understanding of how they do so, and accept the challenge to interpret that understanding to the public.

Recommended Reading

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Notes

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2. We use the term molecular genetics broadly to include statistical genetic techniques that test for gene-behavior associations.

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