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Special Article

Behavioral Genetics and Child Temperament

KIMBERLY J. SAUDINO, Ph.D.
Psychology Department, Boston University, Boston, Massachusetts

ABSTRACT. Most temperament theories presume a biological basis to those behavioral tendencies thought to be temperamental in origin. Behavioral genetic methods can be used to test this assumption. Twin and adoption studies suggest that individual differences in infant and child temperament are genetically influenced. However, behavioral genetics has much more to offer to the study of temperament than simple heritability estimates. The present paper describes some recent findings from behavioral genetics research in temperament that go well beyond the basic nature-nurture question. These findings include the importance of nonshared environmental influences on temperament, genetic continuity and environmental change during development, links between temperament and behavior problems, and harnessing the power of molecular genetics to identify specific genes responsible for genetic influence on early temperament. *J Dev Behav Pediatr 26:214–223, 2005.* Index terms: *genetic, shared environment, nonshared environment, heritability, temperament.*

Temperament is of fundamental interest to developmental-behavioral pediatrics, and readers of this journal are very familiar with the clinical correlates of infant and child temperament. Other research on temperament seeks to identify the foundations of temperament and the mechanisms underlying its variability. Dr. Saudino's article reviews this research and also illustrates the scope and methods of behavioral genetics. It should be evident through this review that behavioral genetics is not only relevant to reductionist explanations of behavior, but that it also can help to document environmental influences on behavior and their importance and can help to illuminate the processes by which behavioral traits such as temperament change throughout the lifespan. —Editor

Although there are many different theories of child temperament, most agree that temperament refers to stable, early-appearing individual differences in behavioral tendencies that have a constitutional basis.[1] Soon after birth, children show a great deal of variation in those behavioral dimensions considered to be temperamental (e.g., emotionality, activity level, attention/persistence, sociability, reactivity). For example, some children cry easily and intensely, whereas others are more easy going; some are highly active and always on the go, whereas others are more sedentary; some attend and persist in tasks for long periods of time, whereas others' attention wanders quickly. It is these individual differences and the variations between that are of interest to behavioral geneticists. That is, we are interested in understanding why children differ in their temperaments. Temperament theories suggest that such individual differences have a biological or constitutional foundation. This is an empirical question that can be answered using behavioral genetic methods.

After a brief review of behavioral genetic methodology, this paper examines research exploring the etiology of individual differences in infant and child temperament. Behavioral genetics research, however, has much more to offer the study of temperament than estimates of genetic influence. To that end, this article also examines the nature of environmental influences on temperament, the etiology of continuity and change in temperament, links between temperament and behavior problems, and the merging of behavioral and molecular genetic techniques to identify specific genes that affect temperament.

QUANTITATIVE BEHAVIORAL GENETICS METHODS

A goal of behavioral genetic research is to estimate the extent to which genetic and environmental factors contribute to behavioral variability in the population under study. This involves decomposing the observed (i.e., phenotypic) variance of a trait into genetic and environmental variance components (Table 1). Heritability (h^2), the genetic effect size, is the proportion of phenotypic variance that can be attributed to genetic factors. The remaining variance is attributed to environmental factors that comprise all nonheritable influences including prenatal factors. Environmental variance can be further decomposed into shared and nonshared environmental influences. Shared environmental

Address for reprints: Kimberly J. Saudino, Psychology Department, Boston University, 64 Cummington Street, Boston, MA, 02215; e-mail: ksaudino@bu.edu.

Table 1. Sources of Variability in Behavior

Individual Differences in Temperament Can be Due to	Definition	Examples	If Important to the Behavior Under Study:	Temperament Findings
Genes	Segregating genes (i.e., genes that differ in a population)	Specific genes that have been associated with behaviors	Result in behavioral similarities between genetically related individuals	Account for approximately 20%–60% of the variability in most temperament dimensions
Shared environments: also known as "common" environments or "between-family" environmental variance	Environmental influences that are shared by family members	Neighborhoods, schools,[a] parent education, family socioeconomic status, family religion, family vacations, pets, and household facilities (e.g., number of books in the home, swimming pool, piano.)	Result in behavioral similarities between family members	Little evidence of any shared environmental influences on temperament; possible exceptions are positive affect, rhythmicity, soothability, shyness, and activity level
Nonshared environments: also known as "unique" environments or "within-family" environmental variance	Environmental influences that are specific to an individual	Friends,[b] peers,[b] teachers,[b] birth order, differential parental treatment, accidents, illnesses, and (random) measurement error	Result in behavioral differences between family members	Environmental influences on temperament tend to be of the nonshared variety, accounting for the remaining 40%−80% of the variance that is not explained by genes

Prenatal environments can be either shared or nonshared, depending on whether they result in similarities or differences between siblings. For example, although twins share a common prenatal environment, fetal transfusion syndrome might result in birth weight differences between identical twins and would be a nonshared environmental influence.
[a]Assuming that children attend the same school. If children attend different schools, this would be a nonshared environment.
[b]Assuming that these differ between siblings. If they do not, then they would be shared environments.

variance (c^2) is familial resemblance that is not explained by genetic variance. Thus, shared environmental variance includes those environmental influences that are shared by family members and act to enhance familial similarity. Nonshared environmental variance (e^2) is a residual variance that includes measurement error and environmental influences that are unique to each individual. These unique environmental influences operate to make members of the same family different from one another. Possible sources of nonshared environmental variance include differential parental treatment; extrafamilial relationships with friends, peers and teachers; and nonsystematic factors such as accidents or illness.[2]

The two designs most frequently used to disentangle genetic and environmental sources of variance in infant and child temperament are the twin design and the adoptive/nonadoptive sibling design. The twin method involves comparing genetically identical (MZ) twins with fraternal (DZ) twins who share approximately 50% of their segregating genes. Genetic influences are implied when cotwin similarity covaries with the degree of genetic relatedness. Thus, according to the genetic hypothesis, MZ twins should be approximately twice as similar as DZ twins. DZ twin resemblance that exceeds that predicted by the genetic hypothesis (i.e., resemblance greater than one half the MZ twin resemblance) suggests the presence of shared environmental influences. Because MZ twins share all their genes, differences within pairs of identical twins can only be due to environmental influences that are unique to each individual (i.e., MZ twin differences indicate nonshared environmental influences). The adoptive/nonadoptive sibling design shares a similar logic but compares the similarity of adoptive and nonadoptive sibling pairs. Genetic influences are implied when nonadoptive siblings who share approximately 50% of their segregating genes are more similar than adoptive siblings who are not genetically related. Shared environmental influences are suggested when genetically unrelated adoptive siblings resemble each other. (See Plomin et al[3] for more information about behavioral genetics methods.)

BEHAVIORAL GENETIC STUDIES OF TEMPERAMENT

Although the theoretical perspective of Thomas and Chess[4] based on data from the New York Longitudinal Study (NYLS) is most common to the pediatric literature, no single theory dominates behavioral genetic studies of temperament. As indicated above, there are many different theories of temperament. These approaches differ in those behavioral dimensions that are considered to fall under the rubric of temperament; however, some dimensions, such as activity level and emotionality, appear in nearly all theories of temperament.[1] (See Goldsmith et al[1] for a discussion of theoretical orientations to temperament.)

Two measures that are frequently employed in behavioral genetic studies of temperament are the Colorado Child

Temperament Inventory (CCTI)[5] and the Infant Behavior Record (IBR)[6]. The CCTI is a questionnaire measure that is based on factor analyses of items designed to assess both the EAS temperaments (emotionality, activity, sociability) of Buss and Plomin[7] and the nine NYLS temperaments.[4] The parent and teacher versions of the CCTI assess emotionality (negative emotionality including distress, fear, and anger), activity (the tempo, energy, and vigor with which the child behaves), sociability (a preference to be with other people), shyness (wariness with strangers), and attention/persistence (the tendency to attend and persist when working on tasks). The IBR is often used to provide an observational measure of infant temperament. This rating scale is typically completed by an examiner after administration of the Bayley Scales of Infant Development.[6] The IBR consists of items evaluating broad dimensions of infant behavior, including interpersonal, affective, motivational, and sensory behavioral domains. Factor analyses of the IBR items yields three factors related to dimensions found in most systems of temperament: activity (energy and body movement), task orientation (attention span and persistence), and affect-extraversion (positive emotionality and sociability).[8,9] The temperament dimensions assessed by these two measures are well studied in behavioral genetics research; however, as is seen below, a variety of other dimensions have also been explored.

GENETIC INFLUENCES ON CHILD TEMPERAMENT

Twin studies using parent ratings, the most frequently employed measure of temperament in infancy and childhood, provide strong evidence of genetic influences on temperament. Such studies consistently find that MZ cotwins are more similar than DZ cotwins across a wide variety of temperament dimensions including emotionality, activity, shyness, sociability, attention/persistence, approach, adaptability, distress, positive affect, and negative affect.[10–13] Although estimates of heritability tend to differ from sample to sample, they generally fall within the range of 0.20 to 0.60, suggesting that genetic differences among individuals account for approximately 20 to 60% of the variability of temperament within a population. With few exceptions (e.g., soothability and rhythmicity, which show little genetic influence), there is no consistent pattern of differential heritability across dimensions.

Given that temperament is assumed to be biologically based,[1] it is not surprising to find that parent-rated temperament is genetically influenced. What is surprising, however, is the unusual pattern of twin resemblances (as indexed by twin correlations) that frequently emerge when temperament is assessed by parent ratings. MZ correlations for parent-rated temperament dimensions are typically moderate, whereas DZ correlations are much lower than one half the MZ correlations as would be predicted from the simple genetic model. In fact, the DZ correlations are often near zero or even negative.[13–15] The pattern of very low DZ correlations that emerges with parent ratings of temperament is significant because it implies that DZ twins are perceived as no more similar as two randomly paired children and in some instances are regarded as having opposing temperaments.

Also puzzling is the finding that, although twin studies consistently yield evidence of a genetic influence on parent-rated temperament, adoption studies suggest little or no genetic influences on children's temperament as rated by their parents. For example, in the Colorado Adoption Project[16,17] (CAP), neither genetically related nonadoptive siblings nor genetically unrelated adoptive siblings displayed any resemblance on parent reports of temperament—a finding that replicated across early childhood, middle childhood, and early adolescence.[18–20] Similarly, a combined twin and stepfamily study found significant genetic influences on each of the four EAS[7] dimensions; however, heritability estimates were greater for twins than nontwins.[21]

These puzzling outcomes do not arise when temperament is assessed via more objective measures such as tester and observer ratings or mechanical measures.[9,15,22–27] Although less frequent than parent-rating studies of temperament, there are a handful of twin studies that have employed observational/behavioral measures of activity level, behavioral inhibition, shyness, fearfulness, affect/extraversion, and task orientation. As with parent ratings, these measures yield evidence of significant genetic influence (and a similar range of heritabilities, i.e., also from 0.20 to 0.60), but the problem of low DZ correlations does not emerge. For example, in the MacArthur Longitudinal Twin Study[28] (MALTS), observational measures of affect/extraversion, activity, task orientation, and shyness were obtained for more than 200 twin pairs at 14, 20, 24, and 36 months of age. Averaging across age, the DZ correlations for all dimensions were positive and significantly different from zero (ranging from 0.19 to 0.63), and consistent with genetic expectations, the DZ twin correlations were approximately half that of the MZ twins.[29] Interestingly, when parents rated the same twins on similar dimensions the DZ twin correlations were negative (ranging from −0.06 to −0.33). Thus, parents reported their DZ twins as having opposing temperaments, whereas when each twin was rated by a different observer, the twins displayed substantial similarity. Although it is possible that contextual differences explain the different outcomes between parent and observer ratings of temperament, this seems unlikely given that similar results have emerged from twin studies of activity level in which parent ratings and mechanical measures of activity are based on the same 48-hour period.[26,30]

Similarly, evidence of genetic influences on temperament emerges from adoption studies when more objective measures of temperament are employed. In the CAP, teacher and tester ratings of temperament yielded correlations for nonadoptive siblings that were higher than when assessed via parent ratings, and consistent with a genetic hypothesis, nonadoptive siblings showed some resemblance in their temperaments, but adoptive siblings did not.[18,31] Moreover, adoption and twin studies of objectively assessed temperament yield similar estimates of heritability.[32]

The fact that the problems of very low DZ resemblance and higher heritability estimates in twin studies as compared to adoption studies occur only for parent-rating measures of temperament suggests that parent ratings are prone to contrast effects.[12,29,33] Contrast effects refer to rater biases that exaggerate the differences between cotwins or nonadoptive siblings. Twin research suggests that some parent rating measures may be more subject to contrast effects than others. For example, very low DZ correlations tend to be particularly evident when parents are required to make global judgments (e.g., "always on the go") as opposed to specific judgments (e.g., "splashes when in the tub") about their children's behavior[34–36]; however, even specific measures can yield low DZ correlations.[11] There are also hints that the tendency to contrast siblings differs across temperament dimensions. Activity level, attention/persistence, and shyness are dimensions that frequently show contrast effects, whereas parent ratings of more affective behavioral dimensions such as approach, fear, pleasure, smiling, and laughter do not seem to show a pattern of low DZ or nonadoptive sibling similarity.[11,37]

Because contrast effects can overestimate heritability in twin designs and underestimate heritability in adoption designs, parent-rating measures that show a pattern of very low DZ or sibling correlations may be inadequate for obtaining precise estimates of heritability unless such biases are incorporated into the statistical analyses (e.g., sibling interaction models). Nonetheless, the greater similarity of MZ than DZ twins is consistent with the general hypothesis of a genetic influence. Moreover, conclusions regarding moderate genetic influences on individual differences in parent-rated temperament are buttressed by similar findings with more objective temperament measures. Thus, there can be little doubt that temperament is genetically influenced.

ENVIRONMENTAL INFLUENCES ON CHILD TEMPERAMENT

The finding of moderate genetic influences on child temperament does not negate the importance of the environment. As indicated above, genetic factors account for between 20 and 60% of the phenotypic variance in personality, which means that the remaining 80 to 40% of the variance is attributed to environmental factors. Clearly, the environment is very important to temperament. However, behavioral genetics research suggests that the types of environments traditionally assumed to influence child behavior may not operate the way that we think they do. Twin and adoption studies consistently find that shared family environment accounts for only a small portion of variance in most temperament dimensions.[10,12,18,24,25,32,38] This is demonstrated in a study of infant temperament that found correlations for tester-rated temperament to be about 0.00 for genetically unrelated adoptive siblings, which provides a direct test of shared family environment, and 0.20 for genetically related nonadoptive siblings.[32] In other words, growing up in the same family does not make family members resemble each other in temperaments. Family members are similar in temperaments primarily because of shared DNA.

If shared family environments do not substantially influence temperament, then what does? The answer lies within, not between, families. The environmental influences that are important to temperament are those factors that are not shared by members of the same family, that is, environmental influences that are unique to family members (i.e., nonshared environmental influences). The finding of significant and substantial nonshared environmental influences on temperament provides an important focus for researchers interested in environmental effects on temperament. Most research exploring environmental influences on temperament have considered between-family effects such as parenting style and family functioning (e.g., work by Eriksson and Pehrsson[39] and Leve et al[40]). Behavioral genetics research suggests that instead of examining environmental factors that differ across families, it will be more profitable to focus on environmental factors that differ within families (e.g., differential parenting). Researchers need to consider why individuals within the same family differ so much with regard to temperament. This will involve studying more than one individual per family and exploring the association of experiential differences within a family with differences in temperament.

There are some exceptions to the general finding of nonshared environmental influences on temperament. Several studies have found shared environmental influences on both parent and observer ratings of positive affect and related behaviors (e.g., smiling, interest in others) during infancy and early childhood.[11,41–45] Maternal personality and attachment security have been suggested as possible sources of shared environmental variance on positive affect.[44] In addition, although not well studied, rhythmicity and soothability have shown no genetic influence but substantial shared environmental influences each in at least one study.[10,44] These findings need to be replicated, but it is possible that, to some extent, the shared environmental influences on these two dimensions reflect parenting behaviors (e.g., scheduling of activities, methods of soothing). Finally, observational measures of shyness and mechanical measures of activity show some shared environmental variance, whereas parent ratings of the same behaviors do not.[15,22,26,27,46] Again, these findings need to be replicated, but they highlight the need for more observational research to assess the possible role of shared environment in personality development.

THE ETIOLOGY OF CONTINUITY AND CHANGE IN TEMPERAMENT

Despite the abundance of evidence indicating that individual differences in temperament are genetically influenced, little is known about the role that genetic factors play in the development of temperament. The failure to consider genetic contributions to developmental change in temperament has likely resulted from the mistaken view that genetic factors are immutable and thus contribute only to behavioral stability. However, genes are dynamic in nature, changing in the quantity and quality of their effects across time and therefore can be sources of change as well as continuity in behavioral development.[47] Behavioral genetics approaches developmental change in two ways. The first explores differential heritability across ages. This issue is important because the investigation of the etiology of individual differences over age may serve to identify points of causal transition. The second examines the role of genetic influences on continuity and change during development and thus addresses the process by which developmental change takes place.[15]

Differential heritability refers to developmental changes in the relative contribution of genetic influences to individual differences in temperament across age. That is, does the heritability of temperament change across age? Intuitively, one might posit that as a child matures and becomes more interactive with increasingly diverse environments, the role of genetic factors on temperament might wane. Empirical research does not support this notion. Many studies find no apparent change in heritability across age.[25,27,48] Moreover, when developmental changes in genetic influences on temperament are apparent, it is in the direction of increased genetic variance.[10,13,32] For example, in the Louisville Twin Study, there was no evidence of a genetic effect on temperament during the neonatal period,[49] but in infancy and early childhood, temperament was moderately heritable.[23,50]

To the developmentalist, the measurement of within-person change is more interesting than cross-sectional age differences because the measurement of change is more informative about underlying processes.[51] For the same reason, genetic influences on continuity and change are more interesting than the presence or absence of genetic influences at a single age. The question of differential heritability is essentially cross-sectional and does not address mechanisms of change. That is, for any temperament dimension, estimates of heritability may differ across age even though the same genes operate at each age. Similarly, the heritability of a temperament dimension may be similar across two ages, but the genes that operate at one age might differ from those that operate at the other. By using behavioral genetic methods within a longitudinal design, we are able to determine the extent to which developmental change and continuity are due to genetic factors.

Longitudinal behavioral genetic studies of early temperament development are rare. One exception is the Louisville Twin Study, which found that MZ twins demonstrated greater resemblance than DZ twins on age-to-age change profiles for observational measures of activity, affect/extraversion, and task orientation across 6 to 18 months and 12 to 24 months, emotional tone across 18 to 24 months, and surgency (related to extraversion) across 36 to 48 months of age.[23,52,53] In other words, MZ twins were more similar than DZ twins in their patterns of change for these temperament dimensions. These results suggest that changes in temperament across infancy and early childhood are, in part, regulated by genetic influences.

Although the analysis of change profiles provides important information about genetic influences on developmental change, they do not reveal the extent to which the genetic effects that influence a trait are consistent from one age to another.[47] This can be addressed by assessing genetic contributions to phenotypic continuity across age. Genetic influences on phenotypic continuity imply that there is some overlap between the genetic factors that affect a trait across age.[54] Longitudinal model-fitting analyses of genetic contributions to phenotypic continuity permit the estimation of the extent to which genetic effects on a trait at one age overlap with genetic effects at another age and whether new genetic influences on the trait emerge across time. To date, most of what we know about the etiology of continuity and change in temperament in infancy and early childhood comes from the MacArthur Longitudinal Twin Study (MALTS).

Observer ratings of activity, affect/extraversion, task orientation, shyness, and behavioral inhibition at 14, 20, 24, and 36 months of age in more than 200 twin pairs participating in the MALTS yielded modest age-to-age stability correlations (i.e., ranging from 0.00 to 0.39), indicating that phenotypically, there is substantial change in these temperament dimensions over the second year of life.[25,55] Despite this, for most dimensions, genetic influences appear to be mediating whatever continuity exists. The age-to-age stability correlations for activity, affect/extraversion, and behavioral inhibition were almost entirely due to genetic factors. Shyness was an exception in that both genetic and shared environmental influences contributed to stability. Developmental change in observed temperament was primarily due to nonshared environmental influences; however, for activity, affect/extraversion, task orientation, and behavioral inhibition, there was evidence of new genetic effects at different ages. Similarly, for shyness, new shared environmental influences emerged across age. Thus, with the exception of shyness, genetic factors appear to contribute to both continuity and change in temperament across age. A caveat is that, in some instances, genetic change coincided with subtle changes in the item content of the measures used to assess temperament; consequently, developmental change was confounded with measurement differences. Nonetheless, these findings of genetic change would be consistent with earlier MALTS analyses that found significant genetic change on activity and sociability when assessed with the same parent-rating measure at 14 to 20 months of age.[15]

Overall, the MALTS results are consistent with longitudinal twin studies of adult personality that find that personality change is largely due to nonshared environmental influences, and the stability of personality is due to genetic factors.[56] This was unexpected because, in contrast to adulthood, infancy and early childhood are periods of rapid change and growth. That developmental change is primarily due to early nonshared environmental influences and is particularly interesting. This means that changes in temperament are likely due to differences within the family environment, such as differential treatment, experiences or accidents. Identifying specific nonshared environmental factors that influence developmental change is an important goal for future temperament research.

LINKS BETWEEN TEMPERAMENT AND BEHAVIOR PROBLEMS

The significance of temperament lies, in part, in the assumption that early temperament shapes personality development and influences developmental outcomes.[57] Child temperament has been seen as a possible precursor to behavior problems.[58,59] Indeed, the link between temperament in early childhood and later behavioral problems has been well documented. For example, dimensions associated with difficult temperament (e.g., emotionality, adaptability, approach/withdrawal, impulsivity) are predictive of both internalizing and externalizing problems[60–63]; activity level predicts externalizing problems[64–66] and shyness and fearfulness predict internalizing problems.[67,68] Importantly, these associations do not appear to be an artifact due to similarity of items on measures used to assess both temperament and problem behavior.[62,69]

Although there is ample evidence of an association between temperament and behavior problems, the question of how the association arises has received little empirical attention. That is, what are the mechanisms that link temperament and behavior problems? Behavioral genetic research can address this question by exploring the extent to which temperament and behavior problems are influenced by common genetic and environmental factors. There have been many twin and adoption studies that indicate substantial genetic influence (i.e., heritabilities in the range of 0.30 to 0.50) for externalizing, internalizing, and total behavior problems.[70–74] Thus, given that both temperament and behavior problems are genetically influenced, it is possible that they are associated because of common genetic factors.

The few studies that have examined sources of covariance between temperament and behavior problems suggest that the association is primarily due to common genetic influences. For example, in the MALTS, emotionality at 14, 20, 24, and 36 months predicted internalizing, externalizing, and total behavior problems at age 4 years, and shyness predicted internalizing across the same age intervals.[68] There was considerable overlap in genetic effects on temperament and behavior problems. Moreover, it was these overlapping genetic effects that fully explained the phenotypic correlations between temperament and behavior problems. Similarly, in the Colorado Adoption Project (CAP), emotionality in later childhood also predicted internalizing, externalizing, and total behavior problems.[75] Although there was some genetic variance unique to emotionality and behavior problems, there was also substantial genetic overlap between the two, and the phenotypic associations between teacher ratings of both and between teachers' ratings of emotionality and mothers' reports of problem behaviors were primarily due to genetic factors.

Other research has looked at more specific problem behaviors, but a similar pattern emerges. In a sample of twins spanning middle childhood to adolescence, emotionality significantly predicted anxious/depressed, attention, delinquent, and aggressive behavior problems assessed 2 years later.[76] The phenotypic correlations between emotionality and aggression and attention problems were due to common genetic factors. There were no significant shared environmental influences on any of the observed associations. Likewise, a study of fear and anxiety symptoms in early childhood found that, despite only modest overlap in the genetic influences on fear and general anxiety, the phenotypic correlation between the two was almost entirely due to genetic factors.[67] Interestingly, however, fear and separation anxiety were genetically distinct and correlated because of common shared and nonshared environmental influences. Thus, links between fear and general anxiety and fear and separation anxiety arise for different reasons.

Research examining genetic and environmental links between temperament and later behavior problems has significance for both genetics researchers and clinicians. A finding of substantial overlap in genetic influences on the two domains would provide empirical support for the possibility that certain behavior problems may be the extreme manifestation of specific temperament dimensions. On the other hand, in those cases in which temperament and behavior problems are genetically distinct (e.g., fear and separation anxiety), it is important to uncover the specific environmental factors that link temperament to later problem behavior. Both outcomes have implications for intervention. Moreover, in both cases, molecular genetics findings on one domain may inform about genes operating (or not operating) on the other.

FINDING GENES ASSOCIATED WITH TEMPERAMENT

Twin and adoption analyses provide strong evidence that genes influence individual differences in temperament and continuity and change in temperament and, at least in part, mediate the link between temperament and behavior problems. However, the genetic effects in these analyses are anonymous. That is, quantitative genetic designs indicate the magnitude of genetic influence but do not identify specific genes responsible for heritability. One of the most exciting new directions for research on personality and temperament comes from recent advances in molecular genetic techniques that now make it possible to identify genes associated with complex phenotypes.

Complex behavioral traits are unlikely to result from the action of major genes segregating in a simple mendelian fashion but are expected to result from the action or coaction of a few (oligo) or many (poly) genes.[77] Behavioral dimensions such as those included under the rubric of temperament are typically distributed continuously in general populations, show substantial environmental influence as well as genetic influence, and are likely to be influenced by many genes, each of varying effect.[78] Genes of small and varying effect size, which contribute to quantitative traits, are referred to as quantitative trait loci (QTLs). The challenge for contemporary molecular geneticists is to use the power of modern molecular techniques and new high-density genetic maps to identify QTLs for complex traits like temperament dimensions that involve multiple genetic and nongenetic factors. The goal of applying molecular genetics techniques to the study of behavior is not aimed at identifying the gene for a particular behavioral dimension, rather it is to identify many genes that each make a small contribution to variability in a particular trait.[77]

Although the merging of molecular genetics and quantitative genetics is still in its infancy, researchers are beginning to identify genes associated with childhood behavioral dimensions and disorders (reviewed in Asherson and Curran[79]). Perhaps most robust is the finding that the dopamine D4 receptor gene (*DRD4*) has been associated with attention-deficit hyperactivity disorder (ADHD), accounting for approximately 2% of genetic variance (see Mill et al[80] for a review). This is of interest to temperament researchers because activity level, as a temperament dimension, has been associated with diagnoses of ADHD and hyperactive problem behaviors in both clinical and nonclinical samples,[81–88] suggesting that hyperactivity may represent the extreme upper end of the normal distribution of the temperament dimension of activity level. Consequently, genes associated with ADHD may also be associated with the temperament dimension of activity level.

Associations between genes and personality traits have also emerged but are less well replicated (see Reif and Lesch[89]). For example, a 48-base pair repeat in exon 3 of DRD4 has been associated with novelty seeking[90,91] and a serotonin transporter promoter polymorphism (5-HTTLPR) has been associated with neuroticism/anxiety[92]; but these associations are questionable due to failures to replicate.[93–95] More specific to child temperament, both the DRD4 and 5-HTTLPR polymorphisms have been associated with motor organization and negative emotionality (i.e., the tendency to fear, anger, and distress) in early infancy.[96,97] DRD4 was also associated with observed attention, interest, anger, and activity level; and 5-HTTLPR associated with stranger fearfulness and positive emotionality at 1 year of age in the same sample.[98,99] Other research has found an interactive effect between DRD4 and 5-HTTLPR and stranger fearfulness in 1-year-old infants.[100] A recent attempt to explore the association of the DRD4 and 5-HTTLPR polymorphisms with shyness and aggression in toddlers has produced mixed results. Although neither polymorphism was associated with observed shyness, DRD4 was associated with mother-reported, but not observed, aggression.[101] Similarly, DRD4 was associated with infant adaptability at 1 month, but not 5 months of age.[102] These early temperament results should be viewed with caution until they have been replicated in a variety of samples. Nonetheless, they hint at the potential for the application of molecular genetic approaches to the study of temperament. This is a particularly exciting area of inquiry because the identification of specific genes for temperament will provide an important first step in understanding how genes influence temperament.

CONCLUSIONS

Nearly all temperament theories presume a biological basis to individual differences in early-appearing, enduring behavioral tendencies considered to be temperamental. Consistent with these theories, most dimensions of temperament have demonstrated moderate genetic influences in twin and adoption studies. However, the finding of genetic influences on temperament is only a first step in the understanding of individual differences in early personality development. As illustrated in this article, behavioral genetic methods can address a wide array of issues of relevance to child development. Researchers have begun to document the importance of environmental factors on temperament dimensions, track the developmental course of genetic and environmental contributions to temperament, address the issue of genetic and environmental overlap between temperament and problem behaviors, and relate specific genetic markers to temperament dimensions. These are just a sampling of the contributions that behavioral genetics has made to the understanding of temperament. Other research has looked at genetic and environmental contributions to the links between temperament and parenting,[103] sibling[104] or peer relationships,[105] measure-specific and situational effects on temperament,[106] and genotype-environment correlations between temperament and the child's environment[107]—just to name a few. It is predicted that behavioral genetics research will make even greater contributions to our understanding of temperament as researchers continue to move beyond the basic heritability question.

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Literary Quotes

The Significance of Huckleberry Finn

Mark Twain's The Adventures of Huckleberry Finn (1884) remains one of the great classics of American literature. The story tells of Huck's flight from his abusive, drunken father down the Mississippi River on a raft with Jim, an escaped slave. As the boys drift downstream and experience many varied contacts with the people and social conditions along the banks of the mighty river, Twain provides an unforgettably vivid picture of the quality of life in western America during the mid-nineteenth century.

In his Huck's Raft: A History of American Childhood (Cambridge, MA: Belknap Press of the Harvard University Press. 2004) Steven Mintz points out that for some literary historians Huck's adventures have not been merely an engaging tale. The story has been variously interpreted as an example of: a) spirited, youthful American resourcefulness, b) irresponsible adolescent behavior unsuitable for the education of today's teenagers, and c) an abused and neglected child possibly troubled with ADHD. "For over a century Huck has served as a lighting rod for popular fantasies and anxieties about childhood," says Mintz and he provides his own more comprehensive understanding of the complexities of the character and his story.

"The image of Huck's raft encapsulates the modern conception of childhood as a period of peril and freedom; an odyssey of psychological self-discovery and growth; and a world apart, with its own values, culture and psychology. But if Huck's raft represents childhood as a carefree time of adventure, it also points to another meaning. The precariousness of Huck's trip down the Mississippi suggests the physical, psychological, emotional, and socioeconomic challenges of childhood. Much as the raft is carried by raging currents that Huck can only partly control, so, too, childhood is inevitably shaped and constrained by society, time, and circumstances." (p. 7)

Anyone who has not read this appealing tale since high school should revisit it to enjoy one of our literary masterpieces from the perspective of adult life. We may or may not concern ourselves with whatever deeper meaning Twain may have intended. The tale has great appeal simply as a fascinating adventure story.

Submitted by William B. Carey, M.D.