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# Parents' Marital Discord Moderating The Genetic And Environmental Influences On Externalizing Problems

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Parents' Marital Discord Moderating the Genetic and Environmental Influences on  
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For the degree of Master of Science

Is approved by the final examining committee:

Susan C. South

Chair

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Approved by Major Professor(s): Susan C. South

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PARENTS' MARITAL DISCORD MODERATING THE GENETIC AND  
ENVIRONMENTAL INFLUENCES ON EXTERNALIZING PROBLEMS

A Thesis

Submitted to the Faculty

of

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Amber M. Jarnecke

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Requirements for the Degree

of

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## ABSTRACT

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Parental marital discord is related to children's externalizing problems at various ages. However, little is known about the mechanisms that explain these associations. The current study assesses the impact of parental marital discord on the etiology of offspring externalizing problems at different ages. Specifically, biometric moderation models were used to test the hypothesis that parental marital discord moderates genetic and environmental influences on offspring externalizing problems at age 11 and age 17. Results suggest that parental marital discord had a moderating effect on the genetic and environmental influences on child's externalizing problems at both ages, though the pattern of moderation differed between cohorts. In the 11-year old cohort, greater genetic influences emerged at lower levels of parents' marital discord. In the 17-year old cohort, greater genetic influences in externalizing problems emerged at lower levels of parents' marital discord and nonshared environmental influences were greatest at the highest levels of discord. These results present a more thorough understanding of the etiological associations between parental marital relationships and offspring externalizing problems as they might differ by age of the child.



## INTRODUCTION

Antisocial behavior, alcohol and substance use disorders, conduct disorder, aggression, and a disinhibited and impulsive personality style are often comorbid (Armstrong & Costello, 2002) and may produce substantial costs for the individual and the larger community. These outcomes tend to be related to problems with personal distress, difficulties with the law, and challenges within interpersonal contexts. Research has shown that these phenotypes are subsumed under a latent construct of externalizing psychopathology (Achenbach, 1966; Krueger, 1999), which is highly heritable (Krueger, Hicks, Patrick, Carlson, Iacono, & McGue, 2002) and passed from parents to offspring (Hicks, Krueger, Iacono, McGue, & Patrick, 2004). Although the structure, consequences, and heritability of externalizing disorders have been explored, there is much to be uncovered in relation to this type of psychopathology. The current study will expand on possible etiological mechanisms involved in the development of externalizing psychopathology using behavior genetic methods. Specifically, the goal of this study is to determine the degree to which parental marital discord moderates genetic and environmental influences on externalizing problems at two different ages—late childhood and late adolescence.

### **Parental Marital Discord and Offspring Externalizing Problems**

Parents' marital discord has significant effects on childhood externalizing problems. Low levels of parental marital satisfaction and the presence of marital conflict have both been linked to child adjustment problems (McHale, Freitag, Crouter, & Bratko, 1993). In one study, hostility between parents of 4- to 5-year old children predicted child externalizing problems three years later (Katz & Gottman, 1993). In another study that examined externalizing problems in children over three one-year time points, increasing conflict between parents at each time point predicted increasing externalizing behaviors in the child at the next time point (Kouros, Cummings, & Davies, 2010). Interparental withdrawal, the extent to which a parent is detached or avoidant during interparental interactions, is another mechanism that predicts childhood psychological problems (i.e., externalizing and internalizing psychopathology). That is, withdrawal during interparental interactions is positively associated with increases in offspring psychopathology one and two years later (Sturge-Apple, Davies, & Cummings, 2006).

In addition to documenting associations between parental marital functioning and offspring externalizing problems, researchers have examined potential mediating and moderating mechanisms of this relationship. Child's age is one such mechanism. Mahoney and colleagues (1997) found that child's age moderated the association between fathers' marital adjustment and offspring internalizing and externalizing problems, with stronger associations found in families with younger children. Also, the parent-child relationship may influence the association between parental marital conflict and externalizing problems. In a longitudinal study of youth age 5- to 11-years

old, harsh discipline and parent-youth conflict fully mediated the relationship between parental marital conflict and child externalizing problems during the first assessment and partially mediated the relationship at the time of the second assessment five years later (Gerard, Krishnakumar, & Buehler, 2006). Both of these studies point to the importance of child's age in understanding the relationship between parents' marital functioning and child externalizing problems. Considering age in this context may not only be important for the phenotypic relationship but may also be an important piece to consider as we explore the etiology of externalizing problems.

### **Exploring Externalizing Problems Using Behavior Genetics Methods**

Having documented a phenotypic association between parents' marital functioning and offspring externalizing problems, it is appropriate to examine the underlying etiological mechanisms that play a role in this relationship. Behavior genetics is one method by which this can be done. Behavior genetic studies use biometric modeling of genetically informative family data to examine the etiology of phenotypes that differ among people in the population. This modeling technique parses variance into heritable components (A), shared environmental components (C), and nonshared environmental components (E). Heritability is the proportion of variance that can be attributed to additive genetic effects, shared environment is the proportion of variance shared between twins that is not attributable to genetic factors and which makes members of the family more similar to each other, and nonshared environmental components are any factors unique to the individual twin in a twin pair and which make family members different from each other. These estimates provide information

about how much of the sample-specific variation in a particular phenotype may be attributed to genetic or environmental influences.

A study employing behavior genetics methods found that additive genetic factors explained approximately 51% of the variance in externalizing problems at age 3 and shared and nonshared environmental factors explained 30% and 19% of the variance, respectively (van der Valk, van den Oord, Verhulst, & Boomsma, 2003). The same study also examined these components of variance again at age 7 and found roughly similar estimates with genetic factors accounting for 55% of the variance, shared environmental factors accounting for 37% of the variance, and nonshared environmental factors accounting for 8% of the variance. In a study that utilized the data from the Minnesota Twin Family Study (MTFS; Iacono, Carlson, Taylor, Wilkins, & McGue, 1999), authors found that genetic effects accounted for 38.2% of the variance in a measure of externalizing psychopathology, created from the mean symptom counts of conduct disorder (CD) and oppositional defiant disorder (ODD), at age 11 (Burt, McGue, Krueger, & Iacono, 2005). Genetic influence for the same cohort at age 14 contributed 30% of the variance in externalizing, and 24.1% of the genetic variance that emerged was unique to that age, suggesting that only some of the same genetic influences are contributing to externalizing psychopathology at age 11 and age 14. Clearly, genetic factors play a large role in childhood externalizing problems, though different sources of genetic influence may play a role at various ages.

Similar analyses have also been conducted in adolescent samples. Young and colleagues (2000) looked at a factor of behavioral disinhibition in adolescents; reports of conduct disorder, attention-deficit hyperactivity disorder, substance use, and a

personality trait of novelty seeking contributed to the latent factor, which was found to be highly heritable (84% of the variance in the factor was due to additive genetic effects). Krueger and colleagues (2002) subsequently conducted a similar study using data from the MTFSS, collected when the twin participants averaged 17 years of age; they estimated genetic and environmental influences on a latent factor of externalizing psychopathology that consisted of measures of antisocial behavior, conduct disorder, substance dependence, alcohol dependence, and the personality trait of disinhibition (reversed constraint). The analysis suggested that the externalizing factor was highly heritable, with additive genetic factors accounting for 81% of the variance in the factor. Together, these studies provide evidence that the variance in externalizing problems in adolescents may also be largely attributed to genetic factors; however, these estimates do not provide an explanation about how environmental processes and other factors contribute to, or moderate, their expression or manifestation.

### **Behavior Genetic Studies of Parental Factors and Childhood Externalizing Problems**

In addition to determining the relative magnitude of genetic and environmental influences on one phenotype (i.e., externalizing), it is also possible to examine genetic and environmental influences shared between two variables, such as externalizing problems and an environmental risk factor (e.g., a parenting or family variable). Research thus far has identified several parent-related variables that are associated with genetic and environmental influences on offspring externalizing problems. For example, parent-child conflict explained 33% of the covariation among different externalizing disorders (i.e., ADHD, CD, ODD) through genetic and environmental

factors in a sample of 11-year old twins from the MTF data (Burt, Krueger, McGue, & Iacono, 2003). In another study, higher rates of psychopathology in children (i.e., drug and alcohol, behavioral, and internalizing problems) were partially accounted for by environmental influences associated with parents' divorce (D'Onofrio et al., 2005). Using a children-of-twins design, Harden and colleagues (2007) looked at influences common between parental marital conflict and offspring conduct problems and found that common genetic influences were shared between marital conflict and offspring conduct problems. These studies suggest that there is overlap in the influences contributing to externalizing problems and environmental factors related to parent-child and family functioning; however, they do not provide any information about how the etiological influences on one factor (e.g., psychopathology) vary as a function of another variable (e.g., parental factor).

For this question, it is necessary to use biometric moderation models. This type of model estimates how the ACE components differ as a function of some other factor (a moderator variable). Essentially, biometric moderation models test for the presence of gene x environment interaction (GxE). If GxE is operating, then the likelihood of an outcome (e.g., externalizing problems) would depend on encountering a certain environmental risk factor. Presence of GxE indicates that the moderator variable (usually an environmental risk or protective factor) serves to increase or decrease the heritability of psychopathology. GxE can be examined by looking at measured genes and a specific environmental variable or by employing biometric moderation models, which use genetically informative family data (e.g., twin samples), to estimate the heritability of an observable variable as it differs by a moderator variable.

In one of the best-known early examples of GxE, Cadoret, Cain, and Crow (1983) found that aversive home environments interacted with a genetic vulnerability to adolescent antisocial behavior in a sample of adoptees, such that the presence of both predicted higher levels of antisocial behavior. A study by Hicks and colleagues (2009) provides an example in which newer biometric moderation models were used to examine the etiological influences on externalizing problems, represented as a composite of antisocial behavior, alcohol, nicotine, illicit drug dependence, and teacher reports of externalizing behavior. This study, which drew participants from the same sample of adolescents used in the current study, found multiple factors (i.e., antisocial peers, prosocial peers, parent-child relationship problems, academic achievement, and stressful life events) interacted with genetic and environmental influences on externalizing problems.

In the study by Hicks and colleagues, the authors found support for a diathesis-stress model of psychopathology. That is, greater environmental adversity was related to greater heritability of externalizing problems. In this model of psychopathology, genetic influences are assumed to exert their influence to contribute to the manifestation of a certain phenotype, such as externalizing behaviors, in stressful environments. Diathesis-stress is one model of psychopathology but there are other models that can account for different patterns of results that may be found in GxE studies. For example, if a study found that the heritability of psychopathology increased in more supportive environments, this might support a ‘social push’ model (Tuvblad, Grann, & Lichtenstein, 2006), suggesting that the genes are “willing-out” and expressing their disposition despite the supportive environment. Burt and

colleagues (2013) found support for this model in a study exploring the moderation of maternal warmth and directiveness on childhood conduct problems. Specifically, the authors found that genetic influences were strongest at the highest levels of maternal warmth and directiveness. A third pattern of heritability is also possible. If genetic influences were greatest in both the most advantaged and the most aversive environments this would reflect a 'differential susceptibility' model (Belsky & Pluess, 2009), suggesting that an individual's developmental plasticity is heritable. Therefore, some individuals may be particularly sensitive to aversive environments, whereas the genetic predisposition to an adverse outcome, like psychopathology, may exert its influence in others despite a relatively supportive environment. Many GxE studies using twin samples have found support for a diathesis-stress perspective or a social-push perspective in psychopathology; however, at this time, there have only been a few studies (e.g., South & Krueger, 2013) finding support a differential susceptibility model of psychopathology.

No GxE study to date has determined the model of psychopathology that best explains the heritability of externalizing problems as it might vary by parents' marital discord; however, several studies have explored other parent variables. Dick and colleagues (2007) found support for a diathesis-stress model of adolescent smoking. They looked at the role of parental monitoring on adolescent smoking and found that parental monitoring moderated the genetic and environmental influences on smoking, with genetic influences playing a greater role at low levels of monitoring and environmental influences contributing the most to smoking at high levels of monitoring. Adolescents with a genetic predisposition to smoking may belong to



environments with low parental monitoring and thus have more opportunities to engage in smoking behaviors. Other work demonstrated that parental discipline moderated genetic and environmental influences on externalizing problems, but effects differed when comparing maternal discipline to paternal discipline (Button et al. 2008). As level of maternal discipline increased the genetic influences on externalizing behaviors decreased, suggesting a social-push model of externalizing behaviors, but as the level of paternal discipline increased the genetic influences on externalizing behaviors increased, supporting a diathesis-stress model.

The majority of studies examining biometric GxE use cross-sectional data confined to one age group (e.g., Hicks et al., 2009); it could be potentially informative to explore how etiological influences on a phenotype, such as externalizing problems, differ by a person's age. There is some evidence to suggest that externalizing symptomology changes over time. Phenotypic associations between fathers' marital adjustment and externalizing symptoms are stronger in families with younger children than in families with older children (Mahoney et al., 1997) and externalizing problems decreased over time in children between ages 6 and 12 (Robbers et al., 2010). However, in a longitudinal investigation of twins it was found that the number of externalizing symptoms increased over time for males and females and increased at a greater rate in males (Hicks et al., 2007). Discrepancies among these studies might be due to differences in how externalizing problems were operationalized and variation in the age of participants at the time points of data collection. The genetic and environmental influences on externalizing symptoms may change as a function of time or age, as well. Trends of increasing genetic variation in externalizing problems for

men and decreasing genetic variation and increasing environmental influences for women have been identified (Hicks, et al., 2007). Rose and colleagues (2001) looked at genetic and environmental influences on drinking patterns over time at ages 16, 17, and 18.5 and found that genetic effects increased and shared environmental effects decreased with age. The relative influence of genes and environment on externalizing problems is unlikely to be stable over time and it is possible that environmental risk factors, such as parental marital discord, may influence the genetic and environmental effects on externalizing problems differently as one ages.

### **The Current Study**

Past research suggests that there is a phenotypic association between parents' marital discord and children's externalizing problems, but the etiology of this relationship is unclear. It has yet to be seen how relationship quality between parents is related to and varies the genetic and environmental influences on children's externalizing problems and how this may differ depending on the age of the child. To date, there are no studies examining biometric moderation effects of parental marital discord on genetic and environmental influences on the externalizing spectrum. Because parental marital discord, as compared to parental divorce alone, may have stronger implications in child functioning and adjustment (Riggio, 2004) we chose to explore the role that parent relationship quality plays in offspring externalizing problems.

The current study will seek to fill several gaps in the literature as it relates to parents' marital discord and its associations with children's externalizing behaviors. Biometric moderation models will be used to examine how genetic and environmental

influences on externalizing problems in a cohort of 11-year old twins and a separate cohort of 17-year old twins varies as a function of parental marital discord. Examining a factor of externalizing problems may provide a greater wealth of information beyond individual disorders that fall under the spectrum. Using a twin-family study design, Hicks and colleagues (2004) found that familial vulnerability to externalizing disorders was largely accounted for by heritable factors ( $h^2=.80$ ) and disorder-specific vulnerabilities had small to moderate effect sizes. This suggests that common variance among externalizing psychopathology may better aid in understanding of the etiology of specific externalizing disorders rather than the variance in each specific disorder.

In the current study, we allowed the externalizing factor scores for 11-year old and 17-year old twins to differ, as evidence suggests that the types of externalizing behaviors one engages in will vary depending on developmental age (Broidy et al., 2003; Lynam, 2006). For example, older adolescents may be more likely to engage in substance use and vandalism than younger adolescents or children. The externalizing problem factor score for the 11-year old cohort included symptoms count variables of CD and ODD, teacher-reports of externalizing behavior, and self-reports of delinquent behavior; the factor for 17-year old twins included all of the same variable (excluding ODD) as well as externalizing behaviors that are more likely to emerge during adolescence (i.e., adult antisocial behavior, alcohol, nicotine, and illicit drug dependence). Consistent with the types of externalizing problems one would expect an 11-year old to engage in, adolescent antisocial behavior was not measured in this cohort and few individuals endorsed any symptoms of substance dependence, hence these variables were not included in the factor score.

It was hypothesized that parental marital discord would moderate genetic and environmental influences on externalizing problems for both cohorts. Because children and adolescents who have parents with lower levels of relationship satisfaction tend to display more externalizing behaviors (McHale, et al., 1993; Katz & Gottman, 1993), children in families marked by parental marital discord may have more opportunities for latent externalizing problems to manifest. When high levels of parent dissatisfaction are present, parental monitoring will likely decrease and parent-child conflict will likely increase (Fauber, Forehand, McCombs Thomas, & Wierson, 1990; Gerard, Krishnakuma, & Buehler, 2006). All of these factors may make it more difficult to control and monitor a child's impulse to engage in externalizing problems, thus his/her predisposition to externalizing problems will emerge in this environment. Therefore it is hypothesized that the current study will find that genetic influences play a greater role at higher levels of parents' marital discord, supporting a diathesis-stress perspective of externalizing problems.

## METHODS

### **Participants**

Participants were twin pairs from the Minnesota Twin Family Study (MTFS). A full overview of the design and procedures of MTFS is available elsewhere (Iacono et al., 1999). Briefly, MTFS is an ongoing longitudinal study that identified twins born in Minnesota using public birth records. Initial assessment was conducted when twins were either 11- or 17-years old. The current study utilized data from both cohorts. Male twins from the 11-year old cohort were born between 1977 and 1982 and female twins from this cohort were born between 1981 and 1985. From the 17-year old cohort, male twins were born between 1971 and 1978 and female twins were born between 1975 and 1979. Individuals were eligible for participation in the study if both members of the twin pair were living, if the family lived within a day's drive from the laboratory, and if neither twin exhibited a physical or intellectual disability that would prohibit them from engaging in a full day of assessment. Approximately 18% of eligible families refused to participate in the study. Brief telephone interviews and self-report measures were obtained from approximately 76% of the families who had refused participation. Results from these measures indicated that non-participating families did not differ from participating families on parental education, occupational status, or

mental health. Participants in the sample are generalizable to the Minnesota state population at the time of data collection.

Determination of zygosity was done utilizing three methods: agreement of questionnaires completed by parents, agreement of questionnaires as completed by MTFS staff in regard to physical similarity of twins, and comparison of twins on ponderal cephalic indices and fingerprint ridge count. If the three estimates did not converge, a blood sample was requested and serological analysis was conducted. At the conclusion of the intake assessment, 756 twin pairs (253 male MZ, 233 female MZ, 123 male DZ, 147 female DZ) made up the 11-year old cohort and 626 twin pairs (188 male MZ, 223 female MZ, 101 male DZ, 114 female DZ) made up the 17-year old cohort. Because of missing data only 445 MZ and 249 DZ twins in the 11-year old cohort were retained for use in the current analyses. In the 17-year old cohort, 362 MZ and 182 DZ twins were retained.

## **Measures**

### **Parental Marital Discord**

Biological parents of the twin participants reported on their marital quality in their current marriage using the Dyadic Adjustment Scale (DAS; Spanier, 1976). The DAS consists of four subscales: Cohesion (5 items) which assesses frequency of positive interaction between the couple; Consensus (13 items) which measures how much couples agree or disagree on a variety of issues; Affectional Expression (4 items) which relates to couple agreement on the expression of affection; and Satisfaction (10 items) which assesses perceived stability of marriage and management of arguments between the couple. Parents were asked to report on their marriage with regard to only

the previous 12 months. For the purposes of this investigation, mother reports of parental marital discord were used unless only father reports were available, in which case father reports were used. Items were reverse coded to aid in the interpretation of the biometric moderation models. Thus, higher scores reflect more marital discord.

Confirmatory factor analysis (CFA) in Mplus (Muthén & Muthén, 1998–2012) was used to create a factor score for parental marital discord. The four DAS subscale scores were summed and used as indicator variables for the factor; even though most scales were roughly normally distributed (the satisfaction subscale was negatively skewed, greater than -1.0, in both samples), a maximum likelihood robust (MLR) estimator was used to maintain consistency of estimators with the externalizing factors (see below). Fit of the model was assessed using the criteria specified in Hu and Bentler (1999), which outlined that good-fitting models tend to have a RMSEA value of approximately .06 or less and CFI and TLI values of approximately .95 or greater. The one-factor solution fit well, with a RMSEA = .017 (90% CI = .00-.058), TLI = .998, and CFI = .999 for the 11-year old cohort. The factor scores were extracted for biometric moderation analyses (mean of 0.00,  $SD = 5.11$ , range = -10.81 – 28.02). The factor solution for the 17-year old cohort also fit well, with RMSEA = .023 (90% CI = 0.00 to 0.069), TLI = .996, and CFI = .999. The mean for this cohort was 0.00 ( $SD = 5.27$ , range = -10.66 to 23.28).

### **11-Year Old Externalizing Problems**

A factor score of externalizing problems was created using four variables: symptom counts of CD and ODD, self-reports of child delinquent behavior, and teacher reports of externalizing behaviors. CD and ODD were assessed via participant

interviews for lifetime mental disorders according to criteria from the Diagnostic and Statistical Manual, 3<sup>rd</sup> edition, revised (DSM-III-R; American Psychiatric Association, 1987), the system in place at time of assessment. Mothers were also interviewed regarding their child's psychopathology. Interview data was reviewed by at least two advanced graduate students with training in differential diagnosis and descriptive psychopathology. Symptoms were considered present if reported by either the twin or mother. Conduct disorder and oppositional defiant disorder included Criterion A symptoms of each disorder's respective diagnostic criteria. For conduct disorder, the criterion "has forced someone into sexual activity with him or her" was not included in assessment to circumvent possible mandated reporting.

Assessment of self-reported child delinquent behavior was assessed with a 36-item self-report measure, referred to as the Delinquent Behavior Inventory (DBI). This measure was adapted from Gibson (1967) and contains ratings of personality and lifetime delinquent acts. Items were scored 0 (not endorsed) or 1 (occurred once or more than once) and summed. Higher scores reflect more delinquent acts. DBI scores were not generated for individuals missing more than four items from the scale.

Teacher reports of externalizing were assessed using items adapted from personality trait ratings, the Conners' Teacher Rating Scale (Conners, 1969), and the Rutter Child Scale (Rutter, 1967). For the purposes of the current study, only teacher rating scales of externalizing behaviors were analyzed and placed into the externalizing factor. Most participants had ratings from three teachers and these reports were averaged to create an overall mean teacher rating score of externalizing behaviors. Higher scores indicated reports of more externalizing behaviors.



A CFA in Mplus (Muthén & Muthén, 1998–2012) was used to create a factor score for externalizing problems with a MLR estimator to handle any skew in the data. The externalizing problems factor fit well, resulting in a RMSEA = .040 (90% CI = .018-.066), TLI = .938 , and CFI = .979. The mean score for this factor was 0.00 (*SD* = .63, range = -0.61 – 4.76). This score was extracted and used in the biometric moderation models.

### **17-Year Old Externalizing Problems**

To examine externalizing problems in 17-year old twins, all variables comprising the 11-year old factor score except ODD were included in the factor score for this cohort and were assessed in the same way that they were in the 11-year olds. In addition, symptom count variables of alcohol dependence, nicotine dependence and drug dependence were examined. Twins were assessed for substance abuse and dependence using the Substance Abuse Module (SAM) of the Composite International Diagnostic Interview (Robins, Babor, & Cottler, 1987). Maternal reports of child substance use disorder symptoms were obtained from the use of the mother reports on the Diagnostic Interview for Children and Adolescents-Revised (DICA-R; Welner, Reich, Herjanic, Jung, & Amado, 1987). Again, interview data for substance use disorders was reviewed by at least two advanced graduate students and symptoms were considered present if indicated by the twin or the mother. Criterion A symptoms of alcohol dependence, nicotine dependence, and drug dependence were included. Drug assessment included cannabis, cocaine, amphetamines, sedatives, hallucinogens, inhalants, opioids, and phencyclidine. The drug dependence variable used for participants involved the substance for which the participant met the greatest number of

symptoms. Adolescent antisocial behavior (AAB) was also included in the factor score for this cohort. The AAB symptom count variable included 9 of the 10 Criterion C symptoms for antisocial personality disorder, excluding the criterion “has never sustained a totally monogamous relationship for more than 1 year,” due to the young age of the twins. For each diagnostic variable, greater scores indicated the endorsement of more criteria.

A one-factor solution for externalizing problems in the 17-year old cohort was found using a CFA with a MLR estimator in MPlus (Muthén & Muthén, 1998–2012) in which the error terms for substance dependence variables were allowed to covary. The model had a RMSEA of .03 (90% CI = .01-.05), TLI of .952, and CFI of .975. The mean for the factor score was 0.00 ( $SD = 7.02$ , range = -24.15 – 44.32).

### **Data Analysis**

In order to examine whether parental marital discord moderates the genetic and environmental influences on externalizing problems, biometrical modeling techniques were employed. This type of modeling utilizes twin methodology and a structural equation framework to decompose the variance in a trait into additive genetic influences (A), common environmental influences (C), and unique environmental influences (E). The E term also includes error. Biometric moderation models for gene X environment interaction (GxE) tested if genetic and environmental components of variance on externalizing problems or substance use varied by level of parental marital discord (Purcell, 2002). The moderation models permit the use of different ACE estimates of externalizing problems for different levels of parental marital discord (see Figure 1). The ACE moderation model estimates genetic influences on externalizing

problems after controlling for parents' marital discord. This moderation model is an extension of the univariate ACE model, but includes a  $\beta$  term for the estimate of the measured variable's (i.e., parental marital discord) moderation of genetic and environmental effects on the outcome (i.e., externalizing problems, substance use). The resulting ACE estimates can be plotted graphically, with the level of parental marital discord for each twin pair and the A, C, and E influences on externalizing problems or substance use for each twin in a pair portrayed as a linear function that varies by level of parental marital discord.

Mx software (Neale, et. al., 2003) was used to fit data to biometric models. To correct for possible biases in fit of the model, scales were adjusted for effects of age and gender (see McGue & Bouchard, 1984)<sup>1</sup>. Standardized residuals for the scales were formed by age, age<sup>2</sup>, age X gender, and age<sup>2</sup> X gender regressions and used in the following analyses. Because some participants lacked complete data, full information maximum likelihood with the raw data was used. The raw data technique treats missing data as randomly missing and then allows the conservation of twin pairs wherein one twin within a pair has missing data.

For each cohort, we tested two models used to assess effects of genetic and environmental moderation. The first model tested was a full moderation model, which included all of the main effects and interaction effects. The second model tested was a univariate no-moderation model, which did not contain the moderation parameters. The two models were compared and the likelihood ratio test and the Akaike Information

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<sup>1</sup> Differences between males and females were examined for all biometric moderation models. For each model, the pattern of results appeared similar for both males and females; thus we chose to combine males and females in all models.

Criterion (AIC; Akaike, 1987) were used to assess model fit. The likelihood ratio test measures goodness-of-fit, assessing the degree of fit among model expectations and observed data. The AIC penalizes for overparameterization while considering goodness-of-fit. The best fitting models include parsimonious descriptions of data and low AIC values.

## RESULTS

### **Externalizing Problems in the 11-Year Old Cohort**

The externalizing problems factor score for the 11-year old cohort was small but significantly correlated with the parental marital discord factor score for this group ( $r = .07, p < .01$ ).

The full biometric moderation model was fit to the externalizing problems factor score and the parental discord factor score then compared to a no-moderation model, which dropped the moderation parameters. The full moderation model (-2 log likelihood = 3126.10,  $df = 1380$ , AIC = 366.10) fit significantly better than the no-moderation model (-2 log likelihood = 3144.01,  $df = 1383$ , AIC = 378.01, change in  $-2\ln L = 17.90, p < .001$ ; see Table 1), suggesting that the genetic and environmental influences on externalizing problems in offspring vary by level of parental marital discord.

To provide a thorough understanding of the moderating role of parental marital discord we report both standardized and unstandardized ACE estimates for our biometric models. As shown in Table 2 and plotted in Figure 2, the heritability of externalizing problems increased from low ( $a^2 = 24\%$  at -2 standard deviations below the mean) to high ( $a^2 = 72\%$  at +2 standard deviations above the mean) parental marital discord. Shared environmental influences decreased from low ( $c^2 = 32\%$ ) to high ( $c^2 =$

16%) parental marital discord. Nonshared environmental influences also decreased from low ( $e^2 = 43\%$ ) to high ( $e^2 = 12\%$ ) parental marital discord. To aid in our understanding of the proportions of variance that resulted from this model, it was found that the unstandardized estimates exhibited a similar pattern as the standardized estimates: unstandardized genetic variance estimates increased, shared environmental estimates decreased somewhat, and nonshared environmental estimates decreased as parental marital discord increased.

### **Externalizing Problems in the 17-Year Old Cohort**

The factor score for externalizing problems in the 17-year old cohort was not significantly correlated with the factor score for parental marital discord ( $r = .05$ ,  $p = .13$ ).

Next, the externalizing problems and parental marital discord factor scores from the 17-year old cohort were fit to the full biometric moderation model and compared to a no-moderation model. As was found in the 11-year old cohort, the full moderation model ( $-2 \log \text{likelihood} = 2773.70$ ,  $df = 1080$ ,  $AIC = 613.70$ ) fit significantly better than the no-moderation model ( $-2 \log \text{likelihood} = 2783.70$ ,  $df = 1083$ ,  $AIC = 617.70$ , change in  $-2\ln L = 10.00$ ,  $p < .05$ ).

The standardized ACE estimates for the full moderation model show that heritability of externalizing problems decreased from low ( $a^2 = 82\%$ ) to high ( $a^2 = 57\%$ ) levels of parental marital discord, nonshared environmental influences increased from low ( $e^2 = 18\%$ ) to high ( $e^2 = 43\%$ ) levels of marital discord, and shared environmental influences did not contribute to the variance in substance use (see Figure 3). The unstandardized estimates show that the genetic influences decreased

only somewhat from low to high levels of marital discord, while nonshared environmental influences show a greater rate of change, increasing from low to high levels of marital discord (see Table 2).

## DISCUSSION

The costs associated with externalizing problems may be severe to the both the affected individual and the larger community. Exploring the etiology of externalizing problems in more depth may bring about greater understanding of how to conceptualize and treat the disorders included in this spectrum. In the current study, we took one step toward this goal by exploring if and how the genetic and environmental influences on offspring externalizing problems are moderated by parental marital discord in cohorts of different ages. Results suggest that the genetic and environmental influences on a factor of externalizing problems varied as a function of parents' marital discord in both the 11-year old cohort and 17-year old cohort; however, the patterns of moderation that emerged for each cohort suggest that parents' marital functioning is operating on the etiological components of externalizing differently for each group.

In the 11-year old cohort, we found support for a diathesis-stress perspective of externalizing. The proportion of variance in externalizing problems accounted for by genetic factors increased as parents' marital discord increased and the proportion of variance accounted for by environmental factors decreased as marital discord increased. It appears that when the parents' marital relationship is marked by discord, genetic predispositions toward externalizing problems in offspring are allowed to exert their influence. Children in this type of environment are more likely to be exposed to



less adaptive parenting styles (e.g., less monitoring, more conflict) and the combination of these factors may allow the genetic predisposition to externalizing problems to manifest behaviorally at a phenotypic level.

This is contrasted against what is happening when parents' marital discord is low. For children raised in homes with more harmonious parent relationships, influences from the shared and unique environments are more likely to contribute to externalizing problems, relative to genetic influences. Offspring who are displaying externalizing problems despite having parents whose relationship quality is high, may be doing so because other factors in their environment are significantly contributing to their manifestation. For example, peers may have a substantial influence on adolescent externalizing problems. Having peer groups that use substances increases the likelihood of an adolescent using (Mason & Windle, 2000; Preston & Goodfellow, 2006; Trucco, et al., 2011; Button, Stallings, Rhee, Corley, Boardman, & Hewitt, 2009). In these instances, genetics are still playing a role but these individuals are likely experiencing relatively high levels of other environmental stress or pressure (more than individuals who come from families marked by high parental marital discord), such that externalizing behaviors and psychopathology emerge. It is also worth considering that perhaps those with a low genetic predisposition and supportive family environment are on track to belong to a more 'adolescent-limited' trajectory of externalizing problems (Moffitt, 2006). That is, their environment is contributing to the manifestation of externalizing problems at this point in time, but these types of behaviors may not persist past emerging adulthood.

For the 17-year old cohort, the proportion of variance attributed to genetic factors decreased and the proportion of variance attributed to nonshared environmental factors increased as parental marital discord increased. Because the proportion of variance in one component (e.g., A) is by definition subject to other variance components (e.g., C and E), we chose to present unstandardized variance components as well. Looking at the results from the biometric moderation model for the 17-year old cohort illustrates the importance of examining both standardized and unstandardized estimates when interpreting the results from the model. The unstandardized estimates for this model suggest that nonshared environmental components of variance increase as parental marital discord increases but genetic influences are relatively stable. Therefore, examining only the standardized estimates from this model would lead to a different interpretation of the results than if they were examined in conjunction with unstandardized estimates.

The relative stability of genetic influences across levels of parental discord may be, in part, attributed to the child's age. By the time an individual reaches age 17, genetic influences contributing to externalizing problems may be only minimally influenced by the parents' relationship. The parents of these twins have been together for at least 17 years so it is possible that they are better able to hide their discord from their children after being in a relationship for that length of time. It may also be that as children begin to transition into adult roles, family of origin factors, such as parents' marital functioning, are increasingly less likely to vary the level of genetic influences seen in externalizing problems. Rather, genetic effects may be subject to greater influence from other elements of the environment.

Although genetic influences were relatively stable across levels of parental marital discord, nonshared environmental influence increased notably from low to high levels of parental discord. Findings indicate that the nonshared environment contributes nearly half of the variance in externalizing problems at the highest level of discord. If children are raised in homes marked by discord they may be more likely to experience other aspects of their environment as stressful, aversive, or dysfunctional. Perhaps the genetic factors that predispose an individual to engage in externalizing problems are also correlated with or predispose them to engage in more unique environmental experiences that contribute to these behaviors. The literature on substance use in adolescents and emerging adults has found that a number of environmental factors, including neighborhood instability, social norms, childhood maltreatment, parental monitoring, and peer groups are phenotypically related to the use of substances (Stone, Becker, Huber, & Catalano, 2012). Some of these factors may share common genetic influences with externalizing problems more generally, and thus contribute to externalizing at high levels of parental marital discord. At low levels of parental marital discord, the nonshared environment is playing little role in externalizing problems and genetics are contributing the most to these behaviors. Taken together, these results provide support for a social-push model of externalizing, suggesting that when adolescents grow up in a family marked by little parental marital discord they engage in externalizing problems because their genetics are pushing them to do so (Tuvblad, Grann, & Lichtensten, 2006).

It is somewhat unclear why the pattern of moderation emerged differently for each cohort. This discrepancy may be due to differences between samples (e.g.,

generational differences) or may be a function of age. Several studies have identified the relative influences of genes and environment in externalizing behaviors as they vary by age (e.g., van der Valk et al., 2003), but have not examined moderators of these influences within a developmental context. Future studies should consider employing longitudinal methods to clarify whether the results of the current study are a function of age or other cohort differences.

Although it was important to create different factor scores for 11- year old and 17-year old twins because certain types of externalizing problems may be present at a young age but shift and change as a child ages (see Rutter, Kim-Cohen, and Maughan, 2006 for a discussion on the continuities and discontinuities in mental disorders as one transitions from childhood to adulthood), this may have also influenced our findings. That is, the moderation of the etiological components of externalizing may differ by cohort because externalizing problems were defined differently for each cohort. Certain externalizing problems are present from a young age (e.g., more disruptive behaviors; Mesman & Koot, 2001) whereas others, such as substances use, tend emerge later during adolescence (Clark, Doyle, & Clincy, 2013). Even though having different factors of externalizing may have influenced the current findings, we feel the use of these factors best represent what is *actually* occurring at those different ages. It is not only important to consider developmental age or other cohort differences when looking at the phenotypic level of externalizing behaviors but also when trying to understand the etiological mechanisms involved in them.

The current study added to the our understanding of externalizing problems in children and adolescents by exploring the moderating role of parental marital discord

on the genetic and environmental influences on externalizing symptomatology in cohorts of two different ages (i.e., 11 and 17). This research has may help inform future studies targeted at identifying specific genetic mechanisms (e.g., genome-wide association studies) or other environmental variables that contribute to externalizing problems. It also has significant implications for clinical treatment and prevention efforts. For example, an 11-year old who is acting disruptively despite being raised in a supportive family environment may require different interventions from a clinician as compared to how this behavior would be treated in an 11-year old who is raised in family marked by parental discord. In the first scenario, it might be important to explore what else is happening in the environment that could contribute to the externalizing behaviors. In the second scenario, it might more appropriate to take a family-systems perspective, allowing the parents to explore how their relationship may contribute to the child's behaviors. Also, explicitly understanding the role of genetic influences on the manifestation of externalizing problems may help the family relate to and understand the child, rather than acting to blame him or her. Overall, integrating this information into real-life practice may prove fruitful for conceptualizing and treating externalizing problems.

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## APPENDICES



Appendix A

Table 1  
*Fit Statistics for Moderation Models*

	-2lnL	df	$\Delta X^2$	$\Delta df$	<i>p</i>	AIC
Parents' Marital Discord Moderating EXT at 11						
No Moderation	3144.01	1383				378.01
Full ACE Moderation	3126.10	1380	17.90	3	<b>0.0005</b>	366.10
Parents' Marital Discord Moderating EXT at 17						
No Moderation	2783.70	1083				617.70
Full ACE Moderation	2773.70	1080	10.00	3	<b>0.0186</b>	613.70

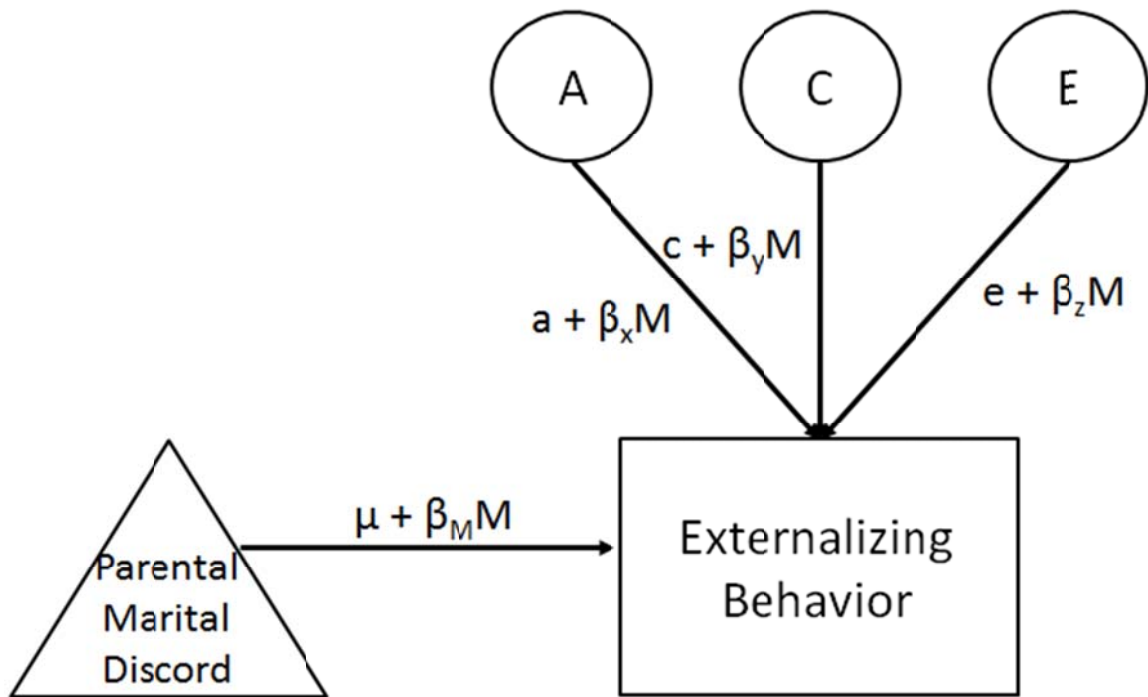
*Note.* -2lnL, -2 log likelihood; df, degrees of freedom; AIC, Akaike's Information Criterion.

Table 2  
*Estimates of Standardized and Unstandardized Variance Components*

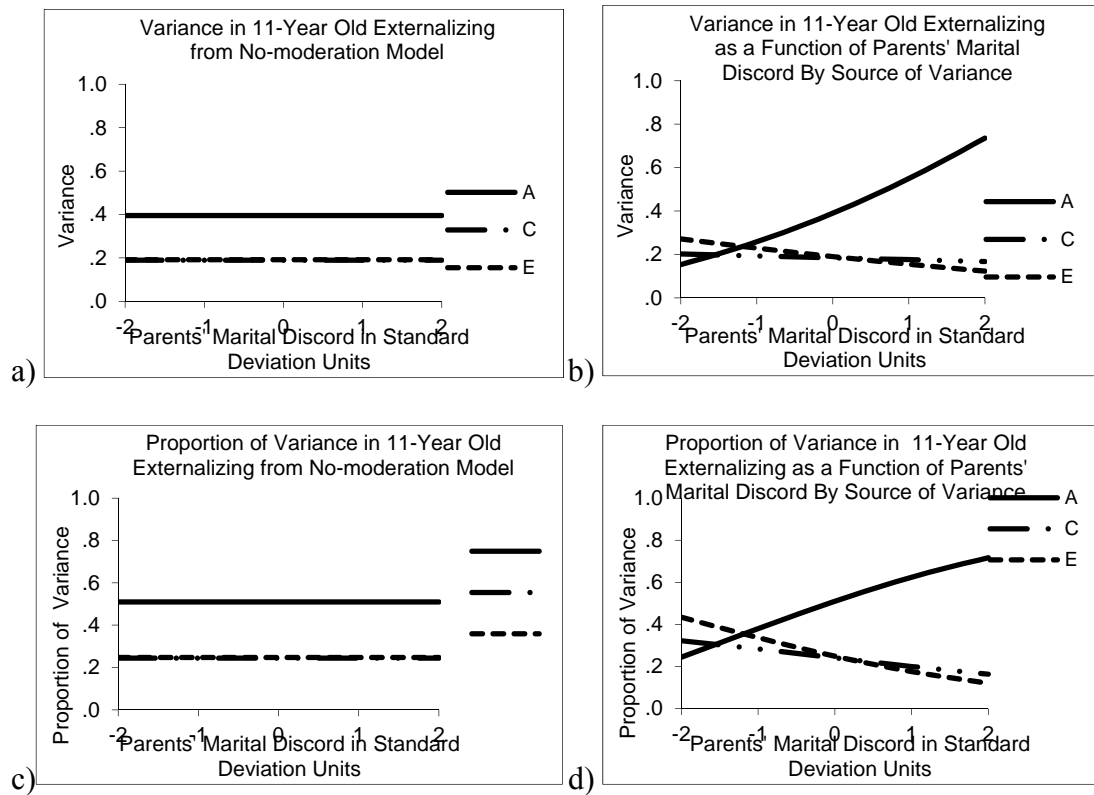
		Standardized			Unstandardized			Total Phenotypic Variance
		Variance Components			Variance Components			
		A	C	E	A	C	E	
Parents' Marital Discord Moderating EXT at 11								
No Moderation Model of Externalizing Problems		0.51	0.24	0.25	0.40	0.19	0.19	0.78
Moderation Model of Externalizing Problems	-2	0.24	0.32	0.43	0.15	0.20	0.27	0.63
	-1	0.38	0.28	0.34	0.26	0.19	0.23	0.68
	0	0.51	0.24	0.25	0.39	0.18	0.19	0.76
	1	0.62	0.20	0.18	0.55	0.18	0.15	0.88
	2	0.72	0.16	0.12	0.74	0.17	0.12	1.03
Parents' Marital Discord Moderating EXT at 17								
No Moderation Model of Externalizing Problems		0.69	0.00	0.31	0.82	0.00	0.54	0.96
Moderation Model of Externalizing Problems	-2	0.82	0.00	0.18	0.69	0.00	0.15	0.85
	-1	0.76	0.00	0.24	0.68	0.00	0.22	0.90
	0	0.69	0.00	0.31	0.66	0.00	0.29	0.96
	1	0.63	0.00	0.37	0.65	0.00	0.38	1.03
	2	0.57	0.00	0.43	0.64	0.00	0.47	1.11

*Note.* A = genetic variance component; C = shared environmental variance component; E = nonshared environmental variance component.

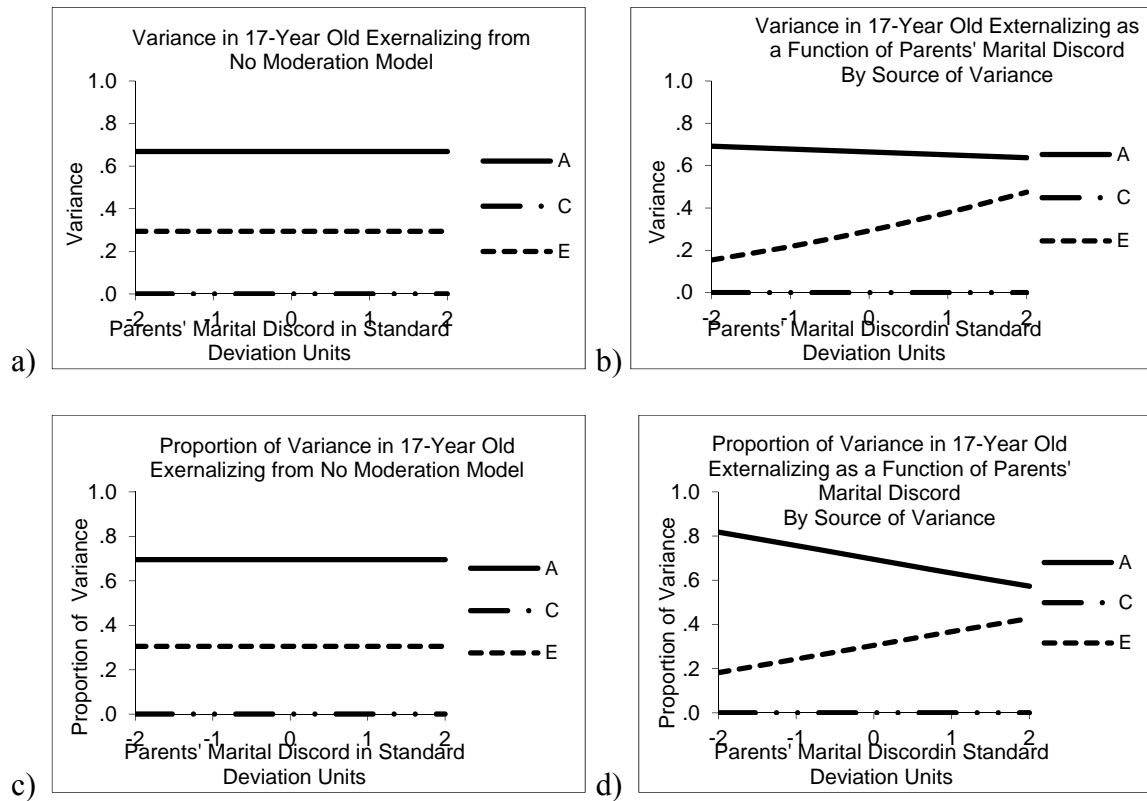
## Appendix B



*Figure 1.* Biometric moderation model with parental marital discord moderating the genetic and environmental influences on externalizing disorders (model is displayed for only a one member of a twin pair). A = additive genetic effects, C = shared (common) environmental variance, and E = nonshared (unique) environmental influences. Moderation of externalizing disorders by parental marital discord is signified by the product of a coefficient that categorizes the magnitude and direction of moderation (e.g.,  $\beta_{xc}$ ) multiplied by the level of the moderator. Total phenotypic variance in externalizing disorders can be calculated by squaring and summing all paths leading to the variance:  $P^2 = (a + \beta_{xx}M)^2 + (c + \beta_{xy}M)^2 + (e + \beta_{xz}M)^2$ .



*Figure 2.* (a) Variance in externalizing from the no-moderation model with parents' marital discord. (b) Variance in externalizing as a function of parents' marital discord. (c) Proportion of variance from the no-moderation model with parents' marital discord. (d) Proportion of variance in externalizing as a function of parents' marital discord. A, genetic variance; C, shared environmental variance; E, unique environmental variance.



*Figure 3.* (a) Variance in substance use from the no-moderation model with parental marital discord. (b) Variance in substance use as a function of parents' marital discord. (c) Proportion of variance from the no-moderation model with parents' marital discord. (d) Proportion of variance in substance use as a function of parents' marital discord. A, genetic variance; C, shared environmental variance; E, unique environmental variance.