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Parental criticism and externalizing behavior problems in adolescents– the role of environment and genotype-environment correlation

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Abstract

Genetic factors are important for the association between parental negativity and child problem behavior, but it is not clear whether this is dueto passive or evocative genotype-environment correlation (rGE). In this study we applied the extended children-of-twins model to directly examine the presence of passive and evocative rGE as well as direct environmental effects in the association between parental criticism and adolescent externalizing problem behavior. The cross-sectional data come from the Twin and Offspring Study in Sweden (TOSS) (N=909 pairs of adult twins) and from the Twin study of CHild and Adolescent Development (TCHAD) (N=915 pairs of twin children). The results revealed that maternal criticism was primarily due to evocative rGE emanating from their adolescent's externalizing behavior. On the other hand, fathers' critical remarks tended to affect adolescent problem behavior in a direct environmental way. This suggests that previously reported differences in caretaking between mothers and fathers also are reflected in differences in why parenting is associated with externalizing behavior in offspring.

Keywords

parenting; externalizing behavior; twins; genotype-environment correlation

Introduction

A multitude of studies have linked adverse parenting practices to various conduct disorders in children (e.g., Campbell, 1995; Hill, 2002; Loeber, Burke, & Pardini, 2009). Specifically,

parental negativity, rejection, and harsh parenting practices have been widely associated with the development of child externalizing behavior problems and delinquency (Loeber & Dishion, 1983; Rothbaum & Weisz, 1994; Shaw, Gilliom, Ingoldsby, & Nagin, 2003). Findings from genetically informative studies reveal that the association between negative parenting practices and adolescent maladjustment is influenced by genetic factors and suggest the presence of evocative genotype-environment correlation (rGE)(Burt, McGue, Krueger, & Iacono, 2005; Deater-Deckard & O'Connor, 2000; Jaffee, et al., 2004; Narusyte, Andershed, Neiderhiser, & Lichtenstein, 2007; Neiderhiser, Reiss, Hetherington, & Plomin, 1999; Neiderhiser, et al., 2004). However, because all of these studies focused only on twin or sibling children they were unable to clearly disentangle whether these genetic effects stemmed from children, their parents or both.

Harsh, negative or critical parenting has been related to later increases in externalizing problems in children, which supports the importance of parent-effects (Collins, Maccoby, Steinberg, Hetherington, & Bornstein, 2000; Nix, et al., 1999; Trentacosta & Shaw, 2008). On the other hand, effects stemming from children have also been found to operate in parent-child relationships. That is, parents may get more critical or adopt harder discipline practices in responseto child problem behavior (Anderson, Lytton, & Romney, 1986; Deater-Deckard, 1996; Lytton, 1990). Recent studies, however, tend to emphasize the bidirectional processes in the association between parent negativity and conduct problems in children (Bullock & Dishion, 2007; Burke, Pardini, & Loeber, 2008; Pardini, 2008; Richmond & Stocker, 2008). These results are usually discussed in light of Patterson's coercion theory, according to which coercive interactions between aggressive children and their parents escalate overtime and through these escalating aggressive interactions contribute to the development of antisocial behavior (Patterson, 1980).

Genetically informative studies have increased our understanding of the mechanisms involved in parent-child relationships by allowing the estimation of genotype-environment correlations for these relationships. Genotype-environment correlation (rGE) is defined as a correlation between the heritable characteristics of an individual and the experienced environment(Plomin, DeFries, & Loehlin, 1977; Scarr & McCartney, 1983). Three types of rGE are typically described: passive, evocative, and active rGE. *Passive* rGE occurs when a child inherits characteristics from the parents and receives treatment from the parents correlating with those characteristics. For example, parents may pass down to their children the genes that are involved in the development of antisocial behavior and, in addition, apply harsh rearing practices that are also influenced by the same genetic factors. Passive rGE may therefore be interpreted as the parent-moderated effects in parent -child relationships. *Evocative* rGE reflects a specific environment a child evokes through his inherited traits. For example, parents may use harsh discipline in response to a child's bullying behavior. This type of rGE can denote child-moderated processes. *Active* rGE corresponds to active choices and selections made by a child that are correlated with that child's inherited traits. In parent-child relationships, it is more difficult to distinguish between children choosing their environments (active rGE) and environments elicited by the child (evocative rGE), thus we will not discuss the active type of rGE further in this study. However, it is worth noting that even though active and evocative rGE can be defined as different processes in theory, they are hardly distinguishable outside a laboratory setting (Neiderhiser et al., 2004).

Several studies suggest that the relationship between parental negativity and child problem behavior is partly due to evocative rGE (Boivin, et al., 2005; Lynch, et al., 2006; Neiderhiser, Reiss, Lichtenstein, Spotts, & Ganiban, 2007; Neiderhiser, et al., 2004; O'Connor, Deater-Deckard, Fulker, Rutter, & Plomin, 1998; Pike, McGuire, Hetherington, Reiss, & Plomin, 1996). For example, Boivin and colleagues(2005) examined 5-month-old infants and found that a moderate part of the maternal hostile-reactive behaviors was

accounted for by the infants'(partly heritable) difficultness. A different study , focused on adolescent twin sand siblings, suggested that parental negativity may be explained by antisocial behavior in adolescents (Pike, et al., 1996). Finally, a negative correlation between parental negativity and prosocial behavior in preschool children was due primarily to genetic effects, providing further support for the importance of the evocative effects of children's characteristics (Knafo & Plomin, 2006). On the other hand, results of studies of monozygotic (MZ)twins discordant for antisocial behavior indicated that aversive parenting was associated with antisocial behavior in children partly for environmental reasons . That is, genetically identical children showed different levels of behavior problems, which could partly be explained by differential parental negativity (McGue, Iacono, & Krueger, 2006; Caspi, et al., 2004). The somewhat inconsistent findings about the processes involved in this association may depend , at least in part, on the fact that earlier studies investigated the appearance of rGE by studying twin children and their parents. By having genetic information available on only children, these traditional twin studies can not disentangle child -moderated (or evocative rGE) from parent-moderated (or passive rGE) genetic influences on parent-child relationships (Narusyte et al. 2008; Neiderhiser et al., 2004; Neiderhiser et al 2007). In addition, it is impossible to separate direct environmental influences from rGE in such designs. Thus, previous suggestions about rGE in parent-child relationships are approximate , highlighting the need for studies that directly investigate the presence of rGE as well as which type of rGE explain the association.

One approach for investigating parental influence son child adjustment is provided by the children-of-twins design. Children of identical (MZ)twins share half of their genes with both their own parent and the aunt or uncle (i.e., parent's co-twin), whereas children of fraternal (DZ)twins share half of their genes with their parent and on average one-quarter of their genes with their aunt or uncle. The rearing (shared) environment is distinct for each child. The environmental effect of parenting on children can thus be estimated by controlling for the genetic correlation between parents and children (Rutter et al., 2001). In such a way, the children-of twins model can be a powerful tool for disentangling direct environmental influences of parents' on their children from genetically confounded influences or rGE (e.g., D'Onofrio et al., 2003) . However, the modest genetic relatedness between pairs of children of twins (on average 25% or 12.5% for children of MZ and DZ twins, respectively) reduces the power to detect evocative rGE, that is, the effect of genetic influences on the children's behavior influencing parenting behavior. In a previously published report we presented an extended children-of-twins (ECOT) model (Narusyte et al., 2008), where the same measures from a companion study of twin children and their parents are included . High contrast of genetic similarity between the twin children (100% for MZ and 50% for DZ) in combination with the children of twins allows the estimation of the effects of parents' and children's genes influencing each construct. Thus, passive and evocative rGE as well as direct environmental influences of parenting on child adjustment may be distinguished.

The majority of studies that have examined both fathers and mothers have reported differences in patterns of associations for mothering with child behavior problems as compared to fathering with child behavior problems(Bogels & Phares, 2008; Formoso, Gonzales, & Aiken, 2000; Phares & Compas, 1992; Rothbaum & Weisz, 1994). A meta-analysis of parental care giving and child externalizing behavior among preadolescents revealed stronger associations for mothers' behavior compared to fathers' (Rothbaum & Weisz, 1994). The authors suggested that in most families mothers were the primary caregiver and thus more involved in handling their children's problems. Studies of parent-child conflict in adolescence show that conflicts between mothers and adolescents are more intense than conflicts between fathers and adolescents because relationships between mothers and adolescents tend to be closer and more interdependent (e.g., Laursen & Collins, 1994; Videon, 2005) . These different aspects of parent-adolescent relationships suggest that

there probably are different mechanisms operating behind the fathering and mothering in relation to problem behavior in children. Only a few studies have investigated possible differences between fathering and mothering in the interplay between genetic and environmental factors (Neiderhiser, et al., 2007; Neiderhiser, et al., 2004; Pike et al., 1996) . Findings of Pike and colleagues (1996) were similar for both parents' negativity and its association to adolescent adjustment, and were in line with evocative rGE. On the other hand, studies by Neiderhiser and colleagues (2004; 2007) suggest that negative mothering is primarily explained by evocative rGE, whereas negative fathering is influenced by both passive and evocative rGE.

In the present study we examine genetic and environmental processes involved in the association between maternal/paternal criticism and its relation to externalizing behavior problems in adolescents. We apply the extended children-of-twins model (ECOT) to two large samples of adult and adolescent twins to directly examine the presence and type of rGE. Further, we extend the scarce genetically informative literature on mothering and fathering by studying the presence of rGE in both maternal and paternal criticism. Research suggests that mothers tend to be more involved in childcare, making them more aware about and exposed to their children's aversive behavior, and, consequently, more reactive to it. We therefore expect the evocative rGE to be more explicit in the association between maternal criticism and adolescents. In contrast, following the suggestions of earlier findings, we hypothesize that father's criticism may affect the child in a more direct way, possibly as a result of their own characteristics. Therefore, we expect the relation between fathers' criticism and adolescent externalizing problems to be explained by a passive rGEor by environmental effects.

Method

Sample

Data for the analyses come from Twin and Offspring Study in Sweden (TOSS) and Twin study of CHild and Adolescent Development (TCHAD). Both samples were drawn from the Swedish Twin Registry (Lichtenstein et al., 2006)and used the same measures of parenting and adolescent externalizing problems. Each sample is described separately, followed by a joint description of measures.

Twin and Offspring Study in Sweden (TOSS)—The TOSS sample includes 909 pairs of twins (559 female and 350 male twin pairs), their spouse/partner and one biological adolescent child (Neiderhiser & Lichtenstein, 2008). TOSS is a two-cohort study. The first cohort included only female twin pairs(326 pairs) and their families. Approximately three years later information was collected from additional female twin pairs as well as from male twin pairs and their families, resulting in the final TOSS sample used in the current report . The same-sex twins included in the study were required to have a long-term relationship (5 years or more) with their current partner and an adolescent child between 11–20 years of age with no more than a 4 year age difference between the children and the same sex as the co-twin's child(49% males) . The average age of twin mothers was 43.6 years (±4.6 years), twin fathers were on average 47.0 years old (±4.7 years), and the mean age of the children was 15.9 years (±2.5 years). Ninety-one percent of twin partners were the biological parents of the target child. Consistent with the population of Sweden, the participants were in principle 100% Caucasian (Neiderhiser & Lichtenstein, 2008). Thirty percent of families were unskilled workers, 24% were skilled workers, 31% were intermediate non-manual employees, and 14% were employed and self-employed professionals, higher civil servants or executives. Elementary school was completed by 14% of the families, secondary school by 27%, junior college by 35%, and university by 24% of the families.

The twins, their spouses and the target child were first sent a questionnaire, followed by a home visit, during which additional questionnaires were administered. Detailed information was collected on parent-child relationships, marital relationships, personality, and the mental health of both parents and the target child.

The zygosity of twins in TOSS was assessed by DNA-testing. The DNA was extracted from mouthwash samples that were collected using Oragene^{R} DNA self -collection kits. For 54 twins who did not provide DNA zygosity was determined by questions concerning twin similarity and applying an algorithm based on a discriminant analysis of twins with DNA-confirmed zygosity. There were 259 monozygotic (MZ)and 288 dizygotic(DZ) pairs of twin mother s and 130 MZ and 192 DZ pairs of twin fathers.

Twin study of CHild and Adolescent Development (TCHAD)—TCHAD is an ongoing Swedish longitudinal study concerning health and behavior in children and adolescents (see Lichtenstein, Tuvblad, Larsson, & Carlstrom, 2007, for a detailed description). Twins and their parents were contacted four times starting when the twins were 8–9 years old. In the present study, we employed data from wave 3, when the twins were 16–17 years old. Questionnaires were sent by mail, and 2,369 (response rate 81.5%) children and 1,068 (response rate 73.5%) parents responded. Fifteen percent of the families in the sample were unskilled workers, 29% were skilled workers, 28% were intermediate non-manual employees, and 28% were employed and self-employed professionals, higher civil servants or executives. Elementary school was completed by 7% of the families, secondary school by 29%, junior college by 18%, and university by 46%. About 86% of parents of twins were born in Sweden, 12% were born in Europe, and 2% were born outside Europe, North America or Australia / New Zealand

The zygosity of 1312 twins was confirmed by DNA-test. The DNA was extracted from twins' saliva that was collected by sending the twins an Oragene^{R}DNA self-collection kit. For 1444 twins who did not provide DNA, the zygosity assignment was based on the parents' and twins' responses about their physical similarity. These twins were classified using an algorithm which was derived from a discriminant analysis of 385 pairs of the twins with DNA-confirmed zygosity (Hannelius, et al., 2007). The final sample consisted of 259 MZ male pairs, 183 DZ male pairs, 274 MZ female pairs, and 199 DZ female pairs of twins.

Measures

Parental Criticism—Parental criticism towards the adolescent was assessed through *parent report* on the Critical Remarks subscale of the Expressed Emotion measure (EE) (Hansson & Jarbin, 1997). The EE instrument was originally developed to assess the impact family members had on schizophrenia patients (Wearden, Tarrier, Barrowclough, Zastowny, & Rahill, 2000). Eventually, the scale was adapted to examine a number of other psychiatric and medical illnesses as well as behavior disorders in children and adolescents. In the current study, parents completed a self-rating questionnaire about the amounts of criticism and emotional over involvement they usually directed towards the child or the spouse. The subscale of Critical Remarks includes 10 items about parent behavior, such as having problems with communication or attempting to change the adolescents' behavior. Some of the items included were: "I find faults with him/her", "He/she makes me irritated", "I have to as him/her to behave differently", or "I try to influence his/her behavior". The internal reliability of the scale was measured by Cronbach's alpha: $\alpha = 0.86$ for TOSS, and $\alpha = 0.90$ for TCHAD.

Externalizing Problems—Adolescent externalizing behavior problems were assessed through *adolescent self-report* on the Youth Self -Report, which measures behavioral and

emotional problems in children and adolescents (Achenbach, 1991). For our analyses we used the Externalizing scale, which combines the Aggression and Delinquency subscales. The Aggression subscale comprises questions on whether the adolescent, for example, threatens, teases, attacks or is cruel to others, while the Delinquency subscale includes more covert behaviors such as stealing, lying, and substance use. Aggression and Delinquency scales were strongly correlated, r= 0.55 in TOSS and r= 0.57 in TCHAD. Heritability pattern was also similar in both scales: genetic effects explained 53% and 58 %, shared environment accounted for 0%, and non shared environment explained 47% and 42% of the total variance in Aggression and Delinquency scales, in the TCHAD sample. Cronbach's alphas was $\alpha = 0.82$ and $\alpha = 0.83$ for TOSS and TCHAD, respectively.

Analyses

Twin studies allow us to estimate the relative importance of genes and environments on the phenotype of interest. The twin method relies on the fact that MZ twins share approximately all of their genes while DZ twins share on average half of all their segregating genes. Thus, comparing how MZ and DZ twins are similar, we can get first estimates of heritability and environmental effects. Higher correlations among MZ than DZ twins indicate genetic influences, while approximately equal and sizable correlations between both zygosity groups suggest shared environmental influences. If DZ twin correlations are greater than a half of correlations for MZ twins, the phenotype is influenced by both genetic and shared environmental effects. Finally, non shared environmental influences are indicated by MZ twin correlations less than 1.0 and also include measurement error.

When twins and their children are studied, we can calculate correlations across generations and across or within families. The cross-generation within-family correlations do not provide information on genetic or environmental influences, because the genetic relatedness between parents and children is the same (50%) for both MZ and DZ twins. Cross-generation cross-family correlations, on the other hand, can be used to evaluate the nature of intergenerational transmission. If the transmission is influenced by genetic factors, the correlation between an MZ parent (i.e. mother or father) and their niece/nephew will be higher compared to the correlation between a DZ parent and their niece/nephew(D'Onofrio, et al., 2003) . Equal correlations for both MZ and DZ parents with their niece/nephew will indicate that the transmission is environmental in nature(see Narusyte et al 2008 for a more detailed explanation of these associations and expectations).

Extended Children-Of-Twins model (ECOT)—The main analyses of this study were performed by applying the ECOT model, which is described in detail elsewhere (Narusyte et al., 2008). The ECOT model is an extension of the children-of-twins model presented in Silberg and Eaves (Silberg & Eaves, 2004) . The ECOT model includes information on one parent and his/her child and is defined in two parts: one that describes *twin parents* and their children, while the other defines *twin children* and their parents (Figure 1). In this study, the model includes two phenotypes: Parental Criticism and adolescent Externalizing Problems. For both phenotypes genetic (A1 or A2), shared environmental (C1 or C2) and non shared environmental effects (E1 or E2)are estimated . Factor A1' represents genetic contributions to externalizing behavior problems that are in common with parental genetic effects on parental criticism. The path leading from A1 to A1' is fixed to 0.5 because children share exactly 50% of their segregating genes with each parent. The path *a1'* denotes genetic contributions to the child phenotype that are shared with his/her parents, while path *a2* denotes child specific genetic effects.

Paths *m* and *n* reflect reciprocity in the relationship between parental criticism and adolescent externalizing behavior. A significant path *m* suggests direct phenotypic influence

of parental criticism on externalizing behavior. That is, parents, by expressing their negativity, directly affect the externalizing behavior problems in adolescents via environmental mechanisms. Passive gene-environment correlation is suggested when parents contribute both genes and environments correlated with their genotype to their children. In the ECOT model this would be reflected by a significant *m* path as well as significant *a1* and *a1'* path s. Finally, evocative gene-environment correlation is indicated when children evoke particular parent behavior for reasons due to their inherited characteristics. Evocative gene-environment correlation is indicated when paths *n*, *a1'* and/or *a2* are significant in the ECOT model (see Silberg & Eaves, 2004).

Finally, in contrast to ordinary univariate or bivariate twin models, the measurement error term has to be estimated as a separate parameter in a reciprocal causation model. Otherwise, the parameter estimates might be biased (Heath, et al., 1993).

Model fitting—Model fitting was performed in the following steps. First, we fitted a saturated model, which estimated different means and variances for each phenotype as well as all possible covariances between the phenotypes. This model explains the data best and thus can serve as a baseline when evaluating how well the model of interest fits the data. In the next step we examined whether there are any differences in parenting for mothers and fathers (after controlling for the effects of the child's sex and age). This can be done by comparing two ECOT models: a model with different variance component parameters for mothers and fathers separately(i.e., sex -limitation model) and a model where the parameters are set equal across mothers and fathers. Finally, following a principle of parsimony (Neale & Cardon, 1992), we tested whether the ECOT model could be simplified by excluding reciprocity parameters *m* or *n* and/or other parameters that are close to zero.

Model fit and parsimony was evaluated by comparing constrained models to the saturated model using the log-likelihood ratio test and Akaike's Information Criterion (AIC). The test statistic of log-likelihood ratio test is calculated as twice the difference between log-likelihood functions of the full and the constrained model, with minus sign. The test statistic follows a χ^2 distribution with the number of degrees of freedom equal to the difference of the estimated parameters in both models. A non-significant difference indicates that a model with fewer parameters explains the data equally well as the unconstrained model and is to be preferred. The fit index AIC represents the balance between the model fit to the data and the parsimony, the number of parameters, with lower values of AIC indicating the most suitable model.

The model fitting was performed using Mx software, employing raw input data. SAS software was used for descriptive data analyses. To avoid possible bias, the data were also corrected for child's sex and age by computing standardized partial residuals from the regression of scores on these variables (McGue & Bouchard, 1984). Likewise, in the TOSS sample, twin parent reports on parental criticism were corrected for the levels of parental criticism in spouses. The variables were then standardized to a mean of zero and standard deviation of one separately in each sample.

Results

Descriptive statistics for the TOSS and TCHAD samples are presented in Table 1. In the TCHAD sample, the number of participating mothers was remarkably higher than that of fathers. In the TOSS sample this difference appears mainly because of the larger number of mothers that were contacted in the first waves of the study. The mean levels of the phenotypes in each respondent group were comparable between the samples as well as between the zygosity groups. Phenotypic correlations between Parental Criticism and

Externalizing Problems were 0.27 for fathers and 0.21 for mothers in TOSS, and 0.18 for fathers and 0.33 for mothers in TCHAD. Risk levels of behavior problems in adolescents were evaluated by calculating T scores for Externalizing Problems. In general, 10.4% and 11.7% of adolescents were in clinical range (i.e., T scores greater than 63) in TCHAD and TOSS samples, respectively.

Intraclass and cross-twin cross-trait correlations are presented in Table 2. As expected, due to the fact that twin children are genetically more related than children of twins, intraclass correlations, in bold, were generally lower in the TOSS sample compared to the TCHAD sample. For both Parental Criticism and Externalizing Problems, intraclass correlations were consistently higher for MZ twins as compared to DZ twins, indicating the influence of child genetic effects.

Differences between fathers and mothers were most apparent in the correlations between parental criticism and adolescent Externalizing problems in the TOSS sample. The correlations between fathers and their niece/nephew were similar between MZ (e.g., 0.06) and DZ twins (e.g., 0.05), suggesting that genetic factors may be of less importance for this association. In contrast, correlations between mothers and their niece/nephew were higher among MZ twins (e.g., 0.10) compared to DZ twins (e.g., 0.07), which indicates that the intergenerational association may partly be heritable. Although the pattern of the correlations between fathers and their niece/nephew as well as mothers and their niece/nephew were different, the cell sizes for each group were modest and thus should be considered with caution.

Model-fitting results

Univariate quantitative genetic analyses of Parental Criticism for TOSS data showed that shared environment was negligible among both fathers and mothers (approximately a^2=0.26, c^2=0.00, e^2=0.74, for both fathers and mothers). Therefore, shared environment was excluded for Parental Criticism (C1) in further estimations of the ECOT model. We then fitted a saturated ECOT model including both fathers and mothers, which estimated all of the means and variances of the variables as well as the covariances between the variables (-2LL=25110.719, *df*=4529, AIC=16052.719). Although lacking parsimony, a saturated model fits data best and therefore can be used to evaluate the fit of more constrained and parsimonious models. In the next step we estimated the ECOT model with all the parameters set to be different between fathers and mothers, which resulted in a non significant worsening in fit (Δ-2LL=83.13, *df*=79, *p*=0.35). There was however a significant deterioration in model fit when all parameters were set to be equal for fathers and mothers (Δ-2LL=53.77, *df*=22, $p<0.001$). Subsequent analyses were therefore performed separately for fathers and mothers.

Results of the model-fitting are presented in Table 3. After estimating the full ECOT model for mothers and fathers, we also tested a constrained model where the shared environmental effect for Externalizing Problems (C2) was set to 0. For both models examining associations with fathers and mothers the C2 parameter could be excluded without any significant loss in model fit (*p*=1.00, ΔAIC=−2.00 for fathers; *p*=1.00, ΔAIC=−2.00 for mothers). Further, we excluded either *m* or *n* parameters and compared how well those models explained the data. The model-fitting was evaluated primarily referring to AIC values, because this criterion not only assesses how well the model fits the data but also takes into account the parsimony of the model. The best-fitting and parsimonious model is indicated by the lowest AIC. For fathers, the best-fitting and most parsimonious model for fathers was the ECOT model with omitted C2 and *n* parameters, while for mothers the data was best explained by the ECOT model with only C2 parameter set to 0.

The unsquared and standardized parameter estimates of the best-fitting model for fathers and mothers are presented in Figures 2a and b. Following path tracing rules, squared parameter estimates provides the amount of variance they account for (Loehlin, 1998). The findings suggest that for both fathers and mothers Parental Criticism is heritable ($a1^2=0.61^2=0.37$ for fathers; $a1^2=0.70^2=0.49$ for mothers) and influenced by nonshared environment ($e1^2=0.48^2=0.23$ for fathers; $e1^2=0.36^2=0.13$ for mothers). Error variance accounted for 40% and 32% of the total variance for both phenotypes , for fathers and mothers, respectively. For the models examining father's Criticism and Externalizing Problems, genetic effects specific to the child accounted for 46% of the variance while the contribution of genetic factors in common with Parental Criticism was close 0%. Nonshared environmental contributions to the total variance of Externalizing Problems were nonsignificant . Fifty-five percent of t he variance of Externalizing Problems was accounted by genetic effects specific to the child for models examining mothers' Criticism and adolescent Externalizing, whereas 12% of the variance was due to by genetic effects shared with Parental Criticism. Nonshared environment was of minor importance for the total variance in adolescent Externalizing Problems.

For fathers, Parental Criticism explained 6% of the variance of Externalizing Problems ($m^2=0.24^2=0.06$). For mothers, Externalizing Problems explained 6% of the variance of Parental Criticism ($n^2=0.25^2=0.06$). The effect of Parental Criticism on Externalizing Problems was not significant.

In sum, the pattern of findings for fathers suggests that higher levels of critical remarks from fathers tend to inflate externalizing behavior problems in adolescents. For mothers, on the other hand, some degree of the association is explained by passive rGE while a larger portion is accounted by evocative rGE.

Discussion

In the current study we have examined the presence and type of rGE operating in the association between paternal/maternal criticism and externalizing problems in adolescents. We have applied the ECOT model to estimate a simultaneous evaluation of these effects. The findings of evocative rGE for maternal criticism suggest that mothers seemed to be more critical as a response to the adolescents' behavior. On the other hand, fathers' criticism tended to affect their adolescents' externalizing behavior problems by environmental mechanisms.

Three previous studies using TOSS or TCHAD samples have examined the presence of rGE in parent-child relationships and suggested evocative effects (Narusyte et al., 2007; Neiderhiser et al., 2004; 2007). The study by Narusyte et al. (2007) only examined twin children(i.e ., only the TCHAD sample was used), whereas Neiderhiser et al. (2004; 2007) compared results from a child-based with a parent-based design(i.e., TOSS sample was used) but none of these studies used both samples in the same model. Due to methodological limitations, these reports were unable to directly distinguish the type of rGE and therefore their findings of evocative rGE were rather approximate. The present study combines data from both TOSS and TCHAD samples, which enables us to directly resolve the role of rGE in the association between parental criticism and externalizing behavior problems in adolescents.

Our results of different processes involved in the association between mother or father-child relationships and externalizing problems in adolescents are consistent with the findings of earlier non-genetically informative studies. A meta-analysis performed by Rothbaum and Weisz (1994) showed that the association between parental care giving and child

externalizing behaviors was stronger in mothers than in fathers. As interpreted by authors, the mothers are usually the primary caregivers and, in turn, more involved with their children. A more involved parent is more likely to get influenced by or have a greater influence on the child. Thus, our findings of maternal criticism as a response to the behavior of their children and environmental effect among fathers may possibly be a reflection of different parent involvement with their children. The different nature of maternal and paternal involvement has been described in a number of studies, where mothers are usually reported to perform more of childcare and household-work as well as to interact with the children more often than do fathers (e.g., Videon, 2005). More frequent interactions and greater responsibility for child's care tend to create more opportunities for mothers to get exposed to conflicts with their child that eventually may elicit critical mothering. On the other hand, fathers spend less time with their children, but are instead engaged in activities like playing or talking with their child (Lamb, 2000) . Important to note that although both mothers and fathers tend to spend less time with their children in adolescence than compared to childhood, patterns of maternal and paternal involvement seem to remain similar despite the child's age (Collins & Russell, 1991). As a result, less involved fathers may have less knowledge and interest in child development and parenting practices. Thus, fathers' criticism toward their externalizing children may be interpreted as a parenting style which is less responsive to a particular child's behavior. However, since the number of fathers in our samples was limited, the magnitude of the paternal effects should be interpreted with caution, and neither evocative nor passive rGE can be totally excluded.

Findings of evocative rGE in the relationship between maternal criticism and externalizing behavior problems are consistent with the results of earlier studies (Burt et al., 2005; Deater-Deckard & Petrill, 2004; Neiderhiser et al., 2004; Pike et al., 1996). For example, previous investigators have suggested that evocative rGE explains the relationship between mothers' or parent s' negativity and adolescent antisocial behavior (Larsson, Viding, Rijsdijk, & Plomin, 2008; Pike et al., 1996), as well as mothers' negativity itself (Neiderhiser, et al., 2004). A report by Burt and colleagues (Burt et al., 2005)suggests that the relationship between mother -child conflict and child externalizing behavior is partially explained by the child's predisposition to externalizing behavior problems, interpretable as an evocative rGE. Another study offered the same explanation for the association between low levels of mother-child mutuality and child behavior problems (Deater-Deckard & Petrill, 2004).

Findings of evocative rGE in mother-adolescent relationships are in line with the coercion theory suggested by Patterson (Patterson, 1980). According to coercion theory, aggressively behaving children may evoke more negative response from their parents, which, in turn, may further elevate the children's aggression level. These coercive cycles tend eventually to play a crucial role in the development of antisocial behavior. An important finding of our study is that heritable features of the child externalizing behavior tend to elicit mother's critical behavior while fathers seem to be less responsive to the behavior of the child. Patterson (1980) suggests that the role of mothers in distressed families includes "crisis management". Being more involved with their children, these mothers tend to be exposed to higher levels of aversive events and become more coercive than mothers of nonaggressive children, as well as experience more confrontational behaviors than other family members. In the light of our results, mothers of children with externalizing behavior problems are probably more often compelled to face these problems and therefore are more likely to react critically to their children.

In addition to evidence about evocative rGE, several studies have found some effect of environmental influences. For example, a report by Burt and colleagues (Burt et al., 2005)suggests that in addition to findings consistent with evocative rGE, conflictual parent-child relationships also had an environmental effect on the externalizing behavior of

adolescents. Similarly, both evocative rGE and environment were found to explain the association between parental negativity and childhood antisocial behavior by Larsson et al. (2008). Burt and colleagues (2006) also demonstrated the environmental impact of parent-child conflict on adolescent externalizing symptoms, in a sample of adolescent MZ twins. The parenting measure used in these studies was a composite derived from the reports of both fathers and mothers. It is therefore possible that the environmental influences could be attributable to fathers while evocative mechanisms may reflect effects of negative mothering. In contrast, Caspi and colleagues (Caspi, et a., 2004)examined mothers and their MZ twins at 3, 5 and 7 years of age, and found a possible causal role of maternal expressed emotion on the later development of antisocial behavior problems. Differences between the Caspi et al. (2004) findings and ours may arise as a result of the use of different measures of parenting, of child outcomes or due to developmental differences in the samples examined. Clearly, future studies should use longitudinal data on both twin parents and twin children to further illuminate the possible impact of the environment on mother-child relationships.

We also found that genetic effects contributing to maternal criticism added significantly to the explanation of externalizing problems in adolescents. In other words, some genes seem to be important for both these behaviors in both generations. There was, however, little evidence for a direct environmental effect (the *m* path explained only 1% of the variance of Externalizing Problems). This pattern, with a genetic correlation without any environmental effect of parents on children , is sometimes interpreted as a passive rGE(e.g., Price & Jaffee, 2008). According to another definition, passive rGE is supported when both genetic overlap and a direct effect of (parental) environment on the behavior are present (Eaves, 2008; Neale & Cardon, 1992; Silberg & Eaves, 2004). The ECOT model is an extension of the children-of-twins model described in Silberg and Eaves (2004) and therefore we refer to this genetic overlap between parents and their children as a genetic correlation (Eaves, 2008), rather than rGE.

The results showed that the direct effect of maternal criticism on child externalizing problems was negative , although not significant. In other words, higher levels of maternal criticism may have a protective effect on the development of the externalizing problems in adolescents. This is not unexpected, because the measure we used to evaluate levels of parental criticism captured less harsh aspects of parental behavior. Moreover, some items tended to reflect parental supervision rather than criticism (e.g., “I have to ask him/her to behave differently”).

Limitations of our study should be kept in mind. First, even after combining two large samples, the number of participants was still too limited to perform analyses by gender of the child and by parent gender . Research indicates that the association between harsh parental disciplines and child problem -behavior is strongest for same-gender parent-child relationship. Also, the number of fathers participating in the TCHAD sample was limited. The power calculations showed that the power of the ECOT model to detect the effect of evocative effects (i.e., path *n*) was 65% in father -child relationships, at the 5% significance level. The findings regarding paternal criticism should therefore be taken with caution until they are replicated in a larger study.

We suggested that different findings about the association between maternal or paternal criticism and externalizing problems in adolescents may reflect different levels of parental involvement in childcare. Unfortunately, neither the TOSS nor TCHAD samples had data on parental involvement available, thust his interpretation should be investigated in future studies, where the role of parental involvement for the adolescent behavior can be tested directly.

By applying the ECOT model to cross-sectional data we cannot distinguish between rGE and GxE. A study by Feinberg and colleagues (Feinberg, Button, Neiderhiser, Reiss, & Hetherington, 2007)has demonstrated that the parenting measure moderated the influence of genotype on antisocial behavior, that is, evidence for genotype-environment interaction. Similarly, another report revealed that both rGE and GxE were operating in the development of the association between maternal punitive discipline and adolescent depressive symptoms (Lau & Eley, 2008). It is possible that, in addition to rGE, GxE may also operate in our observed association between parental criticism and adolescent antisocial behavior. Further longitudinal studies are therefore needed to examine this issue.

A case has been made that children-of-twins models including only one parent should be applied with caution when studying the effect of dyadic parental phenotypes (e.g., divorce). For dyadic parental treatment measures, this model is unable to reliably differentiate between the direct environmental effect and association due to genetic effects (Eaves, Silberg, & Maes, 2005). Although parental criticism is not directly defined as a dyadic measure (i.e., influenced by both parents), it is possible that it is affected to some extent by the other parent's behavior. The results of the current study should therefore be replicated by including both parents in the analyses.

We have included only one parent in our analyses and therefore the possible effects of assortative mating were not taken into account. The association between parental criticism and adolescent externalizing problems should further be tested by using an extended twin kinship model (Maes, et al., 2006). A model combining the extended kinship model with the ECOT has not yet been developed, however, so this is not possible at this time.

The number of mothers of twins that participated in TCHAD study was almost tenfold the number of fathers. It is not unlikely that the few fathers who completed the questionnaire may be different from the non -participating fathers. However, since no spouse information was collected in TCHAD sample, we were not able to test for any potential differences in participating and nonparticipating fathers.

Finally, since the data used in the present report was collected in Sweden, the results are primarily reflect the processes involved in parent-child relationships in the Swedish population, which might be generalized to most western countries. However, it is worth noting that in other non-western cultures mothers and fathers may have different roles in child adjustment and thus rGE may act differently as compared to western culture (Atzaba-Poria & Pike, 2008).

In summary, the present study examined the factors that help to explain the association between parental criticism and adolescent externalizing problems, among fathers and mothers. The results revealed that mothers seemed to express their criticism as a response to the adolescents' externalizing behavior, while fathers' criticism tended to affect behavior problems in adolescents in a direct environmental way.

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References

Achenbach, TM. Manual for the Child Behavior Checklist/4–18 and 1991 Profile. Burlington, VT: University of Vermont Department of Psychiatry; 1991.

Anderson KE, Lytton H, Romney DM. Mothers' interactions with normal and conduct-disordered boys: who affects whom? Developmental Psychology. 1986; 22(5):604–609.

Atzaba-Poria N, Pike A. Correlates of parental differential treatment: parental and contextual factors during middle childhood. Child Development. 2008; 79(1):217–232. [PubMed: 18269519]

Bogels S, Phares V. Fathers' role in the etiology, prevention and treatment of child anxiety: a review and new model. Clinical Psychology Review. 2008; 28(4):539–558. [PubMed: 17854963]

Boivin M, Perusse D, Dionne G, Saysset V, Zoccolillo M, Tarabulsy GM, et al. The genetic-environmental etiology of parents' perceptions and self-assessed behaviours toward their 5-month-old infants in a large twin and singleton sample. Journal of Child Psychology and Psychiatry. 2005; 46(6):612–630. [PubMed: 15877767]

Bullock BM, Dishion TJ. Family processes and adolescent problem behavior: integrating relationship narratives into understanding development and change. Journal of the American Academy of Child and Adolescent Psychiatry. 2007; 46(3):396–407. [PubMed: 17314726]

Burke JD, Pardini DA, Loeber R. Reciprocal relationships between parenting behavior and disruptive psychopathology from childhood through adolescence. Journal of Abnormal Child Psychology. 2008; 36(5):679–692. [PubMed: 18286366]

Burt SA, McGue M, Iacono WG, Krueger RF. Differential parent-child relationships and adolescent externalizing symptoms: cross-lagged analyses within a monozygotic twin differences design. Developmental Psychology. 2006; 42(6):1289–1298. [PubMed: 17087561]

Burt SA, McGue M, Krueger RF, Iacono WG. How are parent-child conflict and childhood externalizing symptoms related over time? Results from a genetically informative cross-lagged study. Development and Psychopathology. 2005; 17(1):145–165. [PubMed: 15971764]

Campbell SB. Behavior problems in preschool children: a review of recent research. Journal of Child Psychology and Psychiatry. 1995; 36:113–149. [PubMed: 7714027]

Caspi A, Moffitt TE, Morgan J, Rutter M, Taylor A, Arseneault L, et al. Maternal expressed emotion predicts children's antisocial behavior problems: using monozygotic-twin differences to identify environmental effects on behavioral development. Developmental Psychology. 2004; 40:149–161. [PubMed: 14979757]

Collins W, Russell G. Mother-child and father-child relationships in middle childhood and adolescence: A developmental analysis. Developmental Review. 1991; 11:99–136.

Collins WA, Maccoby EE, Steinberg L, Hetherington EM, Bornstein MH. Contemporary research on parenting. The case for nature and nurture. Am Psychol. 2000; 55(2):218–232. [PubMed: 10717969]

D'Onofrio BM, Turkheimer EN, Eaves LJ, Corey LA, Berg K, Solaas MH, et al. The role of the children of twins design in elucidating causal relations between parent characteristics and child outcomes. Journal of Child Psychology and Psychiatry. 2003; 44(8):1130–1144. [PubMed: 14626455]

Deater-Deckard K. Within family variability in parental negativity and control. Journal of Applied Developmental Psychology. 1996; 17:407–422.

Deater-Deckard K, O'Connor TG. Parent-child mutuality in early childhood: two behavioral genetic studies. Developmental Psychology. 2000; 36(5):561–570. [PubMed: 10976597]

Deater-Deckard K, Petrill SA. Parent-child dyadic mutuality and child behavior problems: an investigation of gene-environment processes. Journal of Child Psychology and Psychiatry. 2004; 45(6):1171–1179. [PubMed: 15257673]

Eaves, L. Passive genotype-environment correlation: Personal communication with Paul Lichtenstein. 2008.

Eaves LJ, Silberg JL, Maes HH. Revisiting the children of twins: can they be used to resolve the environmental effects of dyadic parental treatment on child behavior? Twin Research and Human Genetics. 2005; 8(4):283–290. [PubMed: 16176710]

Feinberg ME, Button TM, Neiderhiser JM, Reiss D, Hetherington EM. Parenting and adolescent antisocial behavior and depression: evidence of genotype x parenting environment interaction. Archives of General Psychiatry. 2007; 64(4):457–465. [PubMed: 17404122]

Formoso D, Gonzales NA, Aiken LS. Family conflict and children's internalizing and externalizing behavior: protective factors. American Journal of Community Psychology. 2000; 28(2):175–199. [PubMed: 10836090]

Hannelius U, Gherman L, Makela VV, Lindstedt A, Zucchelli M, Lagerberg C, et al. Large-scale zygosity testing using single nucleotide polymorphisms. Twin Research and Human Genetics. 2007; 10(4):604–625. [PubMed: 17708702]

Hansson K, Jarbin H. New self-rating questionnaire in Swedish for measuring expressed emotion. Nordic Journal of Psychiatry. 1997; 51:287–297.

Heath AC, Kessler RC, Neale MC, Hewitt JK, Eaves LJ, Kendler KS. Testing hypotheses about direction of causation using cross-sectional family data. Behavior Genetics. 1993; 23(1):29–50. [PubMed: 8476389]

Hill J. Biological, psychological and social processes in the conduct disorders. Journal of Child Psychology and Psychiatry. 2002; 43(1):133–164. [PubMed: 11848334]

Jaffee SR, Caspi A, Moffitt TE, Polo-Tomas M, Price TS, Taylor A. The limits of child effects: Evidence for genetically mediated child effects on corporal punishment but not on physical maltreatment. Developmental Psychology. 2004; 40(6):1047–1058. [PubMed: 15535755]

Knafo A, Plomin R. Parental discipline and affection and children's prosocial behavior: genetic and environmental links. Journal of Personality and Social Psychology. 2006; 90(1):147–164. [PubMed: 16448315]

Lamb ME. The history of research on father involvement. Marriage & Family Review. 2000; 29(2/3): 23–42.

Larsson H, Viding E, Rijsdijk FV, Plomin R. Relationships between parental negativity and childhood antisocial behavior over time: a bidirectional effects model in a longitudinal genetically informative design. Journal of Abnormal Child Psychology. 2008; 36(5):633–645. [PubMed: 17602294]

Lau JY, Eley TC. Disentangling gene-environment correlations and interactions on adolescent depressive symptoms. Journal of Child Psychology and Psychiatry. 2008; 49(2):142–150. [PubMed: 18211276]

Laursen B, Collins WA. Interpersonal conflict during adolescence. Psychological Bulletin. 1994; 115(2):197–209. [PubMed: 8165270]

Lichtenstein P, Sullivan PF, Cnattingius S, Gatz M, Johansson S, Carlstrom E, et al. The Swedish Twin Registry in the third millennium: an update. Twin Research and Human Genetics. 2006; 9(6):875–882. [PubMed: 17254424]

Lichtenstein P, Tuvblad C, Larsson H, Carlstrom E. The Swedish Twin study of CHild and Adolescent Development: the TCHAD-study. Twin Research and Human Genetics. 2007; 10(1):67–73. [PubMed: 17539366]

Loeber R, Burke JD, Pardini DA. Development and Etiology of Disruptive and Delinquent Behavior. Annual Review of Clinical Psychology. 2009

Loeber R, Dishion T. Early predictors of male delinquency: A review. Psychological Bulletin. 1983; 94:68–99. [PubMed: 6353467]

Lynch SK, Turkheimer E, D'Onofrio BM, Mendle J, Emery RE, Slutske WS, et al. A genetically informed study of the association between harsh punishment and offspring behavioral problems. Journal of Family Psychology. 2006; 20(2):190–198. [PubMed: 16756394]

Lytton H. Child and parent effects in boys' conduct disorder: A reinterpretation. Developmental Psychology. 1990; 26:683–697.

Maes HH, Neale MC, Kendler KS, Martin NG, Heath AC, Eaves LJ. Genetic and cultural transmission of smoking initiation: an extended twin kinship model. Behavior Genetics. 2006; 36(6):795–808. [PubMed: 16810566]

McGue M, Bouchard TJ. Adjustment of twin data for the effects of age and sex. Behavior Genetics. 1984; 14(4):325–343. [PubMed: 6542356]

Narusyte J, Andershed AK, Neiderhiser JM, Lichtenstein P. Aggression as a mediator of genetic contributions to the association between negative parent child relationships and adolescent antisocial behavior. European Child and Adolescent Psychiatry. 2007; 16(2):128–137. [PubMed: 17136502]

Narusyte J, Neiderhiser JM, D'Onofrio BM, Reiss D, Spotts EL, Ganiban J, et al. Testing different types of genotype-environment correlation: an extended children-of-twins model. Developmental Psychology. 2008; 44(6):1591–1603. [PubMed: 18999324]

Neale, MC.; Cardon, LR. Methodology for genetic studies of twinsand families. Dordrecht, The Netherlands: Kluwer Academic Publisher; 1992.

Neiderhiser JM, Lichtenstein P. The Twin and Offspring Study in Sweden: Advancing our understanding of genotype-environment interplay by studying twins and their families. Acta Psychologia Sinica. 2008; 40(10):1116–1123.

Neiderhiser JM, Reiss D, Hetherington EM, Plomin R. Relationships between parenting and adolescent adjustment over time: genetic and environmental contributions. Developmental Psychology. 1999; 35:680–692. [PubMed: 10380859]

Neiderhiser JM, Reiss D, Lichtenstein P, Spotts EL, Ganiban J. Father-adolescent relationships and the role of genotype-environment correlation. Journal of Family Psychology. 2007; 21(4):560–571. [PubMed: 18179328]

Neiderhiser JM, Reiss D, Pedersen NL, Lichtenstein P, Spotts EL, Hansson K, et al. Genetic and environmental influences on mothering of adolescents: a comparison of two samples. Developmental Psychology. 2004; 40:335–351. [PubMed: 15122961]

Nix RL, Pinderhughes EE, Dodge KA, Bates JE, Pettit GS, McFadyen-Ketchum SA. The relation between mothers' hostile attribution tendencies and children's externalizing behavior problems: the mediating role of mothers' harsh discipline practices. Child Development. 1999; 70(4):896–909. [PubMed: 10446725]

O'Connor TG, Deater-Deckard K, Fulker D, Rutter M, Plomin R. Genotype-environment correlations in late childhood and early adolescence: antisocial behavioral problems and coercive parenting. Developmental Psychology. 1998; 34:970–981. [PubMed: 9779743]

Pardini DA. Novel insights into longstanding theories of bidirectional parent-child influences: introduction to the special section. Journal of Abnormal Child Psychology. 2008; 36(5):627–631. [PubMed: 18437550]

Patterson GR. Mothers: the unacknowledged victims. Monographs of the Society for Research in Child Development. 1980; 45(186):1–55.

Phares V, Compas BE. The role of fathers in child and adolescent psychopathology: make room for daddy. Psychol Bull. 1992; 111(3):387–412. [PubMed: 1594718]

Pike A, McGuire S, Hetherington E, Reiss D, Plomin R. Family environment and adolescent depressive symptoms and antisocial behavior: A multivariate genetic analysis. Developmental Psychology. 1996; 32:590–604.

Plomin R, DeFries JC, Loehlin JC. Genotype-environment interaction and correlation in the analysis of human behavior. Psychological Bulletin. 1977; 84:309–322. [PubMed: 557211]

Price TS, Jaffee SR. Effects of the family environment: gene-environment interaction and passive gene-environment correlation. Developmental Psychology. 2008; 44(2):305–315. [PubMed: 18331124]

Richmond MK, Stocker CM. Longitudinal associations between parents' hostility and siblings' externalizing behavior in the context of marital discord. Journal of Family Psychology. 2008; 22(2):231–240. [PubMed: 18410210]

Rothbaum F, Weisz JR. Parental caregiving and child externalizing behavior in nonclinical samples: a meta-analysis. Psychological Bulletin. 1994; 116(1):55–74. [PubMed: 8078975]

Scarr S, McCartney K. How people make their own environments: atheory of genotype greater than environment effects. Child Development. 1983; 54:424–435. [PubMed: 6683622]

Shaw DS, Gilliom M, Ingoldsby EM, Nagin DS. Trajectories leading to school-age conduct problems. Developmental Psychology. 2003; 39:189–200. [PubMed: 12661881]

Silberg JL, Eaves LJ. Analysing the contributions of genes and parent-child interaction to childhood behavioural and emotional problems: a model for the children of twins. Psychological Medicine. 2004; 34:347–356. [PubMed: 14982140]

Trentacosta CJ, Shaw DS. Maternal predictors of rejecting parenting and early adolescent antisocial behavior. Journal of Abnormal Child Psychology. 2008; 36(2):247–259. [PubMed: 17805957]

Wearden AJ, Tarrier N, Barrowclough C, Zastowny TR, Rahill AA. A review of expressed emotion research in health care. Clinical Psychology Review. 2000; 20:633–666. [PubMed: 10860170]

Videon TM. Parent-Child Relations and Children's Psychological Well-Being: Do Dads Matter? Journal of Family Issues. 2005; 26(1):55–78.

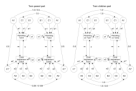

Figure 1.

Extended children-of-twins model. The model is described in two parts: for *twin parents* and for *twin children*. Phenotypes Parental Criticism and Externalizing Problems are denoted in rectangles. Genetic (A) and environmental (C, E) influences are depicted in circles. Parental Criticism phenotype is influenced by genetic (A1), shared (C1), and non-shared environment (E1), while Externalizing Problems is influenced by genetic (A1' and A2), shared (C2), and non-shared environmental effects (E2). Measurement error (ε1 and ε2) contributes directly to the variance of both phenotypes. In *twin parents* part, the genetic effects correlate by 1.0 or 0.5, depending on the twin zygosity. Shared environment (C1) correlated perfectly for both MZ and DZ twins. Genetic effects for children, or cousins, correlate by 0.25 or 0.125, depending on the zygosity of the parents. Shared environmental effects are uncorrelated since the cousins do not share the family. In *twin children* part, genetic and shared environmental effects correlated perfectly for Parental Criticism phenotype, because there was always the same parent rating both twins. For children, genetic effects correlated by 1.0 or 0.5 for MZ and DZ twins, respectively, and shared environmental effects correlated perfectly for both zygosity groups. Paths *m* and *n* denote reciprocity in the relationship between the phenotypes. Path *m* reflects direct environmental effect of Parental Criticism on Externalizing Problems, while path *n* denotes evocative processes in the relationship. Significant paths *m*, *a1'* and *a1* will indicate passive rGE, while evocative rGE will be suggested by significant *n*, *a1'* and/or *a2*.

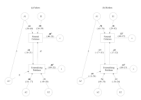

Figure 2.
Figure 2a and b. Best-fitting ECOT model for fathers (a) and mothers (b). Note: [a] Parameter was fixed to zero; [b]The estimate is squared. Significant estimates are denoted in bold.

Table 1

Descriptive statistics of TOSS and TCHAD samples

Measure	MZ		DZ	
	***n* of individuals**	**mean (sd)**	***n* of individuals**	**mean (sd)**
TOSS				
Parental Criticism:				
- Twin fathers	251	16.2 (4.7)	373	16.9 (5.1)
- Twin mothers	512	17.7 (5.1)	567	17.8 (5.7)
Externalizing Problems:				
- Children of twin fathers	256	10.2 (5.3)	371	11.2 (5.6)
		48.60 (8.76)		*50.36 (9.33)*
- Children of twin mothers	513	11.6 (6.0)	570	11.3 (6.1)
		51.06 (10.04)		*50.51 (10.16)*
TCHAD				
Parental Criticism:				
- fathers of twins	119	18.5 (6.4)	82	16.9 (5.7)
- mothers of twins	623	16.5 (5.4)	456	16.7 (6.0)
Externalizing Problems:				
- Twin children of fathers	110	10.47 (6.51)	81	10.46 (5.32)
		49.11 (10.84)		*49.09 (8.86)*
- Twin children of mothers	629	9.42 (5.94)	456	10.28 (5.79)
		47.36 (9.89)		*48.80 (9.64)*

Note. Mean T scores are presented in italics. T scores: less than 60 are in the normal range, 60–63 are borderline clinical, and greater than 63 are in the clinical range.

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Table 2

Intraclass correlations for Parental Criticism and adolescent Externalizing Problems

Measure (respondent)	**Twin parent 1**	**Twin parent 2**	**Child 1**	**Child 2**
TOSS				
Fathers:				
Parental Criticism (twin parent 1)	-	**0.22***	0.33*	0.07
Parental Criticism (twin parent 2)	**0.11***	-	0.06	0.33*
Externalizing Problems (child 1)	0.21*	0.05	-	**0.21***
Externalizing Problems (child 2)	0.03	0.21*	**0.08**	-
Mothers:				
Parental Criticism (twin parent 1)	-	**0.29***	0.19*	0.10
Parental Criticism (twin parent 2)	**0.22**	-	0.10	0.18*
Externalizing Problems (child 1)	0.21*	0.07	-	**0.24***
Externalizing Problems (child 2)	0.07	0.22*	**0.12***	-
	Parent 1	Parent 2	Twin child 1	Twin child 2
TCHAD				
Fathers:				
Parental Criticism (parent 1)	-	**0.66***	0.21*	0.17
Parental Criticism (parent 2)	**0.32***	-	0.17	0.21*
Externalizing Problems (twin child 1)	0.13	0.01	-	**0.50***
Externalizing Problems (twin child 2)	0.01	0.13	**0.31***	-
Mothers:				
Parental Criticism (parent 1)	-	**0.73***	0.35*	0.32*
Parental Criticism (parent 2)	**0.45***	-	0.32*	0.35*
Externalizing Problems (twin child 1)	0.31*	0.07	-	**0.56**
Externalizing Problems (twin child 2)	0.07	0.31*	**0.29***	-

Note. MZ and DZ twins are displayed above and below the diagonal, respectively;

* p<0.05

Table 3

Results of model-fitting comparison

Estimated ECOT model	−2log L	df	ΔChi2	Δdf	p-value	AIC	ΔAIC
Fathers							
Full model	3364.02	1207	-	-	-	950.02	-
Constrained, C=0	3364.02	1208	.00	1	1.00	948.02	-2.00
Constrained, C=0 and m=0	3366.83	1209	2.81	1	.09	948.83	.81
Constrained, C=0 and n=0	**3364.08**	**1209**	**.06**	**1**	**.80**	**946.08**	**−1.94**
Mothers							
Full model	9116.59	3378	-	-	-	2360.59	-
Constrained, C=0	**9116.59**	**3379**	**.00**	**1**	**1.00**	**2358.59**	**−2.00**
Constrained, C=0 and m=0	9120.94	3380	3.51	1	.06	2360.10	1.51
Constrained, C=0 and n=0	9126.23	3380	9.64	1	<.01	2366.23	7.64

Note.Best -fitting model in bold.

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