Regular Articles

A Multidimensional Twin Study of Mental Health in Women

Kenneth S. Kendler, M.D., John M. Myers, M.S., and Michael C. Neale, Ph.D.

Objective: While researchers have increasing insight into the role of genetic and environmental factors in the etiology of psychiatric and substance use disorders, they know much less about how such factors influence the dimensions of healthy psychological functioning. **Method:** In a population-based sample of 794 female-female twin pairs, the authors examined, by using multivariate structural equation modeling, six dimensions of mental health: perceived physical health, nonconflictual interpersonal relationships, anxious-depressive symptoms, substance use, social support, and self-esteem. **Results:** The best-fit model was complex and constituted five common factors (two genetic, one family environmental, and two unique environmental); variable-specific genetic effects for physical health, substance use, and social support; and variable-specific family environmental effects for interpersonal relationships and substance use. Genetic effects were seen for all six dimensions; total heritabilities ranged from 16% to 49%. Family environment was an important influence on interpersonal relationships, substance use, and social support. **Conclusions:** Mental health is a complex phenotype that is influenced by a diverse array of genetic and environmental factors. While genetic factors appear to be of moderate etiologic importance in all major dimensions of mental health, the family environment is an important influence on only interpersonal relations, social support, and substance use.

(Am J Psychiatry 2000; 157:506–513)

An increasing number of twin, family, and adoption studies are clarifying the role of genetic and environmental factors in the etiology of a wide range of psychiatric and substance use disorders (1). By contrast, we understand much less about how these factors influence overall mental health. While twin studies have examined individual variables such as happiness (2), self-esteem (3), and social support (4, 5), these constructs reflect only a part of what is generally considered to be mental health.

In this study, we begin to address this disparity by examining, in a large sample of female-female twin pairs ascertained from a population-based registry, six variables chosen to reflect at least part of the diversity of functions that constitute mental health. We attempt to address the following specific questions about these variables:

1. What is the structure of the genetic factors that influence these dimensions of mental health? Is there a set of mental health genes, or is mental health more genetically complex, with distinct genetic factors that influence certain dimensions?

2. While family environment appears to play little role in the etiology of major psychiatric disorders (1, 6), is the same pattern true of dimensions of healthy

Received Jan. 19, 1999; revision received June 21, 1999; accepted July 12, 1999. From the Department of Psychiatry and the Department of Human Genetics, Virginia Institute for Psychiatric and Behavioral Genetics, Medical College of Virginia, Virginia Commonwealth University. Address reprint requests to Dr. Kendler, Department of Psychiatry, Box 980126, Medical College of Virginia, Richmond, VA 23298-0126; kendler@hsc.vcu.edu (e-mail).

Supported by NIMH and National Institute on Alcohol Abuse and Alcoholism grant MH/AA-49492, NIMH grants MH-40828 and MH-54150, and a NIMH Research Scientist Award (MH-01277) to Dr. Kendler. The Virginia Twin Registry, established by W. Nance, M.D., Ph.D., and maintained by L. Corey, Ph.D., is supported by National Institute of Child Health and Human Development grant HD-26746 and National Institute of Neurological Disorders and Stroke grant NS-31564.

The authors thank Carol Prescott, Ph.D., for her comments on an earlier version of the article.

psychological functioning? If family environment is important in mental health, does it affect all dimensions or only some? Is there a single factor that reflects a health-inducing family environment, or are there several dimensions of family experience that affect mental health?

3. While individual environmental experiences certainly influence mental health, to what extent do these environmental effects influence all dimensions or selected dimensions of psychological functioning?

METHOD

Participants

The subjects examined in this study were participants in a longitudinal investigation of the risk factors for common psychiatric disorders in women. They were members of Caucasian female same-sex twin pairs from the Virginia Twin Registry (6), a population-based registry formed from a systematic review of all birth certificates in the Commonwealth of Virginia. Twins were eligible to participate if they were born during 1934–1971 and both members had previously responded to a mailed questionnaire. In our first interview, we assessed 92% of the eligible individuals (N=2,163)—90% face-to-face, the rest by telephone. Zygosity was determined blindly by standard questions (7), photographs, and—when necessary—DNA (6, 8). We recently conducted a validation study that involved performing polymerase chain reaction zygosity tests on an additional 269 pairs of twins and oversampling those for which our prior zygosity assignment was uncertain. On the basis of these tests (where the mean number of markers tested per pair was 17.5, SD=8.4), zygosity was changed in 12 pairs (4.5%).

We performed three additional waves of telephone interviews with this sample, but here we use data only from the third interview, which was completed by 1,898 individuals—87.7% of the individual twins from the original sample. The mean number of months between the first interview and the third interview was 61.3 (SD=5.1). The mean age of the participating twins in the third interview was 34.6 years (SD=7.5, range=22–59). From all twins who participated in interview wave 1, pairs in which both members participated in the third wave were similar in age ($t=1.33$, $df=2161$, $p=0.18$) to pairs in which one or both twins did not cooperate in the third wave, but the former group had, on average, approximately 0.6 more years of education ($t=5.56$, $df=2161$, $p<0.0001$). All interviews were conducted by interviewers who were blind to information about the co-twin. Written informed consent was obtained before face-to-face interviews, and oral assent was obtained before telephone interviews.

Measures

We chose, a priori, six measures from the first and third interviews that reflected broad aspects of functioning that relate to mental health. For simplicity, we scaled all dimensions so that increasing levels reflected increasing mental health.

Self-perceived physical health was assessed by two items in the wave 1 interview: 1) satisfaction with health and 2) number of days spent sick in bed in the last 12 months. This variable was included because of the strong evidence for a positive association between physical and emotional health (9). The mean scores for these two items were calculated after each was rescaled to contribute equal weight. Cronbach's alpha (10), a standard measure of internal scale reliability, for these two items was 0.41.

Nonconflictual interpersonal relationships were assessed by separate questions from a standard inventory of stressful life events (11), and participants were asked at both the wave 1 and wave 3 interviews about any serious problems getting along during the preceding 12 months with 1) parents, 2) twin, 3) other siblings, 4) other relatives, 5) close friends, 6) neighbors, or 7) in-laws. We examined the mean number of problems across the two interview waves. Cronbach's alpha for these items was 0.61.

Levels of anxiety and depression were assessed by the response to 18 questions asked at both interviews about the experience, for at least 5 days over the last 12 months, of 16 disaggregated symptoms of major depression, as outlined by DSM-III-R (e.g., separate items for weight gain and loss and psychomotor retardation and agitation), and two screening questions for generalized anxiety disorder ("feeling anxious, nervous, or worried" and "your muscles felt tense, or you felt jumpy or shaky inside"). Positive responses to these items, which were adapted from the Structured Clinical Interview for DSM-III-R (12), were not counted if the symptoms were judged to be the result of medications or physical illness. We examined the mean number of symptoms reported across the two waves. Cronbach's alpha for these items was 0.89.

Levels of substance use were measured with three variables that assessed 1) alcohol consumption at both waves, measured as the product of the number of days per month when an alcoholic drink was consumed and the number of drinks consumed on an average day when drinking occurred, 2) the frequency of use of "medicine for your nerves or sleeping medicines," assessed at the wave 1 interview, and 3) the average number of cigarettes smoked per day in the last year, assessed at the wave 3 interview. We examined the first principal component derived from these measures. Cronbach's alpha for these three items was 0.39.

Social support was assessed as the first principal component of a 15-item social interaction scale that was previously developed and used at the Institute for Social Research (13) and with which ratings were obtained at both interviews. These items reflected the frequency and quality of contact with friends and relatives, the frequency of attendance at clubs or other organizations, and the number of friends and confidants. The highest negative loadings on this factor (<–0.40) were for items that reflected interpersonal tensions (e.g., "Do your relatives criticize you? Do your friends make too many demands on you?"), whereas the highest positive loadings (>0.40) were on items that reflected warm relationships (e.g., "Do your relatives express interest in how you are doing? Do your relatives make you feel that they care about you?"). Cronbach's alpha for these 15 items was 0.61.

Self-esteem was assessed by the 10-item Rosenberg Self-Esteem Scale (14), which was completed at the wave 3 interview. We examined the first principal component derived from these items. Cronbach's alpha for this scale was 0.89.

The distributional properties of these variables, even after analysis of principal components, were often highly nonnormal. Therefore, before analysis, we polychotomized all variables into three approximately equal classes that reflected low, intermediate, and high scores. We then fitted to these resulting contingency tables a multiple-threshold model, which assumes a normally distributed underlying latent distribution. We tested the goodness-of-fit of this model separately in monozygotic and dizygotic twins. Of the 12 tests, the model failed at the 5% level only twice, a result not different from chance expectations (15); no variable failed in both zygosities. We also examined the relationship between these six variables and age. The highest correlation was with nonconflictual interpersonal relationships (0.13); all other correlations were under 0.05. We did not, therefore, include age in our model.

Statistical Analysis

Our approach to the analysis of twin data has been outlined in detail elsewhere (16, 17) and consists of inferring the action of genetic and environmental risk factors from the pattern of resemblance in monozygotic and dizygotic twin pairs. For this article, we performed a multivariate genetic analysis of our six putative dimensions of mental health. While the goal of univariate genetic analysis is the decomposition of the variance of a trait into its genetic and environmental components, in multivariate genetic analysis, the focus shifts to decomposing sources of covariance among traits. To illustrate the difference between univariate and multivariate twin analysis, the concept of latent or unobserved factors is introduced. In a traditional or phenotypic factor analysis, latent factors are postulated to cause the resemblance (or, more technically, covariation) among

TABLE 1. Within- and Between-Twin Correlations for Indices of Mental Health in 794 Pairs of Female Twins[a]

Twin and Index	Tetrachoric: Twin 1 Physical Health	Non-conflictual Relationships	Low Anxiety/ Depression	Low Substance Use	Social Support	Self-Esteem
Twin 1						
Physical health		0.26	0.22	0.13	0.14	0.11
Nonconflictual relationships	0.25		0.42	0.17	0.30	0.04
Low anxiety/depression	0.30	0.53		0.39	0.32	0.17
Low substance use	0.18	0.23	0.36		0.22	–0.02
Social support	0.11	0.41	0.28	0.07		0.20
Self-esteem	0.04	0.04	0.29	0.08	0.20	
Twin 2						
Physical health	0.09[b]	0.09	0.10	0.06	0.14	0.12
Nonconflictual relationships	–0.03	0.25[b]	0.10	0.05	0.14	0.03
Low anxiety/depression	–0.02	0.17	0.17[b]	–0.03	0.16	0.01
Low substance use	0.01	0.11	0.21	0.47[b]	0.02	0.02
Social support	0.10	0.15	0.00	0.04	0.30[b]	0.03
Self-esteem	–0.01	–0.05	0.01	–0.12	–0.04	0.20[b]

[a] Shaded areas above the diagonal are monozygotic twins; clear areas below the diagonal are dizygotic twins.

TABLE 2. Results of Model Fitting to Determine Influence of Genetic and Environmental Factors on Mental Health Indices in 794 Pairs of Female Twins

Model	Number of Factors: Additive Genetic	Family Environmental	Individual-Specific Environmental	Analysis: χ^2	df	p	Akaike's Information Criterion
Saturated	6	6	6	83.0	75	0.25	–67.0
Common pathway	1	1	1	184.3	111	<0.001	–37.7
Independent pathway							
1	1	1	1	137.3	102	0.01	–66.7
2	2	1	1	105.0	97	0.27	–89.0
3	1	2	1	112.6	97	0.13	–81.4
4	1	1	2	114.6	97	0.11	–79.4
5	2	2	1	100.4	92	0.26	–83.6
6	2	1	2	93.7	92	0.43	–90.3[a]
7	2	0	2	114.2	98	0.13	–81.8
8	2	2	2	90.7	87	0.37	–83.3

[a] Best-fit model according to Akaike's information criterion (22).

items. The goal of factor analysis is to explain the correlations among a large number of variables as a result of the effects of a small number of latent factors. Multivariate genetic analysis is also a method of explaining correlations among multiple items. However, it goes beyond traditional factor analysis in that it provides insight into the causes of resemblance among variables.

As with all our twin modeling, we here assume that the variation and covariation in liability to mental health can be ascribed to three potential sets of factors: 1) additive genetic variables, which contribute twice as much to the correlations between monozygotic twins as they do to the correlations between dizygotic twins (because monozygotic twins share identical genes by descent, whereas dizygotic twins share, on average, half their genes), 2) common or family environment (those familial factors such as parental attitudes that are shared by members of a twin pair), which contribute equally to the correlation between monozygotic and dizygotic twins, and 3) individual-specific environmental factors, which reflect environmental experiences not shared by both members of a twin pair and therefore contribute to differences between them in their reported levels of mental health.

In univariate analysis, information regarding the causes of variation is obtained by comparing the resemblance of monozygotic and dizygotic twin pairs for a single variable. In multivariate analysis, the correlation between two or more variables is the primary unit of analysis. By comparing the cross-twin, cross-variable correlation in monozygotic and dizygotic twins, and contrasting that to the cross-twin, within-variable and within-twin, cross-variable correlations, the covariation of two or more variables can be partitioned into its genetic and environmental components.

Two alternative models were tested to describe how genetic and environmental factors may influence covariation. In the common pathway model (17–19), genetic and environmental factors influence covariation through a single pathway. Such a model contains no separate genetic and environmental latent factors. Rather, genetic and environmental variables act conjointly through one or more latent phenotypes. By contrast, in the independent pathway model, genes and the environment can contribute to covariation through separate genetic and environmental latent factors. Because we had only six dimensions of mental health, no model with more than two common factors could be identified. In addition to these common factors, the model estimated additive genetic (A), common or family environmental (C), and/or individual-specific or unique environmental (E) factors that are specific to individual dimensions of mental health. The common and specific factors are identified by subscripts so that A_{C1} and E_S represent, respectively, the first common genetic factor and a unique environmental factor specific to a particular variable.

The form of data for our multivariate genetic analysis is two 12×12 polychoric correlation matrices calculated by PRELIS (20), which gave the tetrachoric correlations within and across twins for the six dimensions of mental health and separately for monozygotic and dizygotic twins. To best describe how genes and the environment influence resemblance among the dimensions of mental health, a series of multivariate models was fitted to these matrices by using Mx software (21) by the method of asymptotic-weighted least

Correlation					
Twin 2					
Physical Health	Non-conflictual Relationships	Low Anxiety/ Depression	Low Substance Use	Social Support	Self-Esteem
0.28[b]	0.14	0.17	0.03	0.09	0.13
0.14	0.37[b]	0.25	0.17	0.24	0.06
0.20	0.35	0.49[b]	0.27	0.16	0.16
0.07	0.22	0.27	0.70[b]	0.09	–0.05
0.13	0.27	0.25	0.22	0.51[b]	0.08
0.10	–0.01	0.13	–0.01	0.13	0.36[b]
	0.29	0.30	0.09	0.15	0.15
0.22		0.45	0.29	0.33	0.15
0.32	0.46		0.38	0.32	0.27
0.13	0.30	0.36		0.14	0.02
0.23	0.31	0.22	0.10		0.19
0.14	–0.05	0.06	–0.07	0.25	

[b] Within-trait, cross-twin correlation.

squares. The model, which best combined the features of parsimony and goodness-of-fit, was selected by Akaike's information criterion (22), one of the best performing of such indices in a thorough simulation study (23). To identify uniquely second common factors, the loading of these factors on the first variable (physical health) was set to zero.

RESULTS

Complete data were available from both members of 794 twin pairs, of whom 471 were classified as monozygotic twins and 323 as dizygotic twins.

Correlation Matrix

The complete within- and between-twin correlation matrix for the six variables is shown in table 1. Results for monozygotic twins are above the diagonal (the upper-right shaded portion), and those for dizygotic twins are below the diagonal (the lower-left unshaded portion). For both monozygotic and dizygotic twins, the matrix has three parts: correlations within twin 1, correlations between twins 1 and 2, and correlations within twin 2. The following patterns in this complete matrix are noteworthy:

1. The within-twin correlations for the six traits are generally positive and modest and range largely from 0.15–0.30. The strongest correlations are seen between interpersonal relationships and anxiety/depression, interpersonal relationships and social support, and anxiety/depression and substance use.

2. The within-trait, cross-twin correlations (in table 1) are higher for all six variables in monozygotic twins than in dizygotic twins. These results suggest that genetic factors are of etiologic importance for all of these traits. However, the magnitude of twin resemblance for these traits varied widely: for physical health, the traits correlated to 0.09 in dizygotic and 0.28 in monozygotic twins; for substance use, they correlated to 0.47 in dizygotic and 0.70 in monozygotic twins.

3. For any two traits, there were two cross-twin, cross-trait correlations (i.e., trait 1 in twin 1 correlated with trait 2 in twin 2, and trait 2 in twin 1 correlated with trait 1 in twin 2). With few exceptions, these cross-twin, cross-trait correlations were higher for monozygotic twins than for dizygotic twins. For example, the correlations between interpersonal relationships and anxiety/depression were considerably higher in monozygotic twins (0.25 and 0.35, respectively) than in dizygotic twins (0.17 and 0.10). This pattern of results was consistent with the hypothesis that genetic factors are in part responsible for the covariance of these traits in the population.

Model Fitting

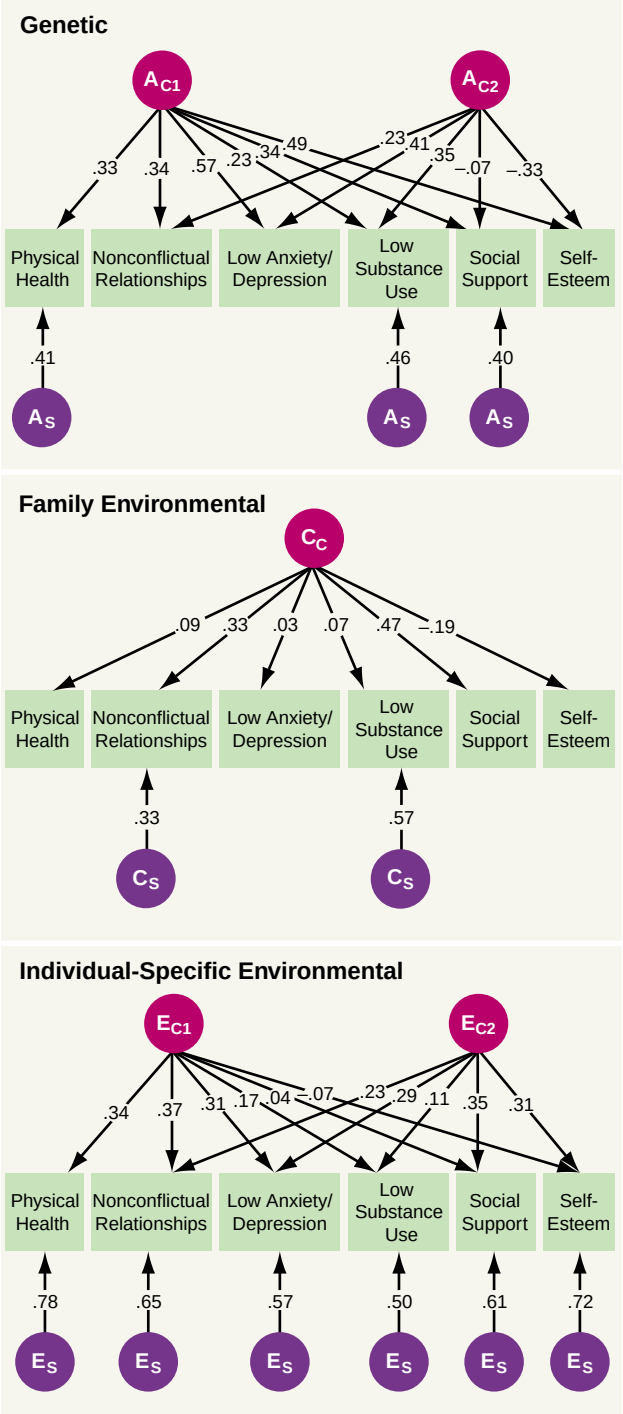
The results of model fitting are outlined in table 2. We began by fitting a fully saturated Cholesky model, which fit well but required the estimation of 63 separate parameters. We then attempted to fit two very simple models. The common pathway model allowed for a single factor that influenced all six traits by acting through a common latent variable. This produced a relatively poor fit. The second simple model assumed one genetic, one family environmental, and one unique environmental common factor that acted on the six variables independently of one another. This model (independent pathway model 1 in table 2) fit much better than the common pathway model and nearly as well as the saturated model.

We then added to this very simple independent pathway model a second genetic factor (independent pathway model 2), a second family environmental factor (independent pathway model 3), or a second unique environmental factor (independent pathway model 4). All three of these models produced an improvement in Akaike's information criterion, but the best fit was found with independent pathway model 2, which was substantially better than that found with the saturated model.

We then explored whether we could improve the fit yet further with additions to independent pathway model 2. We added a second family environmental factor (independent pathway model 5) and a second unique environmental factor (independent pathway model 6). By Akaike's information criterion, independent pathway model 5 was clearly inferior, but independent pathway 6 produced a slightly superior fit.

We then tested two further variations on independent pathway model 6. We tried dropping the one family environmental factor (independent pathway model 7) and adding a second such factor (independent pathway model 8). Neither improved upon the fit of independent pathway model 6, which we concluded was the model that provided the best overall explanation of the data.

FIGURE 1. Path Estimates of the Best-Fitting Model for Genetic, Family Environmental, and Individual-Specific Environmental Factors in Mental Health Indices for 794 Pairs of Female Twins[a]



[a] Path estimates are standardized partial regression coefficients and must be squared to determine the proportion of variance accounted for in the dependent variable. Observed variables are depicted in squares and latent variables in circles. The following abbreviations are used: A, additive genetic effects; C, common or family environment; E, individual-specific or unique environment. The subscript C indicates a common factor, and the subscript S indicates a factor that is unique to a single variable.

Parameter Estimates

The path coefficients that were estimated from the best-fitting model (independent pathway 6) are seen in figure 1. Table 3 presents the proportion of variance in these six aspects of mental health accounted for by the various aspects of the model.

Seven aspects of these results are noteworthy:

1. The first genetic factor has substantial loadings on all six variables, with the highest loadings on anxiety/depression and self-esteem and the lowest loading on substance use.
2. The second genetic factor—which, by definition, did not load on physical health—had its highest loadings on anxiety/depression and substance use and negative loadings on social support and self-esteem.
3. Genetic risk factors for three of the variables (interpersonal relationships, anxiety/depression, and self-esteem) were entirely accounted for by the two genetic common factors. By contrast, substantial variable-specific genetic loadings were found for physical health, substance use, and social support.
4. The single common family environmental factor had substantial loadings on only two variables: interpersonal relationships and social support.
5. Variable-specific family environmental effects were found for two variables—interpersonal relationships and substance use—one of which (substance use) was particularly large.
6. The first unique environmental common factor had substantial loadings on physical health, interpersonal relationships, and anxiety/depression; a modest loading on substance use; and very small loadings on social support and self-esteem. By contrast, the second unique environmental common factor had its highest loadings on social support and self-esteem.
7. Substantial variable-specific unique environmental factors were seen for all of the putative dimensions of mental health.

DISCUSSION

We sought, in this report, to explore the pattern of genetic and environmental factors that influence important dimensions of mental health in women. We attempted to address three specific questions and will examine our results in turn.

Genetic Factors That Influence Mental Health

Our first goal was to clarify the structure of the genetic factors that influence healthy mental functioning. One plausible hypothesis is that the genetic component of mental health has a very simple structure; there is a single set of mental health genes that are entirely responsible for the genetic contribution to the dimensions of mental health. This hypothesis might seem analogous to a genetic version of the unitary hypothesis of mental illness (24). An alternative hypothesis is

TABLE 3. Variance in Mental Health Indices Accounted for by Best-Fit Model of Genetic and Environmental Factors for 794 Pairs of Female Twins

Source of Variance	Proportion of Variance Accounted for by Model					
	Physical Health	Nonconflictual Relationships	Low Anxiety/ Depression	Low Substance Use	Social Support	Self-Esteem
Additive genetic factors						
Factor 1	0.11	0.11	0.32	0.05	0.12	0.24
Factor 2	—[a]	0.05	0.17	0.12	0.01	0.11
Variable-specific factors	0.16	0.00	0.00	0.21	0.16	0.00
Total	0.27	0.16	0.49	0.38	0.29	0.35
Family environmental factors						
Factor 1	0.01	0.11	0.00	0.01	0.22	0.04
Variable-specific factors	0.00	0.11	0.00	0.32	0.00	0.00
Total	0.01	0.22	0.00	0.33	0.22	0.04
Individual-specific environmental factors						
Factor 1	0.12	0.14	0.10	0.03	0.00	0.00
Factor 2	—[a]	0.05	0.08	0.01	0.12	0.10
Variable-specific factors	0.60	0.42	0.33	0.25	0.37	0.52
Total	0.72	0.61	0.51	0.29	0.49	0.62

[a] Set to zero.

that each dimension of healthy mental functioning is influenced by its own independent genetic factors.

We found, however, that the impact of genes on the dimensions of mental health were owing neither to a single common factor nor to only dimension-specific genetic effects. Rather, our results were more complex than either of these simpler models. We found evidence for two common genetic factors. High levels of the first of these factors tended to produce individuals who had warm, easy interpersonal relationships, were not prone to developing symptoms of anxiety or depression, and were predisposed to feeling good about themselves. High levels of the second genetic factor tended to produce individuals with little propensity toward substance use or anxious/depressive symptoms yet who tended to have surprisingly low levels of self-esteem.

However, these two common factors did not explain all of the genetic variance for mental health. Substantial variable-specific genetic effects were seen for physical health, substance use, and social support. Individuals with high levels of mental health, who functioned well across multiple psychological domains, were likely to have a fortuitous combination of a range of genetic factors.

Family Environment and Mental Health

Genetic studies of typical psychiatric disorders, including schizophrenia (25), major depression (26), and bipolar disorder (27), rarely find evidence for an etiologic contribution of family environment. Only in the area of substance use or abuse (e.g., references 28–30) is there a consistent impact of family environmental variables. What would we find for dimensions of healthy mental functioning?

Our results indicated that family environment significantly contributed to mental health. One common factor was found that strongly influenced the two variables of interpersonal relationships and social support. The general impact of family background on mental health appears to be in the domain of interpersonal functioning.

However, this single factor did not account for all of the impact of family environment on dimensions of mental health. Specific family environmental effects influenced the rates of conflictual relationships and, especially, substance use. The shared environment of twins might affect the rates of drug use through several mechanisms that cluster in families, including parental monitoring, religious and cultural values, community organizations, and drug availability (31).

Nonshared Environmental Factors and Mental Health

The structure of nonshared environmental factors that affect mental health was also quite complex. Two general factors were observed. High levels of the first factor predisposed individuals to low levels of both physical and anxious/depressive symptoms and to nonconflictual relationships. High levels of the second factor tended to produce individuals with good social support, high levels of self-esteem, and low levels of psychological symptoms. While it is difficult to speculate with any precision about the origin of these effects, it is plausible that the second factor results from success in a key life role such as marriage or work.

Unlike the results with genetic and family environmental factors, strong variable-specific, nonshared environmental effects were seen for all six dimensions. The interpretation of these loadings, however, is problematic because they reflect a confounding of true environmental influences and measurement error. Error or unreliability of measurements is likely to be substantial for many of the variables examined here. For example, the test-retest reliability for self-esteem over a 5-year period in this sample was 0.74 (3), which suggests that almost one-half of the variance of our assessment may be short-term fluctuations, actual change, or error.

Common and Independent Pathways

One of the advantages of genetic multivariate analysis is the ability to peer below phenotypic correlations to clarify the mechanisms of covariation. Standard factor analysis of our six dimensions produced evidence for a single factor with substantial loadings on all dimensions but self-esteem. These results might lead to the conclusion that the causes of the dimensions of mental health would have a simple structure and be very highly intercorrelated. Our findings suggest that this is unlikely.

We were also able to test whether the genetic and environmental causes of mental health had the same underlying structure (as predicted by the common pathway model) or had a different effect on the pattern of covariation of the dimensions of mental health. Our results clearly support the independent pathway model, which further elucidates the complex and distinct ways in which genetic and environmental factors affect healthy mental functioning.

Limitations

These results should be interpreted in the context of five potential methodologic limitations. First, the sample was entirely women, and our findings may not extrapolate to men. Second, our third interview, data from which contributed to four of our six measures, was performed by telephone. It is possible that different results might have been obtained had this assessment been face-to-face. Third, the traits examined in this study, some of which were based on quite a small number of items, had variable reliability. Only two of them (anxiety/depression and self-esteem) reflected a priori scales, and our measures of social support had only moderate internal reliability because social support was the first principal component of a multidimensional scale (5). In standard twin studies, errors of measurement result in an overestimation of the individual-specific environment and an underestimation of heritability (16). This might be a greater problem for the two of our measures that were obtained at a single wave (physical health and self-esteem) than for the four measures (interpersonal relationships, anxiety/depression, substance use, and social support) for which we averaged results obtained over two waves of assessment.

Fourth, our twin models assume that the exposure to relevant environmental factors was similar in monozygotic and dizygotic twins. We tested the validity of this assumption by examining whether standard measures of the similarity of childhood environments (32) and the current frequency of contact (as assessed at our wave 1 interview) predicted twin similarity for the six measures. Of these 12 analyses, two were significant at the 5% level (frequency of contact predicted twin similarity for physical health and substance use), a result that would occur by chance approximately 12% of the time (15). Of these two, the frequency of twin contact at the wave 3 interview predicted twin similarity only for substance use. Our estimates of the heritability of substance use may be upwardly biased. However, as we discussed previously in the *Journal* (30), it is also likely that the similarity in twin pairs of substance use patterns or associated personality traits influences the frequency of contact.

Fifth, we make no pretensions to have measured all the possible dimensions of what might constitute mental health. Were different dimensions included (e.g., the capacity to play), our results might have differed substantially. We assessed some important dimensions (e.g., marital adjustment and work satisfaction) but did not include them because they were not available for significant (and nonrandom) portions of our sample (e.g., single women and married homemakers).

REFERENCES

1. McGuffin P, Owen MJ, O'Donovan MC, Thapar A, Gottesman II: Seminars in Psychiatric Genetics. London, Gaskell, 1994
2. Lykken DT, Tellegen A: Happiness is a stochastic phenomenon. Psychol Sci 1996; 7:186–189
3. Roy M-A, Neale MC, Kendler KS: The genetic epidemiology of self-esteem. Br J Psychiatry 1995; 166:813–820
4. Bergeman CS, Plomin R, Pedersen NL, McClearn GE, Nesselroade JR: Genetic and environmental influences on social support: the Swedish adoption twin study of aging (SATSA). J Gerontol 1990; 45:101–106
5. Kendler KS: Social support: a genetic-epidemiologic analysis. Am J Psychiatry 1997; 154:1398–1404
6. Kendler KS, Neale MC, Kessler RC, Heath AC, Eaves LJ: A population-based twin study of major depression in women: the impact of varying definitions of illness. Arch Gen Psychiatry 1992; 49:257–266
7. Eaves LJ, Eysenck HJ, Martin NG, Jardine R, Heath AC, Feingold L, Young PA, Kendler KS: Genes, Culture and Personality: An Empirical Approach. London, Academic Press, 1989
8. Spence JE, Corey LA, Nance WE, Marazita ML, Kendler KS, Schieken RM: Molecular analysis of twin zygosity using VNTR DNA probes (abstract). Am J Hum Genet 1988; 43:A159
9. Dew MA: Psychiatric disorder in the context of physical illness, in Adversity, Stress and Psychopathology. Edited by Dohrenwend BP. New York and Oxford, UK, Oxford University Press, 1998, pp 177–218
10. Cronbach LJ: Coefficient alpha and the internal structure of tests. Psychometrika 1951; 16:297–334
11. Kendler KS, Kessler RC, Walters EE, MacLean C, Neale MC, Heath AC, Eaves LJ: Stressful life events, genetic liability, and onset of an episode of major depression in women. Am J Psychiatry 1995; 152:833–842
12. Spitzer RL, Williams JBW: Structured Clinical Interview for DSM-III-R (SCID). New York, New York State Psychiatric Institute, Biometrics Research, 1985
13. Schuster TL, Kessler RC, Aseltine RH Jr: Supportive interactions, negative interactions, and depressed mood. Am J Community Psychol 1990; 18:423–438
14. Rosenberg M: Society and the Adolescent Self-Image. Princeton, NJ, Princeton University Press, 1965
15. Feild HS, Armenakis AA: On use of multiple tests of significance in psychological research. Psychol Rep 1974; 35:427–431
16. Kendler KS: Twin studies of psychiatric illness: current status and future directions. Arch Gen Psychiatry 1993; 50:905–915
17. Neale MC, Cardon LR: Methodology for Genetic Studies of Twins and Families. Dordrecht, the Netherlands, Kluwer Academic, 1992
18. Kendler KS, Heath AC, Martin NG, Eaves LJ: Symptoms of anxiety and symptoms of depression: same genes, different environments? Arch Gen Psychiatry 1987; 44:451–457

19. McArdle JJ, Goldsmith HH: Alternative common-factor models for multivariate biometric analyses. Behav Genet 1990; 20: 569–608
20. Joreskog KG, Sorbom D: PRELIS 2: User's Reference Guide. Chicago, Scientific Software International, 1996
21. Neale MC: Mx: Statistical Modeling. Richmond, Virginia Commonwealth University, Department of Psychiatry, 1994
22. Akaike H: Factor analysis and AIC. Psychometrika 1987; 52: 317–332
23. Williams LJ, Holahan PJ: Parsimony-based fit indices for multiple-indicator models: do they work? Structural Equation Modeling 1994; 1:161–189
24. Menninger K, Ellenberger H, Pruyser P, Mayman M: The unitary concept of mental illness. Bull Menninger Clin 1958; 22: 4–12
25. Gottesman II: Schizophrenia Genesis: The Origins of Madness. New York, WH Freeman, 1991
26. McGuffin P, Katz R, Watkins S, Rutherford J: A hospital-based twin register of the heritability of DSM-IV unipolar depression. Arch Gen Psychiatry 1996; 53:129–136
27. Kendler KS, Pedersen NC, Neale MC, Mathe AA: A pilot Swedish twin study of affective illness including hospital- and population-ascertained subsamples: results of model fitting. Behav Genet 1995; 25:217–232
28. Kendler KS, Prescott CA, Neale MC, Pedersen NL: Temperance board registration for alcohol abuse in a national sample of Swedish male twins born 1902–1949. Arch Gen Psychiatry 1997; 54:178–184
29. Tsuang MT, Lyons MJ, Eisen SA, Goldberg J, True W, Meyer JM, Eaves LJ: Genetic influences on abuse of illicit drugs: a study of 3,297 twin pairs. Am J Med Genet 1996; 67:473–477
30. Kendler KS, Prescott CA: Cannabis use, abuse, and dependence in a population-based sample of female twins. Am J Psychiatry 1998; 155:1016–1022
31. Hawkins JD, Catalano RF, Miller JY: Risk and protective factors for alcohol and other drug problems in adolescence and early adulthood: implications for substance abuse prevention. Psychol Bull 1992; 112:64–105
32. Loehlin JC, Nichols RC: Heredity, Environment and Personality: A Study of 850 Sets of Twins. Austin, University of Texas Press, 1976