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ADOLESCENT ADJUSTMENT PROBLEMS: THE ROLE OF HERITABILITY AND FAMILY ENVIRONMENT

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ABSTRACT

Approximately one fifth of children and adolescents in Europe and United States of America suffer from behavioral, emotional or developmental problems. More effective prevention and intervention of these problems may be achieved through understanding the role of genetic and environmental factors. This thesis investigates the interplay between genes and environments in the development of adolescent adjustment problems, with a focus on the role of parental practices.

The studies included in this thesis are based on data from two studies: Twin study of Child and Adolescent Development (TCHAD) and Twin and Offspring Study in Sweden (TOSS). TCHAD is an ongoing Swedish longitudinal population-based study of 1,480 twin pairs concerning health and behavior in children and adolescents. The twins and their parents have been contacted on four different occasions (8-9 years, 13-14 years, 16-17 years, and 19-20 years) with good to excellent response rates. TOSS is a two-cohort study of 909 pairs of twins, their spouse or partner, and one biological adolescent child. TOSS aims to better understand the relationships within the family and how they are associated with the mental health of the family members.

The data was analyzed using conventional and newly developed twin methods. Results of Paper IV revealed that antisocial behavior that persists from late childhood to early adulthood is to a major part influenced by familial factors in both males and females.

One of the well-investigated environmental familial risk factors for antisocial behavior is parenting practices. Research suggests that parenting is partly explained by genetic effects emanating from child, which is usually interpreted as an indication of evocative genotype-environment correlation (rGE). Paper I shows that the genetic contributions to the association between parental criticism and antisocial behavior in adolescents can be explained by heritable early adolescent aggression. These findings are consistent with evocative rGE.

The main focus of Paper II is an extension of the existing children-of-twins model (ECOT), enabling to test for different types of rGE. The ECOT was applied to examine the nature of rGE in the association between maternal emotional overinvolvement and internalizing behavior problems in adolescents. The results suggest that evocative rGE is important for this association. That is, mothers tend to get more emotionally overinvolved in their parenting as a response to internalizing behavior problems in their children. Similarly, mothers' critical behavior seems to be evoked by externalizing behavior in adolescents, as suggested by Paper III, whereas fathers' criticism was found to influence the development of externalizing problems in an environmental way, that is, a way independent of either fathers' or adolescents' heritable characteristics.

Future research should focus on studying the association between adverse parenting and adjustment problems across the development, from childhood to adulthood. In such studies, different types of mechanisms – rGE, genotype-environment interaction, and direct environmental influences – are possible to be examined simultaneously. As a result, more details about when and how behavior problems start and develop could be gained, hopefully helping to identify effective prevention and intervention targets.

LIST OF PUBLICATIONS

This thesis is based on the following four papers, which will be referred to in the text by their Roman numerals (I-IV):

- I. Narusyte J., Andershed A-K., Neiderhiser J.M. & Lichtenstein P.
Aggression as a mediator of genetic contributions to the association between negative parent-child relationships and adolescent antisocial behavior.
European Child & Adolescent Psychiatry, 2007, 16, 128-137.
- II. Narusyte J., Neiderhiser J.M., D’Onofrio B., Reiss D., Spotts E.L., Ganiban J. & Lichtenstein P.
Testing different types of genotype-environment correlation: an extended children-of-twins model.
Developmental Psychology, 2008, 44, 1591-1603.
- III. Narusyte J., Andershed A-K., Neiderhiser J.M., D’Onofrio B., Reiss D., Spotts E.L., Ganiban J. & Lichtenstein P.
Parental criticism and externalizing behavior problems in adolescents – the role of environment and genotype-environment correlation.
Submitted for publication
- IV. Tuvblad C., Narusyte J., Grann M., Sarnecki J. & Lichtenstein P.
The genetic and environmental etiology of antisocial behavior from childhood to emerging adulthood.
Submitted for publication

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LIST OF ABBREVIATIONS

A	Additive genetic factor
AIC	Akaike's Information Criteria
ASB	Antisocial behavior
C	Shared environmental factor
CBCL	Child Behavior Checklist
CI	95% Confidence interval
Df	Degrees of freedom
DZ	Dizygotic
E	Nonshared environmental factor
ECOT	Extended Children-of-Twins model
EE	Expressed Emotion
EOI	Emotional Overinvolvement
GxE	Genotype-environment interaction
MZ	Monozygotic
OR	Odds ratio
OS	Opposite-sexed
p	p-value
rGE	Genotype-environment correlation
SRD	Self-Report Delinquency
TCHAD	Twin study of Child and Adolescent Development
TOSS	Twin and Offspring Study in Sweden
-2LL	-2(log-likelihood)
χ^2	Chi-square

INTRODUCTION

The World Health Organization defines health as “a state of complete physical, mental and social well-being, and not merely the absence of disease” (WHO, 2006). Following the definition, mental health is described to be as important as physical health and playing a critical role for an individual’s overall well-being. Today, mental health problems are considered as one of the major public health concerns. The reported lifetime prevalence for any mental disorder varies between 33 and 46% (Alonso et al., 2004; Kessler et al., 2005). Mental health problems and disorders not only affect an individual’s quality of life but also imply a heavy burden for societies through direct and indirect medical and non-medical costs (Smit et al., 2006).

Most of the mental health problems and disorders usually take their start in childhood and adolescence. Approximately one fifth of children and adolescents in Europe and the United States of America suffer from behavioral, emotional or developmental problems (European Commission, 2004; U.S. Department of Health and Human Services, 1999). Children and adolescents experiencing difficulties with mental health also tend to have problems with physical health, relationships with family members and peers as well as with functioning at school (Jané-Llopis & Braddick, 2008). In adolescence, poor mental health is also associated with substance use and abuse, violence, and poor reproductive and sexual health (Patel, Flisher, Hetrick, & McGorry, 2007).

Since several decades intensive efforts have been paid to find strategies to intervene and prevent the development of behavioral and emotional problems in children and adolescents. There is a strong consensus concerning the recognition of early detection of behavior problems as an undeniable component of successful intervention programs. However, lack of detailed knowledge about the etiology of mental health problems restricts these programs from being fully effective. Valuable insights in the origins of the development of adjustment problems have been gained through studying the role of heritable and environmental factors. The next step is to understand the mechanisms regulating these factors, a goal possible to achieve by performing extensive twin studies as well as finding new and innovative ways to analyze these data.

BACKGROUND

ADOLESCENT ADJUSTMENT PROBLEMS

Child and adolescent adjustment problems relate to behavioral and emotional problems in adolescents. Research has indicated that these problems may be classified into two broad dimensions: externalizing and internalizing behavior problems (Achenbach, 1991; Frick & Kimonis, 2008).

Externalizing behavior problems

In children and adolescents, externalizing behavior problems are typically represented by problems related to hyperactivity as well as conduct problems (Campbell, Shaw, & Gilliom, 2000; Frick & Kimonis, 2008; Hinshaw, 1987). Conduct problems refer to a range of acting out, disruptive, defiant, aggressive, and antisocial behaviors (Hinshaw, 1987). In the widely-applied empirically derived behavior scale Child Behavior Checklist (CBCL) (Achenbach, 1991), the externalizing dimension is defined by aggressive and delinquent behavior, that is, by conduct problems alone. Attention and hyperactivity related syndromes here were grouped under a separate factor (Achenbach, 1991). The definition of externalizing behavior used in the current thesis is adapted from CBCL and thus refers to various conduct problems and *not* hyperactivity. However, it is important to note that conduct problems and hyperactivity overlap considerably (e.g., Hinshaw, 1987).

Antisocial behavior, as discussed in this thesis, relates to self-reported and more severe types of externalizing or conduct problems, such as violence and delinquency. The development of antisocial and externalizing behavior tends to be highly interrelated and therefore is discussed together in the next sections.

Development of externalizing and antisocial behavior

A large number of studies have documented the fact that for certain groups of children, conduct problems in childhood tend to continue across development as well as predict later delinquency in adolescence and adulthood (Broidy et al., 2003; Loeber & Dishion, 1983). Understanding the etiology and development of conduct and antisocial problems is therefore crucial for prevention of these behavior problems.

One way to understand the development of antisocial behavior is by trying to identify different types of offenders depending on their behavior over time (Loeber, Burke, & Pardini, 2009). The dual taxonomy of antisocial behavior proposed by Moffitt (1993) originates from the fact that the prevalence of antisocial behavior peaks in adolescence and that age of onset is related to persistence. The theory differentiates the most deviant offenders with persistent childhood-onset conduct problems from those with temporary adolescence-onset behavior problems (Moffitt, 1993; Moffitt & Caspi, 2001). “Life-course-persistent” and “adolescence-limited” types of antisocial behavior are suggested to have different etiologies, developmental courses, and prognoses of behavior outcomes in adulthood. Life-course-persistent antisocial behavior is thought to have neurodevelopmental origins, and begin in early childhood and continue into adolescence and adulthood. Persistent antisocial behavior is associated with individual level risk factors,

such as aggression, impulsivity, cognitive impairment, poor peer relationships and family adversity. On the other hand, adolescence-limited antisocial behavior is proposed to be restricted to adolescent years as well as to be more influenced by social peer pressure (Moffitt, 1993; Moffitt & Caspi, 2001). DiLalla and Gottesman (1989) also theorized about early-onset or continuous antisocial behavior, and late-onset or transitory antisocial behavior. In addition, they suggested a third type of antisocials called 'late bloomers', who are thought to begin their offending in adulthood (DiLalla & Gottesman, 1989).

The development of conduct problems and further antisocial behavior is related to a number of risk factors. These factors range from individual risk factors (e.g., difficult temperament, verbal deficits, executive dysfunction, or psychopathy) to family influences (e.g., inadequate parental discipline, parental psychopathology, or parental discord), peer relationships as well as poverty and social disadvantage (Frick & Kimonis, 2008; Hill, 2002).

Genetic and environmental influences

Behavioral genetics aims to study the role of nature and nurture or, in other words, the role of inheritance and environment in behavioral traits. Twin and adoption studies belong to the main research methods of behavioral genetics used to disentangle genetic and environmental sources of family resemblance. Knowledge of whether and how genetic and environmental factors are present increases our understanding of the etiology and mechanisms involved in the development of behavior problems.

Heritability of externalizing problems and antisocial behavior has been studied in a number of cross-sectional and longitudinal twin studies. A summarizing picture of genetic and environmental influences on antisocial behavior was given by a meta-analysis of fifty-one twin and adoption cross-sectional studies of broadly-defined antisocial behavior in children, adolescents, and adults (Rhee & Waldman, 2002). The assessment of antisocial behavior included aspects of aggression, criminal offending, conduct problems and psychiatric disorders. The results of the analysis showed that genetic factors account for 41%, while shared and nonshared environmental effects explain 16% and 43% of the total variance of antisocial behavior, respectively (Rhee & Waldman, 2002). In both males and females, the magnitude of genetic and environmental influences on antisocial behavior was reported to be the same.

Several longitudinal twin studies have been conducted to investigate the influence of genetic and environmental factors on the development of externalizing and antisocial behavior. The results have been rather consistent about the stability of antisocial and externalizing behavior, which was mainly attributable to genetic and shared environmental effects (Bartels et al., 2004; Burt, McGue, Carter, & Iacono, 2007; Jacobson, Prescott, & Kendler, 2002). However, in these studies, the development of antisocial behavior has only been investigated at separate time periods across development, either from childhood to adolescence or from adolescence to adulthood. There is still a lack of research on the genetic and environmental etiology of antisocial behavior throughout the entire development, from childhood to adulthood. Following Moffitt's developmental typology

(1993), the results of such studies could help to explain the etiology of childhood-onset and adolescence-onset antisocial behavior.

A few genetically informative studies have reported findings that can be interpreted in support of Moffitt's developmental theory, or at least in support of separate aspects of it. An early study of male twins by Lyons and colleagues (1995) found that shared environmental influences were relatively more important for adolescent antisocial behavior, whereas genetic factors were more prominent for adult antisocial behavior. Further, Taylor and colleagues (2000) demonstrated that genetic influences were greater on early-onset than late-onset delinquent behavior in 11-year-old boys (Taylor, Iacono, & McGue, 2000). These results suggest that persistent antisocial behavior tends to be explained by genetic etiological processes to a larger extent than transitory antisocial behavior. In line with this, a recent study of male twins showed that a common genetic factor influenced antisocial behavior from age ten and through young adulthood, hence, reflecting persistent antisocial behavior (Silberg, Rutter, Tracy, Maes, & Eaves, 2007). The findings of these studies increase our knowledge on the etiology of persistent and transitory antisocial behavior in males. However, it is still less obvious whether the same origins of developmental typology may be applicable for females. That is, less information is available on how genetic and environmental effects influence antisocial behavior across development in females.

Internalizing behavior problems

Internalizing problems in children encompass behavior problems related to anxiety, depression, withdrawn behavior, and somatic complaints (Achenbach, 1991). Several longitudinal studies have suggested that anxious or depressed children tend to experience major depression later in adolescence as well as generalized anxiety and major depression disorders in adulthood (Moffitt et al., 2007; Roza, Hofstra, van der Ende, & Verhulst, 2003). However, research also suggests that the continuity of anxiety and depressive disorders from childhood to adulthood is rather low (Last, Perrin, Hersen, & Kazdin, 1996; Weissman et al., 1999).

Previous twin studies have shown that genetic factors explain a large proportion of individual differences in adolescent anxiety and depression symptoms in childhood and adolescence (Rice, Harold, & Thapar, 2002; Thapar & McGuffin, 1994). For example, a longitudinal twin study followed the development of anxiety and depression symptoms from late childhood to early adulthood (Kendler, Gardner, & Lichtenstein, 2008). The results revealed that genetic effects influencing childhood anxiety and depression tended to attenuate over time, whereas problems in adolescence and adulthood seemed to be influenced by new sets of genetic factors (Kendler, Gardner, & Lichtenstein, 2008).

There are two well-established predictors of internalizing behavior problems: child temperament and family environment, both of which may act independently as well as in interaction (Leve, Kim, & Pears, 2005). Higher risk groups include children who are fearful, shy, or emotionally reactive/inhibitive, especially in combination with experienced maternal depression, parental conflict, or psychological conflict (Leve et al., 2005; Morris et al., 2002).

PARENTAL BEHAVIOR AND ADOLESCENT ADJUSTMENT

Family factors associated with the development of child and adolescent mental health problems have been studied intensively for several decades. In addition to inherited vulnerability, parenting experiences were shown to have a major impact on the development of child mental health difficulties (Hoghughi, 2004). Aspects of adverse parental practices such as critical, hostile, inconsistent, harsh, or neglectful parenting have been associated with, for example, aggression, antisocial behavior, violence, and depression in children and adolescents, both concurrently and prospectively (Capaldi, Pears, Patterson, & Owen, 2003; Herrenkohl et al., 2000; Hill, 2002; Loeber et al., 2009; Reiss et al., 1995; Shaw, Gilliom, Ingoldsby, & Nagin, 2003). Parents of anxious children were found to be more controlling, restrictive, and overinvolved as well as less accepting and granting psychological autonomy than parents of non-anxious children (Dumas, LaFreniere, & Serketich, 1995; Hirshfeld, Biederman, Brody, Faraone, & Rosenbaum, 1997b; Krohne & Hock, 1991; Siqueland, Kendall, & Steinberg, 1996). However, despite a widely-acknowledged association between parental behavior and adjustment problems in children, less agreement is reached on the direction and origins of the association as well as processes involved.

Processes involved in parent-child relationships

A traditional notion has been that parents by their behavior, or lack of certain behaviors, directly affect the behavior of their children. The importance of parent-effects is supported by several studies, where harsh, negative or critical parenting was related to later increase in externalizing problems in children (Collins, Maccoby, Steinberg, Hetherington, & Bornstein, 2000; Denham et al., 2000; Nix et al., 1999; Trentacosta & Shaw, 2008). Similarly, parent-effects may explain the consistent findings of the association between parental overcontrol and childhood anxiety in cross-sectional studies (Ollendick, Alison, & Sander, 2008).

On the other hand, effects emanating from children have also been shown to operate in parent-child relationships. That is, parents may adapt harder discipline or get more critical as a reaction to child problematic behavior (Anderson, Lytton, & Romney, 1986; Deater-Deckard, 1996; Lytton, 1990). For example, findings of a cross-sectional study by Moore and colleagues (Moore, Whaley, & Sigman, 2004) suggested that anxious children tended to elicit overprotective responses from their mothers.

Recent studies, however, tend to emphasize the bidirectional processes appearing in the association between parental negativity and conduct problems in children and adolescents (Bullock & Dishion, 2007; Burke, Pardini, & Loeber, 2008; Eisenberg et al., 2008; Pardini, 2008; Richmond & Stocker, 2008). The reciprocity in parent-child relationships is usually discussed in light of Patterson's coercion theory, where coercive interactions between aggressive children and their parents are thought to escalate throughout the time and eventually contribute to the development of antisocial behavior (Patterson, 1980). Possible reciprocal effects involved in the association between parental behavior and internalizing problems in children and adolescents still needs to be examined in further longitudinal studies (Pardini, 2008).

Mothering and fathering

Mothering and fathering have been shown to be differently associated with child behavior problems (Bogels & Phares, 2008; Formoso, Gonzales, & Aiken, 2000; Phares & Compas, 1992; Rothbaum & Weisz, 1994). A meta-analysis of parental caregiving and child externalizing behavior among preadolescents revealed stronger associations among mothers compared to fathers (Rothbaum & Weisz, 1994). The authors suggested that in most families, mothers were primary caregivers and thus more involved in 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). Patterson (1980) contrasted the roles of fathers and mothers in families with non-problem children and families with antisocially behaving children. According to the author, in normal families mothers usually act as caretakers, fathers function as social facilitators, with both parents sharing child management problems. Mothers of antisocial children also tend to act as "crisis managers", while fathers' roles appear to remain unchanged (Patterson, 1980). A mother's role as a crisis manager implies that a mother gets more involved in coercive interactions with the child and consequently experiences more confrontational behavior from the child (Patterson, 1980). Such different aspects of parent involvement raise the possibility that the mechanisms behind fathering and mothering of children with problem behavior are different.

Genotype-environment correlation

Processes involved in parent-child relationships have also been investigated in a number of genetically informative studies. The association between negative parenting and adolescent adjustment problems have consistently been shown to be influenced by genetic factors originating from the child (Deater-Deckard & O'Connor, 2000; Neiderhiser, Reiss, Hetherington, & Plomin, 1999; Pike, McGuire, Hetherington, Reiss, & Plomin, 1996). These findings are usually interpreted in terms of the genotype-environment correlation. Genotype-environment correlation (rGE) is defined as a correlation between the heritable characteristics of an individual and the environment he or she is exposed to (Plomin, DeFries, & Loehlin, 1977). Typically, three types of rGE are distinguished: passive, evocative, and active rGE. *Passive* rGE appears when a child inherits characteristics from the parents and receives a treatment from the parents correlating with the inherited characteristics. For example, parents may pass down to their children the genes that are involved in the development of antisocial behavior and, as a result of these genes, also behave coercively with their children. Passive rGE may therefore reflect the parent-driven effects in parent-child relationships. *Evocative* rGE corresponds to specific environments a child tends to evoke through his or her inherited traits. For example, parents may get overprotective as a response to a child's anxious behavior. This type of rGE can denote child-driven processes. *Active* rGE is defined as active choices and selections made by child who is driven by the inherited traits. The active rGE is less likely to operate in parent-child relationships and, thus, will not be further discussed in this thesis.

It is important to emphasize that parent-effects may also be present in absence of rGE. That is, the parental style can be uncorrelated with the genes contributing to either parental or child characteristics. This would support a hypothesis that parenting has a direct environmental causal effect on child behavior (Moffitt, 2005; Neiderhiser et al., 2004), suggesting that parents, by their behavior, directly influence the behavior of their children.

Negative parenting and externalizing problems

Several studies have suggested that the relationship between parental negativity and child problem behavior appears, at least in part, due to evocative rGE (Boivin et al., 2005; Forget-Dubois et al., 2007; Lynch et al., 2006; Neiderhiser, Reiss, Lichtenstein, Spotts, & Ganiban, 2007; Neiderhiser et al., 2004; O'Connor, Deater-Deckard, Fulker, Rutter, & Plomin, 1998; Pike et al., 1996). For example, Boivin and colleagues (2005) examined 5-month-old infants and reported that a moderate part of the maternal hostile-reactive behaviors was accounted by partly heritable infant's difficultness. Further, findings of a study of adolescents suggested that parental negativity tended to be explained by antisocial behavior in adolescents (Pike et al., 1996). A negative correlation between parental negativity and children prosocial behavior was reported to primarily be mediated by genetic effects, interpreted as evocative effects of children's characteristics (Knafo & Plomin, 2006). On the other hand, studies of monozygotic twins (MZ) discordant for antisocial behavior indicated that aversive parenting had an environmentally effect on antisocial behavior in children (Burt, McGue, Iacono, & Krueger, 2006; Caspi et al., 2004).

The presence of evocative rGE in the association between negative parenting and antisocial behavior is usually suggested to reflect Patterson's coercion theory of the development of antisocial behavior (Patterson, 1980). That is, coercive interactions between parents and adolescents may originate from negative parental responses to genetically influenced aspects of child problem behavior. Being continuously reinforced, these interactions are eventually related to adolescent maladjustment. This sequence of events may be tested in a longitudinal genetically informative study. The child evocative processes would be supported if genetic effects contributing to the association between negative parenting and adolescent antisocial behavior could be explained by some earlier harsh child's behavior. One heritable trait that has been associated with both parenting and antisocial behavior is childhood aggression. Studies showed that childhood aggression is a stable and early detectable personality characteristic, influenced primarily by genetic effects (DiLalla, 2002). It is one of the best and most frequently studied predictors of antisocial behavior later in life (Farrington & Loeber, 2000). Also, aggressive behavior runs in families, often mediated by parenting practices (Conger, Neppel, Kim, & Scaramella, 2003). Thus, it is possible that genetic influences on child aggression may also contribute to subsequent parenting practices and antisocial behavior in adolescence.

Inconsistent findings about the processes involved in the association between negative parenting and behavior problems in children may depend on the fact that earlier studies investigated the appearance of rGE by either studying twin children (and their parents) or adults twins (and their offspring). By having genetic information available on only children or parents, these traditional twin studies cannot disentangle child-driven (or evocative rGE) from parent-driven (or passive rGE) genetic influences on parent-child relationships.

Similarly, environmental influences are also not possible to separate in some of these designs. Thus, previous suggestions about rGE in parent-child relationships are rather approximate, highlighting the need for a possibility to directly test the presence of rGE as well as which type of rGE exists.

Overprotective parenting and internalizing problems

Overprotective parenting may be reflected by parents' emotional overinvolvement (EOI) with their children. EOI is a component of the expressed emotion construct and refers to overprotective and self-sacrificing parent behavior targeted toward a child (Asarnow, Tompson, Woo, & Cantwell, 2001; Hirshfeld, Biederman, Brody, Faraone, & Rosenbaum, 1997a). EOI has been shown to be a state-related measure, meaning that parents get more emotionally overinvolved as a response to their child's illness (Schreiber, Breier, & Pickar, 1995). In terms of rGE, this may correspond to the evocative type of rGE, that is, inherited anxious traits in children are likely to elicit overprotective behavior in parents. Higher EOI was related to higher levels of childhood anxiety disorders in several studies (e.g., Asarnow et al., 2001; Hirshfeld et al., 1997a; Stubbe, Zahner, Goldstein, & Leckman, 1993). For example, Hirshfeld and colleagues (1997) demonstrated that EOI in mothers was significantly associated with child separation anxiety in the at-risk sample (i.e., the sample of children at risk for anxiety disorders). The authors suggested that either EOI could have more influence on vulnerable children, or anxious children could evoke overprotective behavior in mothers who were themselves anxious. These findings may be explained by passive rGE, where children of anxious mothers tend to both inherit anxious traits and be treated more overprotectively. Obviously, the origins of internalizing behavior in children and adolescents are still ambiguous and could possibly be understood better by investigating the role of rGE.

Passive vs. evocative rGE: Children-of-twins design

Passive and evocative rGE can be distinguished under the condition that genetic and shared environmental influences on children's and parents' behavior are possible to separate. Conventional twin studies alone can not fulfill this requirement because genetic information is only available for either the parent or the child. In other words, a twin study of parenting typically examines parents who are twins or children who are twins, but does not include both parent and child pairs who vary in degree of genetic relatedness. Therefore, in such studies, evocative and passive rGE are confounded with genetic and shared environmental effects, respectively (Silberg & Eaves, 2004). Some studies have attempted to address this issue and distinguish between passive and evocative rGE by comparing findings from studies of twin children and studies of twin parents (Neiderhiser et al., 2007; Neiderhiser et al., 2004). However, the findings of such studies are still approximations because the samples are not nested.

A more elegant method to evaluate parental influences on children includes assessments of child adjustment within the framework of the powerful children-of-twins model (CoT) (Rutter, Pickles, Murray, & Eaves, 2001; Silberg & Eaves, 2004). It is assumed that children of MZ twins share half of their genes with both their own parent and the parent's co-twin (the child's aunt or uncle) while children of dizygotic (DZ) twins share half of their genes with their parent and approximately a fourth of their genes with their parent's co-

twin (like any niece/nephew-aunt/uncle pair). The rearing environment, on the other hand, is supposed to be distinct for each child. The environmental effect of parenting on children can thus be estimated by controlling for genetic relatedness between parents and children (Rutter et al., 2001). As a result, the children-of-twins model provides an effective strategy for disentangling the direct environmental influences of parenting from passive rGE (e.g., D'Onofrio et al., 2003; Lynch et al., 2006). However, the power for detecting evocative rGE is low even in this design. This is due to the fact that the children of twins are cousins who are, on average, 25% or 12.5% genetically similar, for children of MZ and DZ twins, respectively. Given such a modest variation in the degree of genetic relatedness, the effects of the children's *genotypes* influencing parenting behavior (i.e., evocative rGE) are difficult to detect.

Extension of children-of-twins model

The power of the CoT design to identify evocative rGE may be enhanced by including information on the same measured constructs provided by a companion study of twin children and their parents. High contrast of genetic similarity between the twin children in the companion study (100% for MZ and 50% for DZ) together with the cousin pairs in the CoT-design study allows the estimation of the effects of parents' and children's genes influencing each construct. In this extended CoT model, passive and evocative rGE as well as *direct environmental influences* of parenting on child adjustment may be distinguished. Similar strategies have been used in the past, where a single study design has not been powerful enough to disentangle the complex gene-environment interplay that shapes human behavior (Heath, Kendler, Eaves, & Markell, 1985; Reiss, Neiderhiser, Hetherington, & Plomin, 2000; Neiderhiser et al., 2004).

The strength of the extended children-of-twins model can be illustrated by comparing it separately to simple children-of-twins model and twin-children based designs. In studies of adult twins and their children, the nature of parental influences on child behavior can be examined by avuncular correlations (i.e., correlations between aunt/uncle and niece/nephew) for parenting and child behavioral outcomes among MZ and DZ twins. Higher correlations between children of MZ twins and their aunts or uncles would indicate the genetic effects involved in the relationship between parenting and child behavior. This may be interpreted as evidence for passive rGE, although it could also be a result of evocative rGE, not detected because of low power. On the other hand, findings of evocative rGE in twin-children studies of parenting may be just a manifestation of passive rGE. By pooling these two study designs, twin-parents and twin-children, the extended CoT model provides us an opportunity to examine both types of rGE simultaneously.

AIMS

The overall aim of this thesis is to investigate and understand the mechanisms underlying the association between adverse parenting practices and adolescent adjustment problems. Specifically, the aims are:

- To study genetic and environmental factors influencing the development of antisocial behavior from late childhood to early adulthood;
- To study aggression as a possible mediator of genetic and environmental effects influencing the association between parental criticism and adolescent antisocial behavior;
- To extend the existing children-of-twins model to be able to identify the type of genotype-environment correlation explaining the association between parental behavior and adolescent adjustment;
- To investigate the role genotype-environment correlation in the association between maternal emotional overinvolvement and internalizing behavior problems in adolescents;
- To study the role of genotype-environment correlation in the association between maternal and paternal criticism and adolescent externalizing behavior problems.

MATERIALS AND METHODS

SAMPLE

This thesis is based on data from two studies: Twin study of Child and Adolescent Development (TCHAD) and Twin and Offspring Study in Sweden (TOSS).

TCHAD

Participants

The TCHAD is an ongoing Swedish longitudinal study concerning health and behavior in children, adolescents, and young adults. The sample was derived from the population-based Swedish Twin Registry and initially included all 1480 twin pairs born in Sweden between May 1985 and December 1986 (Lichtenstein, Tuvblad, Larsson, & Carlstrom, 2007).

The twins and/or their parents were contacted at four occasions: in childhood (Wave 1, age 8-9), in early (Wave 2, age 13-14) and late (Wave 3, age 16-17) adolescence as well as in young adulthood (Wave 4, age 19-20). The mail-questionnaire included questions on different sociodemographic factors, physical health, personality, externalizing and internalizing behaviors as well as relationships with parents, siblings, and friends (Lichtenstein et al., 2007). Non-responders to the questionnaires were approached with up to three reminders.

At *Wave 1*, the response rate to the parent-questionnaire was 75% (n = 1,103 parents) of all parents. After conducting a telephone follow-up with a reduced battery of questions, the response rate reached 91% (n = 1,335 parents). At *Wave 2*, 73% of the parents (n = 1063) and 78% of the twins (n = 2,263) responded. At *Wave 3*, the questionnaire were completed by 74% of parents (n = 1,067) and 82% of twins (n = 2,368). Responses were obtained from additional 5% of the twins after the telephone follow-up with a reduced battery of questions. Complete information from the whole family between Wave 2 and Wave 3 is available for 906 of the twin pairs. The vast majority of parent-reported information was supplied by mothers rather than fathers (75%-90%). At Wave 4, mothers and fathers were approached separately. Response rate for parents was 51% (n=1,197) and 59% for twins (n= 1,698) (Lichtenstein et al., 2007).

Zygosity determination

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 and the frequency with which people confused them. These twins were classified using an algorithm which was derived from a discriminant analysis of 385 like-sexed pairs of the twins with DNA-confirmed zygosity (Hannelius et al., 2007).

The DNA of the twins was not yet collected at the time the Study I was conducted, the zygosity of the twins in this study was therefore determined by only using parents' and twins' responses. In Study II, III and IV, the zygosity classification was based on both DNA and response data.

Representativeness of the sample

Attrition rate

Selective attrition may lead to biased estimates in longitudinal data analyses (Little, 1995). Subjects lost to follow up at the later waves in TCHAD were tested whether they differed from the responders on measures at previous waves in a systematic way.

Comparisons of responders at Wave 1 that were lost to follow up at Wave 2 revealed no significant differences in sex ratio (OR = 0.96, 95% CI 0.74-1.22), parental ratings of aggressive (OR = 1.02, CI: 0.68-1.58) or non-aggressive (OR = 1.78, 95% CI: 0.94-3.32) behavior. However, the results indicated that families with lower socioeconomic status were somewhat more likely to cease to participate (OR = 1.30, 95% CI: 1.09-1.40) (Lichtenstein et al., 2007).

Responders at Wave 3 did not differ significantly from the non-responders at Wave 2 in terms of sex ratio (OR = 0.69, 95% CI 0.48-1.00), levels of antisocial behavior (OR = 1.22, 95% CI 0.77-1.93), or family socioeconomic status (OR = 0.42, 95% CI 0.11-1.58) (Lichtenstein et al., 2007).

At Wave 4, however, the analyses revealed that more male participants dropped out between Wave 3 and Wave 4 than compared to female participants (OR = 0.39, 95% CI 0.32-0.48). Also, individuals scoring higher on antisocial behavior at Wave 3 were more likely to be non-responders at Wave 4 (OR = 1.46, 95% CI 1.15-1.86) (Tuvblad, 2006).

Telephone interview

The twins who did not respond at Wave 3 (age 16-17) were contacted by telephone and asked questions from selected parts of self-report questionnaire. A reduced battery of questions included items on psychopathic personality, antisocial behavior, fears and phobias, parental education and occupation, legal and illegal drug use. Twins who responded to telephone interview scored higher on the measure of psychopathic personality compared to the twins who responded to the questionnaire ($t = -5.92$, $df = 2310$, $p > 0.001$). Also, telephone-responders more often came from families with lower socio-economic status than compared to those who filled out the questionnaire ($\chi^2 = 27.63$, $p > 0.001$). There were no differences between responders to questionnaire and telephone interview for measures of antisocial behavior, fears and phobias, and illegal drug use (Lichtenstein et al., 2007).

Neighborhood characteristics

At Wave 3, participants and nonparticipants were compared in terms of neighborhood characteristics. No differences were found for unemployment level ($t = -1.13$, $df = 2925$, $p = 0.26$), educational level ($t = -1.65$, $df = 2925$, $p = 0.10$), buying power ($t = -1.27$, $df =$

2925, $p = 0.21$), or neighborhood crime-rate ($t = 0.97$, $df = 2937$, $p = 0.33$). However, non-participating families were more likely to live in neighborhoods characterized by ethnic heterogeneity than compared to participant-families ($t = -3.63$, $df = 2925$, $p > 0.001$) (Tuvblad, Grann, & Lichtenstein, 2006).

TOSS

Participants

The TOSS is a study of adult twins and their families (Neiderhiser & Lichtenstein, 2008). The main objective of this study was to better understand the relationship within the family and how they are associated with the mental health of family members. The TOSS sample includes 909 pairs of twins (559 female and 350 male pairs), their spouse or 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. 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 11-22 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 (Neiderhiser & Lichtenstein, 2008).

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.

Zygosity determination

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.

Representativeness of the sample

Consistently 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.

MEASURES

The main focus of this thesis is on the development of behavioral problems alone as well as in relation to negative / adverse parenting. Below is a description of measures used to evaluate levels of behavior problems in adolescents (Paper I-IV) and to assess adverse parent behavior directed toward their adolescents (Paper I-III).

Problem behavior in adolescents

Aggressive behavior (Paper I)

Adolescent aggression levels at age 13-14 were assessed using two measures in TCHAD sample: Childhood Aggression Scale (Olweus, 1980) and Aggression subscale included in Child Behavior Checklist (CBCL) (Achenbach, 1991).

The Childhood Aggression Scale (Olweus, 1980) is a self-report questionnaire, which helps to assess the extent and type of aggression. The instrument was shown to have a high validity and reliability (Halperin, McKay, & Newcorn, 2002). The subscales used in this thesis were *Aggression* and *Irritability*. The Aggression subscale measures attitudes toward physical and verbal aggression, and includes 10 items concerning fighting, teasing, seeking out conflicts, and making trouble for others (Table 1). The Irritability subscale consists of 8 items assessing a tendency to be irritated and react aggressively. The internal consistencies of the two subscales were adequate: Cronbach's alphas (α) were 0.76 for Aggression and 0.80 for Irritability.

Table 1. Items included in Childhood Aggression Scale (Olweus, 1980)

<i>Aggression</i>				
I sometimes think it is fun to fight a little	I rather walk away if someone fights with me.	I tease other people quite a lot.	I get into fights with others fairly often.	I think it's better to be quiet than to fight if someone is stupid.
It's ok to make life difficult for a teacher, coach or similar who is stupid.	If someone insults me I try to beat him/her up.	Usually I don't feel there is much point in getting angry.	I think it "sucks" to fight.	I really don't hide my feelings when I'm angry.
<i>Irritability</i>				
Sometimes I'm in such a bad mood that I feel like throwing things around.	I easily get irritated if things don't work the way I imagined	Fairly often I feel irritated that I feel like breaking things.	I often feel like a powder-keg about to explode.	
Sometimes I'm so furious that I just hit someone.	If someone irritates me often, I try to punch him/her in the face.	If I have an argument with a boy/girl, I easily lose my temper and shout at them.	People around me probably think I'm easily annoyed	

Child Behavior Checklist (CBCL) is a widely used measure of behavioral and emotional problems in children and adolescents (Achenbach, 1991). Several studies showed that CBCL is a reliable and valid instrument for assessment of behavioral and emotional problems in children and adolescents (Achenbach & Rescorla, 2000). The CBCL consists of eight scales: aggressive behavior, attention problems, delinquent behavior, depression/anxiety, social problems, somatic complaints, thought problems, and withdrawn. In this thesis, the parents of 13-14 years old adolescents completed the *CBCL-Aggression* scale, which consists of 20 items (Table 2) covering physically aggressive behaviors (e.g., destroying one's own and others' belongings, screaming, threatening, attacking others), as well as personality-type behaviors (e.g., mood changes, attention demand, arguing, bragging, jealousy, stubbornness). The internal consistency for *CBCL-Aggression* scale was $\alpha = 0.77$.

Table 2. Items included in CBCL: Aggressive and Delinquent Behavior, Withdrawn, Somatic complaints, and Anxious/Depressed scales (Achenbach, 1991)

Aggressive behavior				
Argues a lot	Demands a lot of attention	Disobedient at home	Gets teased a lot	Shows off or clowns
Bragging, boasting	Destroys his/her own thing	Disobedient at school	Physically attacks people	Talks too much
Cruelty, bullying, or meanness to others	Unusually loud	Easily jealous	Screams a lot	Teases a lot
Destroys things that belongs to his/her family members or others	Threatens people	Temper tantrums or hot temper	Sudden changes in mood or feelings	Stubborn, sullen, or irritable
Delinquent behavior				
Don't seem to feel guilty after misbehaving	Prefers being with older kids	Steals at home	Thinks about sex too much	Vandalism
Hangs around with others who get in trouble	Runs away from home	Steals outside the home	Truancy, skips school	
Lying or cheating	Sets fires	Swears and uses obscene language	Uses drugs for non-medical purposes	
Withdrawn				
Rather be alone	Secretive	Stares	Underactive	Withdrawn
Won't talk	Shy	Sulks	Sad	
Somatic complaints				
Dizzy	Aches	Nausea	Skin	Vomit
Tired	Headaches	Eye	Stomach	
Anxious/Depressed				
Lonely	Perfect	Worthless	Guilty	Sad
Cries	Unloved	Nervous	Self-Conscious	Worries
Fear do bad	Out to get	Fearful	Suspicious	

For the purposes of Paper I we created a composite Aggression measure to minimize a possible reporter bias. The internal consistency of all three subscales assessing aggression was adequate, Cronbach's $\alpha = 0.77$. Also, the subscales of parent and child reports were genetically homogenous in a moderate way ($r_g \approx 0.40$) and the covariance between the subscales due to genetic effects were higher than 0.95, supporting the suitability of this composite. The new variable was created by principal component analysis to account for as much variance as possible.

Externalizing behavior (Paper III)

Adolescent externalizing behavior problems were assessed through adolescents' report on the Youth Self-Report, in both TCHAD and TOSS. The Youth Self-Report is an adapted self-report version of CBCL used to measure behavioral and emotional problems in children and adolescents (Achenbach, 1991). For our analyses we used the Externalizing dimension of behavior problems, which includes *Aggressive* and *Delinquent Behavior* scales. The Aggression scale comprises questions on whether the adolescent, for example, threatens, teases, attacks or is cruel to others (Table 2), while the Delinquency scale includes more covert behaviors such as stealing, lying, and substance use (Table 2). Cronbach's alphas for Externalizing dimension were high, with $\alpha = 0.82$ and $\alpha = 0.83$ for TOSS and TCHAD, respectively.

Antisocial behavior (Paper I and IV)

The levels of antisocial behavior in adolescents were assessed in TCHAD, when the twins were 13-14 and 16-17 years old. The adolescents were asked to complete a comprehensive *Self-Reported Delinquency* (SRD) questionnaire (Ring, 1999) about their delinquent behavior during the past twelve months. The items included were initially derived from a validated instrument employed in the International Self-Report Delinquency Study, which compared youth self reports of delinquency in a number of western countries (Junger-Tas, Terlouw, & Klein, 1994). Overall, the measure was reported to have good psychometric properties and moderate to high validity (e.g., Moffitt, Silva, Lynam, & Henry, 1994). The validity of antisocial behavior measure used specifically in TCHAD was evaluated by comparing the prevalence of antisocial behavior in TCHAD to the prevalence observed using the same measure in another Swedish population-based study of antisocial behavior data (Ring, 2005). In TCHAD, the prevalence of antisocial behavior was somewhat lower compared to the prevalence observed in another Swedish population-based school study (Ring, 2005). Test-retest reliability was measured by comparing the answers of 16-17 years old adolescents that have responded to both the questionnaire and the telephone interview. The correlation between the responses of 72 twins at both occasions was adequate, $r = 0.72$. This suggests that antisocial behavior measure has reasonably good psychometric properties (Tuvblad, 2006).

The SRD questionnaire included 34 (age 13-14), 32 (age 16-17) or 31-items (age 19-20) covering three different areas of illegal acts (Table 3): (1) *Property offences and problem behavior* including items such as shop-lifting, fraud, burglary, serious theft, vandalism, (2) *Violent offenses* including items on simple assault, fighting and robbery, and (3) *Drug related offenses* including items about using and selling various types of illicit drugs and alcohol (Tuvblad, 2006).

Table 3. Items included in Self-Reported Delinquency questionnaire (age 16-17)

Property offences and problem behavior

Shop-lifting	Pocket-picking	Writing on public walls/surfaces
Steal from school	Purse/bag-snatching	Theft from vending machine
Steal at home	Theft from car	Train/bus fare evasion
Unspecified thievery	Graffiti	Ride motorbike/car without license
Buy stolen goods	Motorbike theft	Use false ID card
Bike theft	Car theft	Cheat or lie to get money
Sell stolen goods	Arson	Truancy
Burglary	Vandalism	

Violent offenses

Carry a knife	Threaten for money	Hurt someone with a weapon
Beat non-family member	Beat family member	

Drug-related offenses

Use illicit drugs	Sell hard drugs	Sell soft drugs
Sniff glue		

At age 16-17, the prevalence of *Property offenses and problem behavior* was highest for shop-lifting (17%), vandalism (15%), and bike theft (9%). The prevalence of, for example, using drugs was 5% at the same age-group. Among *Violent offenses*, the prevalence of simple arson was 5%, beating someone 2.5%, and threatening for money 1% (H Larsson, 2005). Factor analyses of SRD-items resulted in a single factor of antisocial behavior at each of time points. The internal consistency was high, $\alpha = 0.87$ (age 13-14), $\alpha = 0.92$ (age 16-17), and $\alpha = 0.83$ (age 19-20).

Internalizing behavior (Paper II)

Adolescent internalizing behavior problems were assessed by adolescent's report on the Youth Self-Report (Achenbach, 1991), in both TOSS and TCHAD. For our analyses in Paper III, we used the Internalizing dimension of behavior problems in adolescents. This dimension combines the scales *Anxious/Depressed*, *Withdrawn*, and *Somatic complaints* (Table 2). The internal consistencies for the Internalizing dimension was high, Cronbach's alphas were 0.86 for TOSS and 0.88 for TCHAD.

Adverse parenting

In this thesis, adverse parenting was investigated in terms of critical remarks parents usually convey to their children and emotional overinvolvement mothers experienced with their adolescents.

Parental Criticism

In both TCHAD (age 16-17) and TOSS, parental criticism towards the adolescent was assessed through parent report on the Critical Remarks subscale of the Expressed Emotion measure (EE) (Hansson & Jarbin, 1997). This measure taps into dyadic personal relationships in a family by measuring amount of criticism, positive comments, hostility,

Table 4. Expressed Emotion measure: Items included in the Critical Remarks and Emotional Overinvolvement scales

Critical Remarks	Emotional Overinvolvement
I fail to start a conversation with him/her.	I am thinking about his/her future
I find faults with him/her	He/she makes me feel psychologically bad
He/she makes me feel psychologically bad	I believe that he/she has personal problems
I have to ask him/her to behave differently	I give up /sacrifice a lot of myself for him/her
Repeatedly I have to ask him/her to do things	I decide not to criticize him/her
It is hard for us to get along	I think about the causes of his/her behavior
He/she does certain things out of spite or in order to tease	I can't sleep because of him/her
I get annoyed or troubled when he/she repeatedly expects things from me	He/she is a far too important part of my life
He/she makes me irritated	
I try to influence his/her behavior	

warmth, as well as emotional overinvolvement of a family member directed towards a targeted person (Wearden, TARRIER, Barrowclough, Zastowny, & Rahill, 2000). The Critical Remarks subscale is made up of 10 items assessing parents' active behaviors, such as having problems with communication, and reactive behaviors, as, for example, attempting to change the adolescents' behavior. The scale is very similar to the Family Questionnaire: 8 of the 10 items were the same, with slight differences in wording (Wiedemann, Rayki, Feinstein, & Hahlweg, 2002). The Critical Remarks subscale showed a high internal consistency; Cronbach's $\alpha = 0.90$ for TCHAD and $\alpha = 0.86$ for TOSS.

The EE-construct was originally developed in the 1960's for studies of patients with schizophrenia, but was eventually applied to explore different psychiatric and medical illnesses as well as disorders in children and adolescents (Wearden et al., 2000). The most reliable method to evaluate EE has been the Camberwell Family Interview (Vaughn & Leff, 1976) but because of its length and cost, other ways to assess EE have been developed. One method is self-report questionnaires that have been shown to be valid. For instance, one study demonstrated that the self-report Family Questionnaire correctly rated EE for over 70% of cases as compared to the Camberwell Family Interview (Wiedemann et al., 2002).

Emotional Overinvolvement

Emotional overinvolvement (EOI) was measured by mothers' report on the Emotional Overinvolvement subscale of the EE measure (Hansson & Jarbin, 1997). The subscale includes items concerning the levels parents sacrifice themselves for their children or are preoccupied with their behavior (Table 4). Internal consistency for EOI subscale was adequate, with Cronbach's $\alpha = 0.70$ for TOSS and $\alpha = 0.78$ for TCHAD.

Because the distribution of all measure scores was skewed to the left, the data was transformed by taking a logarithm of the scores. For analyses in Paper II and III, the data

was also corrected for age and sex by computing standardized partial residuals from the regression scores on these variables (McGue & Bouchard, 1984).

STATISTICAL METHODS

There are several quantitative genetic methods that can be used to investigate genetic and environmental origins of individual differences in behavior. In this thesis, etiology of problem behavior in adolescents and adverse parenting was studied by using the twin method. Below is the description of the twin method in general followed by the description of the models applied to analyze the twin data in this thesis.

Twin method

Twins may be viewed as a near-perfect natural experiment which helps to separate between heritable and environmental effects on human traits (Martin, Boomsma, & Machin, 1997; Neale, 2009). There are two types of twins used for data analyses: monozygotic (MZ) or identical twins, who are assumed to share all their genes in common, and dizygotic (DZ) or fraternal twins, who share, on average, half of their segregating genes. The twin method is based on the comparison of the similarity of MZ and DZ twins, which makes it possible to estimate the relative proportions of phenotypic variance attributable to genetic and environmental effects (Evans, Gillespie, & Martin, 2002).

The variance of the observed phenotype (P) in twins may be partitioned into components of variance due to additive genetic (A), non-additive genetic (D), shared environmental (C), and nonshared environmental (E) effects:

$$\sigma_p^2 = \sigma_A^2 + \sigma_D^2 + \sigma_C^2 + \sigma_E^2$$

The additive genetic component (A) relates to the sum of allele effects over the loci. The non-additive genetic component (D) reflects allelic interactions at a locus (dominance) and/or non-allelic interactions between the loci (epistasis). Shared environment (C) contributes to twin non-genetic similarity while nonshared environmental (E) factors are environmental experiences that make twins different. Nonshared environmental variance component also includes measurement error.

Since MZ twins are genetically identical, they are assumed to share all additive and non-additive genetic variance. DZ twins share half of the additive genetic and one-fourth of the dominant genetic effects. Both MZ and DZ twins are assumed to share all their shared environmental variance and none of the nonshared environmental variance.

The proportion of phenotypic variance that is explained by genetic effects is called heritability. Narrow-sense heritability refers to the proportion of the phenotypic variation attributable to additive genetic effects (A), whereas broad-sense heritability indicates the proportion of the total variation explained by both additive and non-additive effects (A+D) (Plomin, DeFries, McClearn, & McGuffin, 2001).

The importance of heritability and environment on the specific behaviour outcome can be evaluated in different ways. First, we can compare the similarity of twins for the given trait

to get the first impression on how important genetic and environment factors are. By further applying the model-fitting approach, we can get the estimates of genetic and environmental variance components, the information on how well these estimates explain our data as well as a possibility to test different hypotheses.

Similarity between twins

The similarity between the twins is measured by intraclass correlations. If intraclass correlation for DZ twins is approximately half of those for MZ twins ($r_{DZ} = 0.5r_{MZ}$), additive genetic effects are suggested. Non-additive genetic factors seem to be important if intraclass correlation between DZ twins is less than half of that for MZ twins ($r_{DZ} < 0.5r_{MZ}$). Sharing the same environment may increase the similarity between the individuals. Therefore, approximately equal intraclass correlations for DZ and MZ twins ($r_{DZ} = r_{MZ}$) suggest presence of shared environmental influences. The effect of nonshared environmental factors is reflected by differences in MZ twins.

In studies of twins and their children, it is informative to calculate correlations across generations and across families. Comparison of these correlations, that is, correlations between the child of the twin and their uncle/aunt, can be used to approximate the nature of intergenerational transmission. The cross-generation within-family correlations do not provide this information because the genetic relatedness between parents and children is the same (50%) for both MZ and DZ twins. The intergenerational transmission is suggested to be heritable if the correlation between MZ parents and their niece/nephew is higher compared to DZ parents and their niece/nephew. Equal intergenerational correlations between MZ and DZ families will indicate that the transmission is environmental in nature.

Model fitting

Model-fitting approach implies attempts to explain the observed data with a simplified model. Model-fitting procedure for twin data is implemented through applying the structural equation model. Structural equation modeling combines aspects of path and factor analyses (Bollen, 1989; Musil, Jones, & Warner, 1998) and is used to derive the prediction of (estimate) the variances-covariance structure for the variables studied. The pattern of variances and covariances is modeled as follows:

$$\begin{bmatrix} \sigma_A^2 + \sigma_D^2 + \sigma_C^2 + \sigma_E^2 & r_A\sigma_A^2 + r_D\sigma_D^2 + r_C\sigma_C^2 \\ r_A\sigma_A^2 + r_D\sigma_D^2 + r_C\sigma_C^2 & \sigma_A^2 + \sigma_D^2 + \sigma_C^2 + \sigma_E^2 \end{bmatrix},$$

where r_A , r_D , and r_C are additive genetic, non-additive genetic, and environmental correlations, respectively. For MZ twins $r_A = r_D = r_C = 1.0$, whereas for DZ twins $r_A = 0.5$, $r_D = 0.25$, and $r_C = 1.0$.

In a study of twins reared together, dominant genetic and shared environmental components of variance are negatively confounded and therefore cannot be estimated simultaneously (Evans et al., 2002). In this thesis, the parameters of the structural equation model were estimated using maximum likelihood approach, under the assumption of a

multivariate normality (Neale, 2009; Neale, Boker, Xie, & Maes, 2006). The model-fitting procedure was performed in the structural equation-modeling software package Mx (Neale et al., 2006). The different twin models were fitted to raw data, which makes it possible to handle missing data completely at random or missing at random (Neale, 2009). The goodness-of-fit of the models was compared using the likelihood ratio test. The test statistic, twice the difference between log-likelihood functions of the estimated models with minus sign, follows a χ^2 distribution with the number of degrees of freedom equal to the difference of the estimated parameters in both models. A significant difference indicates that the model with fewer parameters fits the data worse. The balance between the model overall-fit to the data and the parsimony, the number of parameters, can be evaluated by the Akaike's Information Criterion (AIC). The best-fitting and parsimonious model is indicated by the lowest value of AIC.

Structural equation models are often represented by path diagrams. The basic twin model for studying one phenotype (also called univariate model) is presented in Figure 1. The variables included in the twin model can either be measured phenotypes or latent (unmeasured) variance components. The observed phenotype is depicted by rectangles, for Twin 1 and Twin 2 separately. The unobserved or latent effects of additive genetic (A), shared environment (C) or non-additive genetic effects (D), and nonshared environment (E) are depicted by circles. Following the genetic relatedness between MZ and DZ twins, the correlation between additive genetic effects is set to 1.0 for MZ and 0.5 for DZ twins, respectively. For non-additive genetic effects the correlation between MZ and DZ twins is set to 1.0 and 0.25, respectively. Both MZ and DZ twins are assumed to experience the shared environment to the same extent and therefore the correlation between shared environmental effects is set to 1.0. Nonshared environment is uncorrelated between the twins by definition. The contributions of latent genetic and environmental factors to the observed phenotype are denoted by path coefficients a , c or d , and e . Squared path coefficients denote the proportion of the variance explained by each factor.

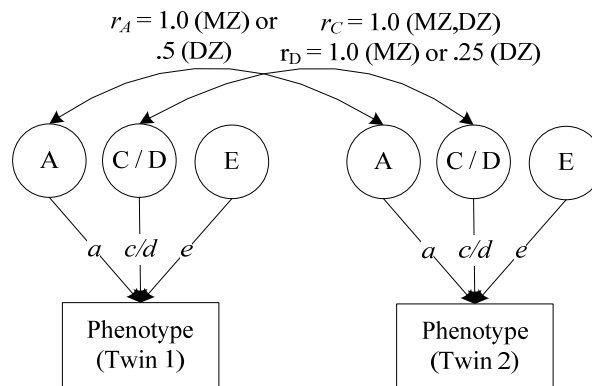


Figure 1. Univariate twin model. Latent additive genetic, non-additive genetic, shared environmental and nonshared environmental factors are denoted by A, C, D, and E, respectively; r_A , r_D , and r_C are genetic and shared environmental correlations, respectively.

The basic univariate twin model can be extended for more complex analyses. For example, we can test whether the variation of the trait is different between the sexes. Also, several observed phenotypes may be included in the same model to investigate the genetic and environmental sources of the covariation between them. Below is the description of different twin models that were applied in this thesis to study adolescent adjustment and its association to adverse parenting.

Sex-limitation models (Paper I, III and IV)

The structure of variance components for a trait may differ between males and females in two ways. First, the genetic and environmental effects may influence the phenotype to a different magnitude in males and females. On the other hand, there might be a different set of genes or shared environmental effects that influence the phenotype in both sexes. In Paper I, III, and IV, two models were applied to investigate the magnitude of genetic and environmental influences on adolescent maladjustment problems and adverse parenting aspects. The variance component parameters of the first model were allowed to differ between the males and females. In the second, constrained, model these parameters were set to be equal between the sexes. The models were then compared in terms of goodness-of-fit.

Cholesky decomposition (Paper I and IV)

For twin data, the Cholesky decomposition is usually a starting point to analyze the genetic and environmental sources and structure of covariation underlying multiple variables (Armitage & Colton, 2009); Evans et al., 2002). The method is merely a decomposition of the genetic and environmental covariance matrices (**A**, **C**, **D**, or **E**) rather than being a theory-based model (Armitage & Colton, 2009). The Cholesky decomposition is parameterized in terms of latent factors, the number of which is equal to the number of observed variables. All variables load on the first latent factor, all variables except the first will load on the second factor, and so on, until the last variable will load on the last factor only (Evans, et al., 2002). This factorization is specified for each latent source of variation, that is, A, C, D, or E. Figure 2 represents the Cholesky decomposition for three observed phenotypes (trivariate), depicted for one twin in a pair.

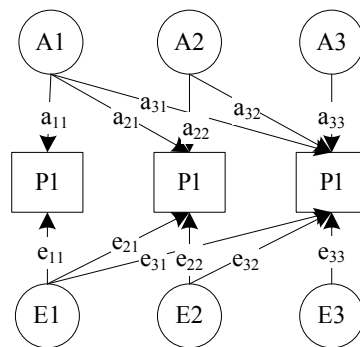


Figure 2. Trivariate Cholesky decomposition. Factor structures are shown for only two sources of variance, A and E. P1, P2, and P3 denote observed phenotypes 1-3. Path coefficients denote latent factor structure of each variance component.

In Paper I, the bivariate Cholesky decomposition was used to study the etiology of covariation between parental criticism and antisocial behavior in adolescents. The trivariate Cholesky decomposition was applied to further investigate whether the sources of this covariation were due to the earlier expressed aggression levels in adolescents. In Paper IV, the Cholesky decomposition was applied to study the covariation of externalizing and antisocial behavior symptoms measured at four time points, from childhood to early adolescence.

Independent and Common pathway models (Paper IV).

Independent and Common Pathway models are more restrictive, as compared to Cholesky decomposition. Both these models make strong theoretical assumptions regarding the causes of the covariation between the phenotypes (Evans et al., 2002). In the independent pathway model (Figure 3a), the covariation between the phenotypes is assumed to be due to common genetic and common environmental factors (A, C, and E). The Common pathway model (Figure 3b) is even more restrictive and assumes that common genetic and environmental effect form an intermediate latent factor which subsequently causes the variation and covariation between the observed phenotypes (Neale, 2009) {Evans et al., 2002}. In both models, the residual variance specific to each variable is modeled by specific genetic and environmental effects (A_i, C_i, and E_i). Variable-specific nonshared environmental component (E_i) includes measurement error.

The Independent pathway model is nested within Cholesky decomposition when more than three phenotypes are studied. The Common pathway model is always nested within the Independent pathway model (and Cholesky decomposition). These models can be tested against each other to select the one that provides the most parsimonious fit to the data. The balance between the model overall-fit to the data and the parsimony, the number of parameters, can be evaluated by the Akaike's Information Criterion (AIC). The best-fitting and parsimonious model is indicated by the lowest value of AIC.

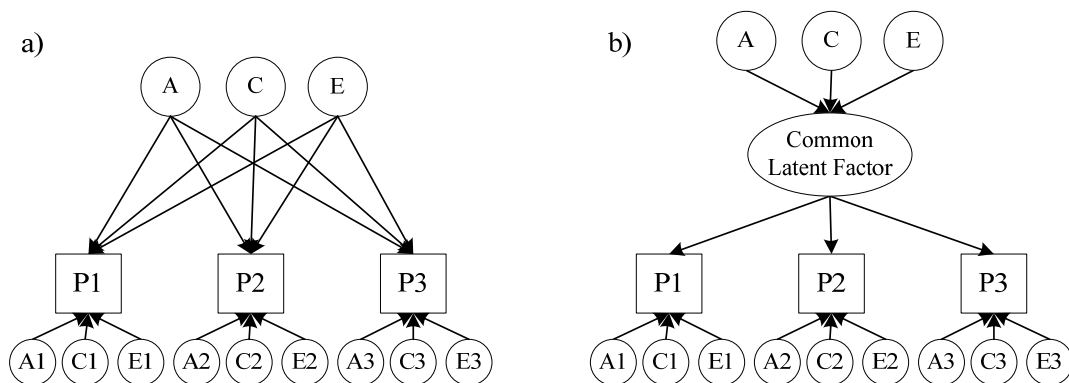


Figure 3. Independent (a) and Common pathway (b) models specified for three phenotypes. Common genetic and environmental factors are denoted by A, C, and E. Variable-specific factors are denoted by A1-A3, C1-C3, and E1-E3.

Extended Children-Of-Twins model (ECOT) (Paper II and III)

The ECOT model is an extension of the children-of-twins model presented in Silberg and Eaves (2004). Two features are specific to the ECOT model. First, the model includes information on one parent and his/her child. Second, the model is defined in two parts: one that describes *twin parents* and their children, while the other defines *twin children* and their parents (Figure 4). By combining information on twin parents and twin children, the ECOT model includes a sufficient number of genetic and environmental sources of variation to be identified and provide unbiased parameter estimates (Heath et al., 1993).

The ECOT model includes two phenotypes: one reflecting parenting practices and one describing child adjustment (denoted as Parenting and Child Adjustment in Figure 4). For both phenotypes genetic (A1 or A2), shared environmental (C1 or C2) and nonshared environmental effects (E1 or E2) are estimated. Factor A1' represents genetic contributions to child adjustment that are in common with parental genetic effects on parenting practices. The path leading from A1 to A1' is fixed to 0.5 because children share 50% of their segregating genes with each parent. 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 practices and child adjustment. A significant path *m* suggests direct phenotypic influence of parenting on child behavior. That is, parents directly affect the child behavior via environmental mechanisms. Passive rGE is suggested when parents contribute both genes and environments correlated

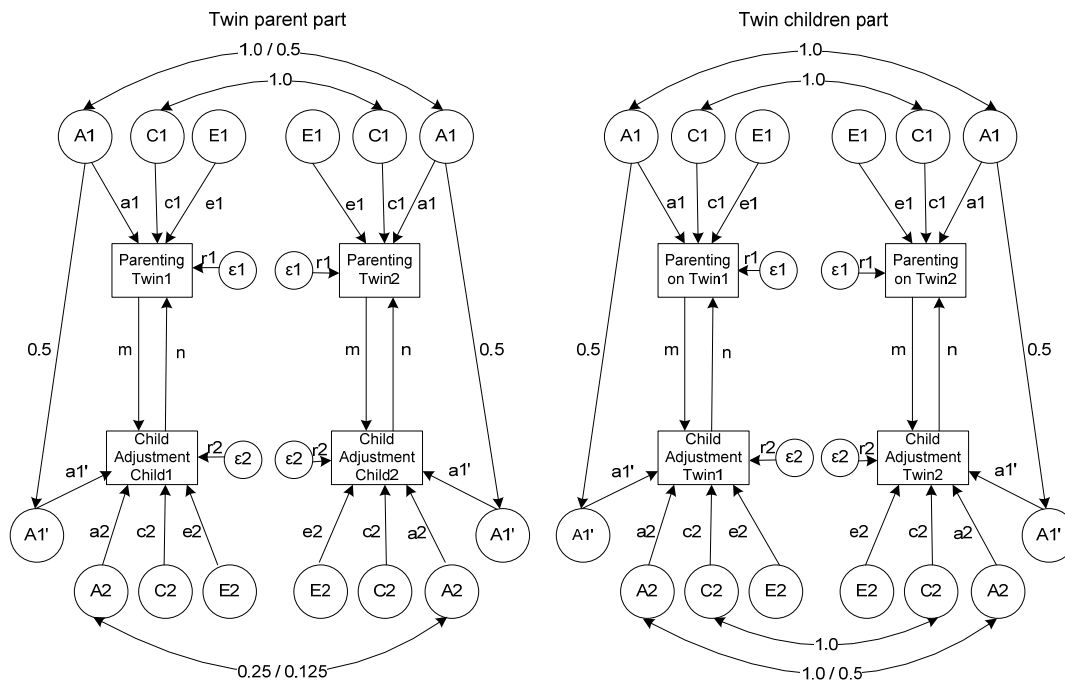


Figure 4. Extended children-of-twins model (ECOT) described for two phenotypes, Parenting and Child Adjustment.

with their genotype to their children. In the ECOT model, this type of rGE is reflected by a significant m path as well as significant $a1$ and $a1'$ paths. Finally, evocative rGE is indicated when children evoke particular parent behavior for reasons due to their inherited characteristics. Evocative rGE is indicated when paths n , $a1'$ and/or $a2$ are significant in the ECOT model (see Silberg & Eaves, 2004).

In contrast to the basic twin model, the measurement error term has to be estimated as a separate parameter in a reciprocal causation model (denoted as $\epsilon1$ and $\epsilon2$ in Figure 4). Otherwise, the parameter estimates might be biased (Heath et al., 1993).

Twin parent part of the model. Parents that are MZ twins share all their segregating genes. Therefore, the correlation between parents' genetic effects ($A1$) is set to 1. DZ twins share on average half of their segregating genes, and thus the correlation is equal to 0.5. Shared environment is, by definition, all nongenetic influences that make family members similar, thus, the correlation between shared environmental ($C1$) effects is set to 1 for both MZ and DZ twins. Following the genetic relatedness between children of MZ and DZ twins, the correlation between the $A2$ paths is set to 0.25 and 0.125, respectively. The correlation between shared environmental effects ($C2$) for children of twins is set to zero since they were not sharing the same rearing environment.

Twin child part of the model. Correlations between parental genetic ($A1$) and shared environment ($C1$) effects are set to 1.0 for both twin children because the same parent is rating his/her behavior with both children. Since the parent reports about each child separately, some aspects of parenting will be specific to each child. Therefore, non-shared environment parameters ($E1$) are uncorrelated. For twin children, the genetic correlation was set to 1 and 0.5, for MZ and DZ twins, respectively. The correlation between shared environmental influences ($C2$) is set to 1.0 for both types of twin children because they are being reared in the same household.

The total estimated phenotypic variance for each trait is calculated as follows (Heath et al, 1993):

$$Var(Parenting) = ((1 - m * n)^{-2} * (a1^2 + c1^2 + e1^2 + n^2 * (a2^2 + a1'^2 + c2^2 + e2^2))) + r1 \quad (1)$$

$$Var(Child Adjustment) = ((1 - m * n)^{-2} * (a2^2 + a1'^2 + c2^2 + e2^2 + m^2 * (a1^2 + c1^2 + e1^2))) + r2 \quad (2)$$

The data for model estimation may be combined from two different studies. The samples should be comparable in measures included, marital status of parents, and age of children as well as in prevalence of the observed phenotypes.

Simulations procedure for the ECOT model

The performance of the ECOT model was tested by running series of Monte Carlo simulations. The simulation procedure may briefly be summarized in the following steps: 1) the true values of variance components were decided; 2) values of variance components from step 1 were used to generate the scores of traits; 3) the ECOT model was estimated and the parameter estimates were recorded; 4) steps 2-3 were repeated 1000 times; 5) the mean of the estimates of variance components across 1000 simulations was calculated and

compared to the true value parameters. The model performs reasonably well if the true and the estimated values of the variance components are close to each other. For each of 1000 replications, the data was generated for 500 pairs of MZ and 500 pairs of DZ twin parents with their children as well as equally many pairs of MZ and DZ twin children together with their parents. In total, 2000 pairs of twins were used in each analysis.

When both phenotypes studied are influenced by genetic and shared environmental effects this type of models has a limited power to reject false causality hypothesis, unless applied to very large data samples (Heath et al., 1993). Also, previous twin research on parenting has shown that parenting style tends not to be influenced by their environment shared in childhood (Perusse, Neale, Heath, & Eaves, 1994; Wade & Kendler, 2000). Therefore, for these simulations only genetic (A1) and non-shared environmental effects (E1) were included for Parenting. Further, since in TOSS and TCHAD studies the reliability of measures of different phenotypes for parents and children usually varied from approximately 0.75 to 0.90, the measurement error was assumed to account for 20% of the observed variance.

The sets of true values of model parameters for generating phenotypes were calculated depending on the assumed variance structure of phenotypes. Of most interesting was to test the performance of the model depending on different heritability of the traits studied. Three possible variance structures were chosen: 1) genetic and environmental effects contributed equally to the phenotypes (50% to 50%); 2) both phenotypes were predominantly influenced by genetic effects (70%), while environmental influences accounted for 30% of total variance; 3) both phenotypes were mainly influenced by environmental influences

Table 5. Sets of true parameter values depending on the variance structure of the phenotypes and presence of gene-environment correlation (rGE)

Presence of rGE	<i>a1</i>	<i>a1'</i>	<i>a2</i>	<i>e1</i>	<i>e2</i>	<i>c2</i>	<i>m</i>	<i>n</i>
Equal genetic and environmental effects								
- no evocative rGE	0.70	0.65	0.00	0.70	0.45	0.45	0.20	0.00
- no passive rGE	0.65	0.55	0.20	0.65	0.45	0.45	0.00	0.20
- small evocative rGE	0.60	0.43	0.43	0.60	0.45	0.45	0.30	0.10
- small passive rGE	0.63	0.25	0.60	0.54	0.45	0.45	0.10	0.30
- equal passive and evocative rGE	0.70	0.00	0.65	0.70	0.50	0.50	0.25	0.25
Genetic predominant								
- no evocative rGE	0.79	0.72	0.00	0.55	0.30	0.35	0.20	0.00
- no passive rGE	0.75	0.60	0.15	0.50	0.35	0.35	0.00	0.20
- small evocative rGE	0.70	0.50	0.50	0.40	0.30	0.35	0.30	0.10
- small passive rGE	0.74	0.20	0.75	0.45	0.40	0.40	0.10	0.30
- equal passive and evocative rGE	0.79	0.00	0.75	0.55	0.45	0.45	0.25	0.25
Environment predominant								
- no evocative rGE	0.55	0.55	0.00	0.80	0.50	0.55	0.20	0.00
- no passive rGE	0.50	0.40	0.15	0.80	0.50	0.55	0.00	0.20
- small evocative rGE	0.50	0.30	0.30	0.70	0.50	0.55	0.30	0.10
- small passive rGE	0.50	0.20	0.50	0.75	0.60	0.60	0.10	0.30
- equal passive and evocative rGE	0.55	0.00	0.55	0.80	0.60	0.60	0.25	0.25

(70%) and genetic effects explained the remaining 30% of the total variance. Given the approximate variance structure of a phenotype, it is possible to calculate the exact size of each variance component by applying equations (1) and (2). Environmental effects for Parenting were generated as non-shared environmental influences, while Child Adjustment was influenced by both shared and non-shared environmental effects, generated of roughly equal proportions.

The performance of ECOT was also tested in the presence of different types of rGE. For this, under each of three variance structure alternatives five scenarios of rGE existence were assumed, ranging from absence of passive or evocative rGE to equal influences of both. Table 5 presents different sets of true variance component values, depending on the variance structure and existence of passive or evocative rGE.

Passive rGE is suggested when paths m , al' and al are significant. Under all simulation scenarios where passive rGE was present, the parental phenotypes were generated to be both heritable (al) and contributing to child phenotypes (al'). Consequently, the main effect of passive rGE becomes reflected solely by the parameter m , which will further be referred to as the non-evocative path. Similarly, the effect of evocative rGE becomes reflected by the evocative path n .

The data analyses were performed using SAS (SAS Institute Inc, 2003), Mx (Neale et al., 2006), and R (R Development Core Team, 2003) software packages.

RESULTS

PARENTAL CRITICISM AND ANTISOCIAL BEHAVIOR

The main findings of Paper I are presented in Figure 5 and 6. The bivariate Cholesky decomposition (Figure 5) of the covariance between Parental Criticism and SRD revealed that of all factors influencing Parental Criticism only genetic effects also contributed significantly to SRD, for both boys and girls. Genetic effects on Parental Criticism contributed to SRD by .34 and .42, for boys and girls, respectively. The environmental effects influencing Parental Criticism did not seem to be important for SRD.

The magnitude of genetic and environmental contributions to the total phenotypic correlation may be calculated in terms of genetic and environmental covariance. Because the parameter estimates are standardized, the covariance between the latent factors actually corresponds to the correlation between the factors and therefore can be used to explain the phenotypic correlation. The covariance between the latent factors is calculated by multiplying the contributions of the first factor (A1, C1, or E1) to both traits. For example, the genetic covariance for boys reached $0.74 * 0.34 = 0.25$. The total estimated phenotypic correlation between the traits is calculated by adding genetic, shared environmental and nonshared environmental covariances: $0.25 - 0.09 - 0.01 = .15$, which is within rounding error of the observed phenotypic correlation of 0.17.

The further trivariate Cholesky decomposition (Figure 6) aimed to test whether the correlation between Parental Criticism and SRD could be explained by genetic effects emanating from earlier expressed aggression. The results revealed that genetic effects on Aggression contributed significantly both to Parental Criticism and SRD, in both boys (0.34 and 0.36) and girls (0.42 and 0.40). In the trivariate model, the genetic covariance between Parental Criticism and SRD is calculated by adding genetic covariance in common with Aggression and genetic covariance without Aggression. For example, for boys, genetic covariance between Parental Criticism and SRD excluding Aggression was $0.64 * 0.23 = 0.15$. The genetic effects in common with Aggression contributed to the total

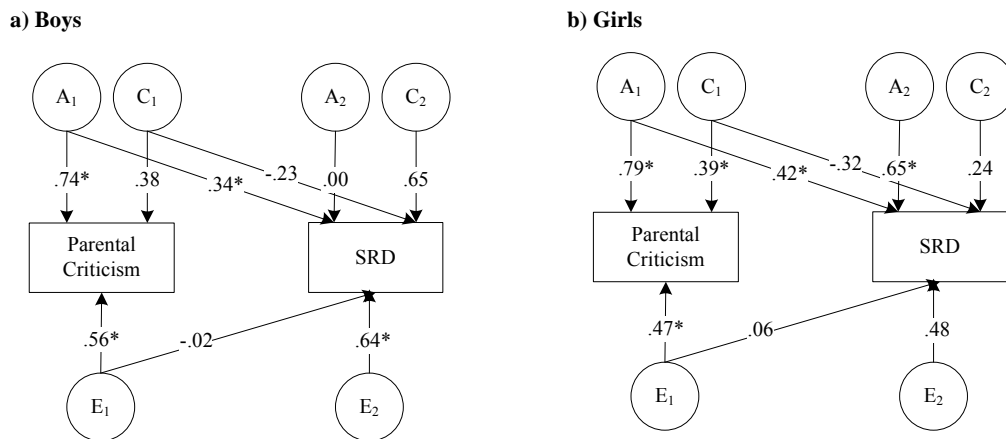


Figure 5. Standardized parameter estimates of bivariate Cholesky decomposition, for boys (a) and girls (b).

genetic covariance between Parental Criticism and SRD by $0.34 \times 0.36 = 0.12$. The total genetic covariance is consequently equal $0.15 + 0.12 = 0.27$. Thus, for boys, genetic effects in common with Aggression accounted for approximately half of all genetic influences contributing to the association between Parental Criticism and SRD (0.12 of 0.27). The results were similar for girls.

PERFORMANCE OF THE ECOT MODEL

The performance of the ECOT model was evaluated in Paper II. The precision of recovery of true sample parameters was assessed by calculating means and standard deviation of all estimates. Results of the simulations are presented as histograms in Figures 7a, b, and c. Every figure represents a different variance structure of the generated phenotypes. In Figure 7a, the phenotypes were assumed to be influenced by equal genetic and environmental influences, whereas Figures 7b and 7c reflect predominantly genetic and predominantly environmental effects on phenotypes, respectively. The most interesting aspect of the ECOT performance is its ability to detect rGE. Therefore, the histograms are presented only for the estimates of reciprocity parameters m (passive rGE) and n (evocative rGE). Ideally, the values of true and estimated parameter values should overlap and the histogram should consist of only one bar. This would indicate that the model recovered the true sample parameter perfectly at every simulation. A reliable model would provide estimates that are symmetrically and narrowly distributed around the mean value, which is also close to the true value of parameters.

In general, all histograms presented in the figures were symmetric, with one distinct peak, other values being distributed compactly around. This suggests that the ECOT model is stable, indicated also by low standard errors (0.01-0.08).

The performance of the model did not seem to be sensible to the variance structure of the phenotypes. For all alternatives – *equal genetic and environmental effects, genetic predominant, and environment predominant* - the reciprocity parameters m and n were recovered very accurately, with only small deviations.

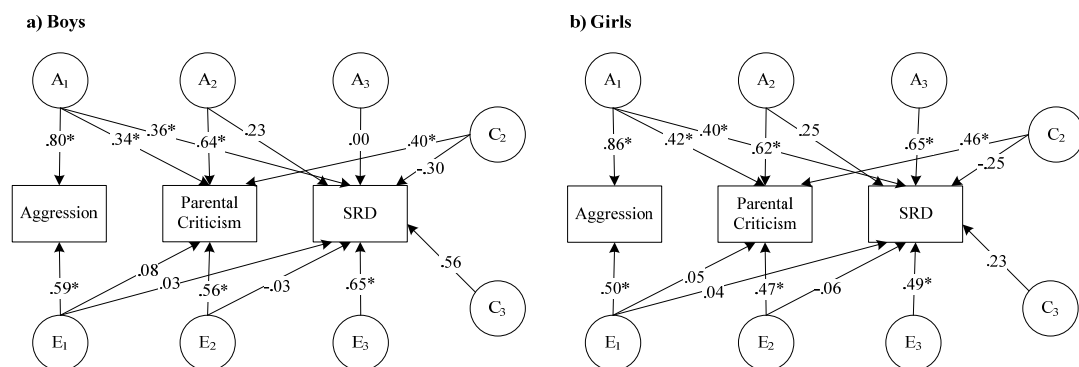


Figure 6. Standardized parameter estimates of trivariate Cholesky decomposition, for boys (a) and girls (b).

The parameters for genetic and environmental effects were also recovered properly (results not shown). Standard errors of estimates varied between 0.01-0.09, 0.02-0.25, and 0.01-0.11 for equal genetic and environmental effects, genetic predominant and environmental predominant variance structures, respectively.

Additional scenarios of simulations were also run to test the ECOT model more extensively. First, the simulations were run by generating a larger sample size, 4,000 individuals in total. In these simulations the parameter estimates more closely approximated the true value of the parameter, which suggests that the estimates provided by ECOT model are consistent.

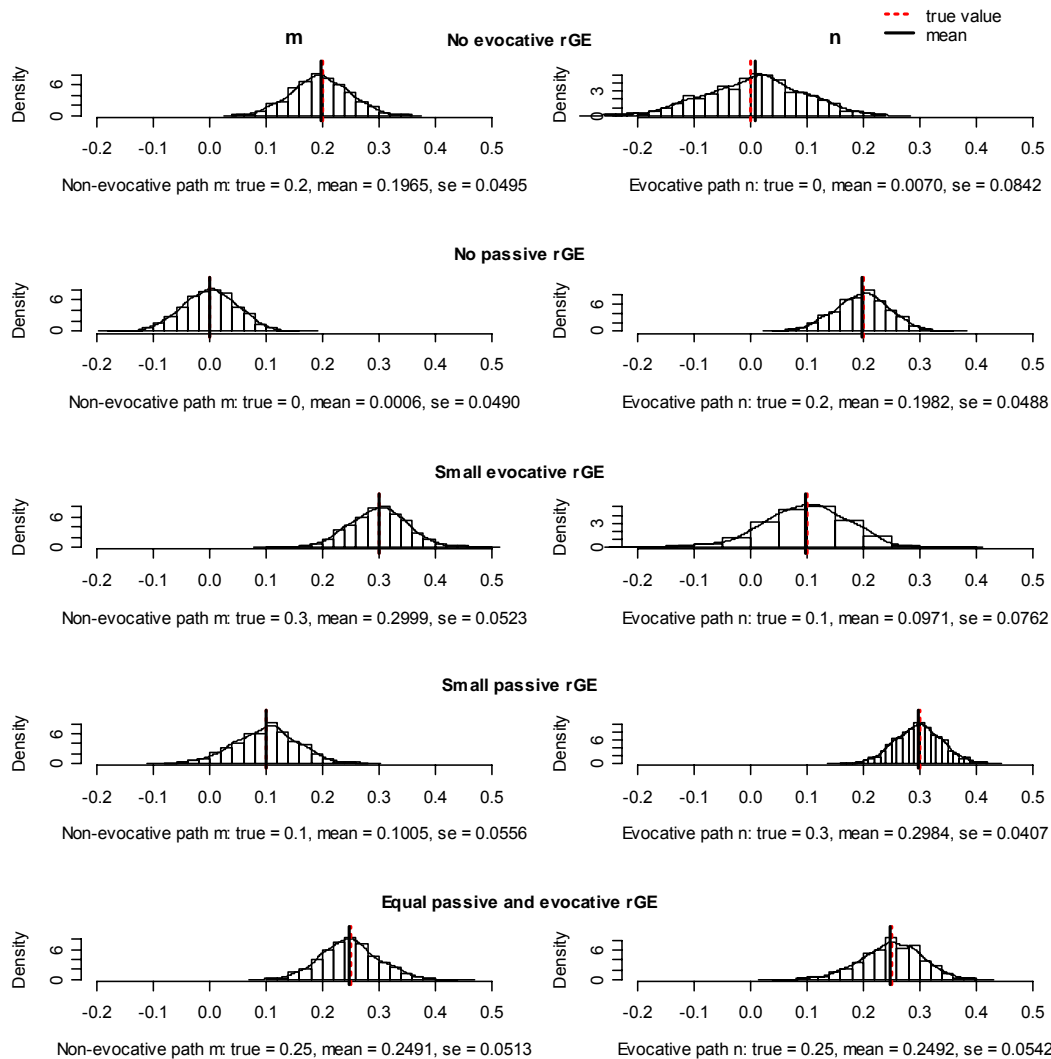


Figure 7a. Results of simulations: the phenotypes were influenced equally by genetics and environment. The dashed line indicates the true parameter value and the solid line denotes the mean of all parameter estimates. Every row of pictures represents the simulation with different values of m and n paths, reflecting different scenarios of rGE presence.

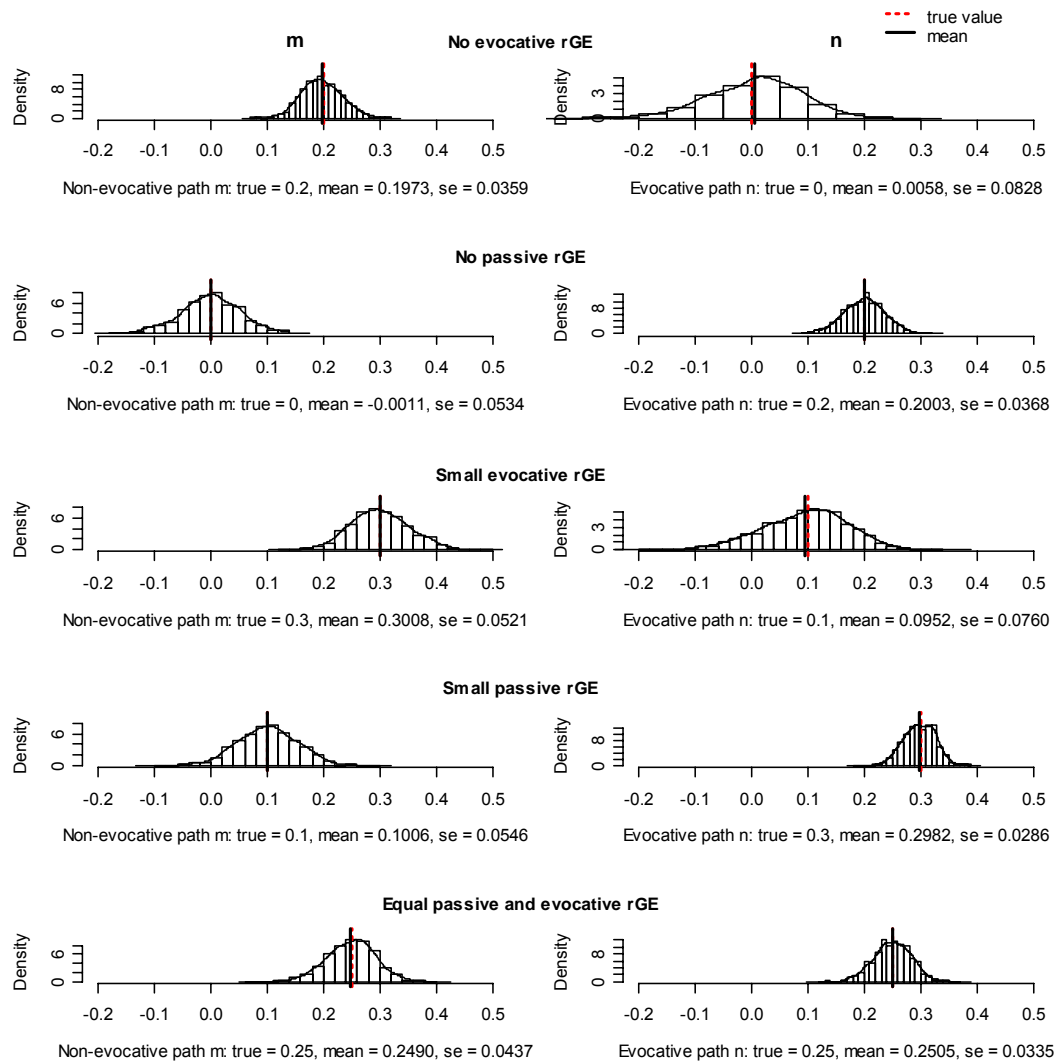


Figure 7b. Results of simulations: genetic predominant variance structure of the phenotypes.

Second, the ECOT model was evaluated by studying phenotypes that were different for parents and children in their variance structure. The phenotypes were again generated to be influenced either equally by genetic and environmental effects or genetic/environmentally predominant. But this time the phenotypes were chosen of one variance structure for parents and of another variance structure for children. For example, there could be genetic predominant phenotype for parents and environment predominant phenotype in children. Eventually, we ended-up with nine different simulation scenarios. The results showed the same tendency as when including both parental and children phenotypes of equal inheritance mode: the model recovered the true values of parameters with high precision.

Third, we investigated whether the ECOT model was tenable when the parental phenotypes also were influenced by shared environment. The simulation procedure was therefore repeated with the model including the shared environment parameter for parents (C1). That is, in this scenario both parental and child phenotypes were influenced by shared environment. The precision of recovery of reciprocity parameters was lower, revealed primarily by higher standard deviations (range from 0.03 to 0.15). Also, for some alternatives of variance structure the model was difficult to estimate because of the optimization problems. This may depend on the sample size. The simulations here were performed on sample size of 2000. However, Heath and colleagues (Heath et al., 1993) showed that when both genetic and shared environmental effects are influential on each phenotype, sample sizes should range from ~4000 to ~27,000 of individuals to reach power for resolving unidirectional causal hypotheses (depending on the size of the true effect).

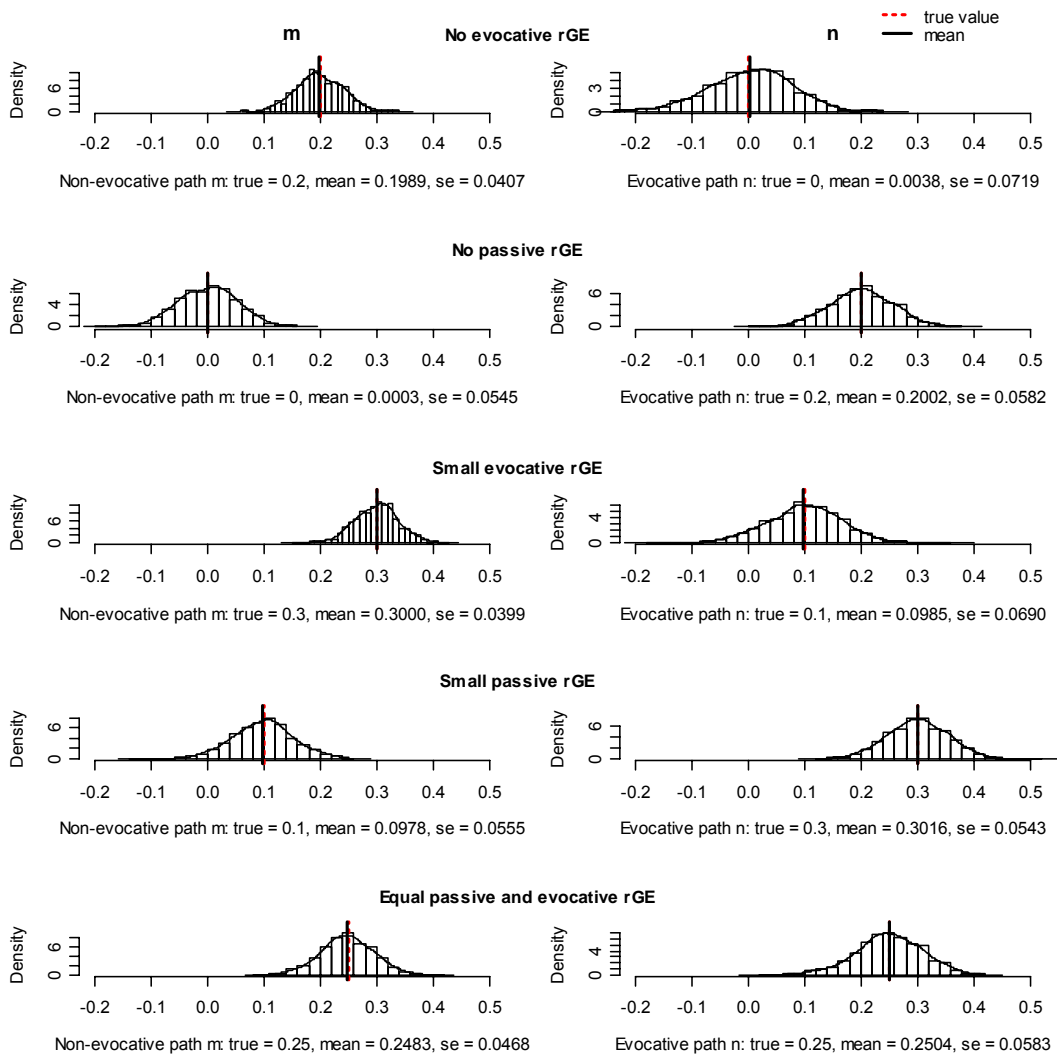


Figure 7c. Environment predominant variance structure of the phenotypes.

MATERNAL EMOTIONAL OVERINVOLVEMENT AND INTERNALIZING BEHAVIOR

The ECOT model was applied to study the association between emotional overinvolvement in mothers and child internalizing behavior in Paper II. The best-fitting estimated ECOT model including maternal emotional overinvolvement (EOI) and child internalizing problems is presented in Figure 8. The parameter estimates are standardized and unsquared. Following path tracing rules, squared parameter estimates provide the amount of variance accounted for (Loehlin, 1998). The findings suggest that EOI is heritable ($a1^2=0.76^2=0.58$). The genetic effects important for EOI also contributed significantly to Internalizing problems (7%). However, since the direct environmental path m was not significant, the passive rGE seemed to be less influential in the development of the relationship. It is also less likely that mothers, by getting more emotionally overinvolved, directly affect the levels of internalizing problems in adolescents. Child-specific genetic factors contributed to the variance of Internalizing problems by 28%. Together with a significant evocative path n , this supports the hypothesis of evocative rGE. Thus, adolescent internalizing problems seem to evoke emotional overinvolvement in their mothers.

GENOTYPE-ENVIRONMENT CORRELATION IN PATERNAL AND MATERNAL CRITICISM

Paper III aimed to study the type of rGE underlying the association between parental criticism and adolescent externalizing behavior, in fathers and mothers. The unsquared and

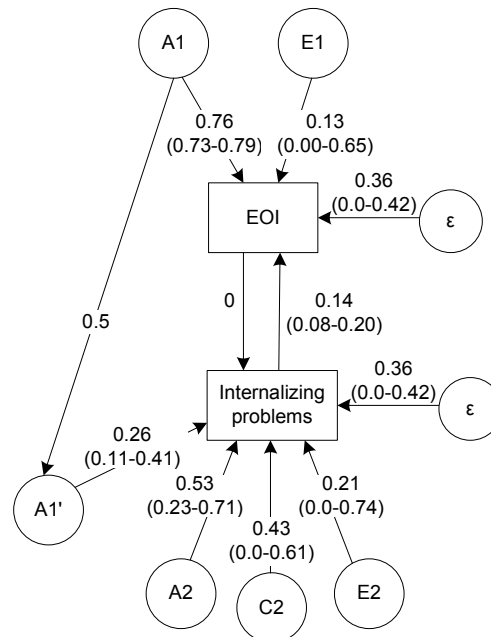


Figure 8. Estimated ECOT model for maternal emotional overinvolvement (EOI) and child internalizing problems.

standardized parameter estimates of the best-fitting ECOT model for fathers and mothers are presented in Figures 9a and b. For both fathers and mothers Parental Criticism was heritable ($a1^2=0.62^2=0.38$ for fathers; $a1^2=0.70^2=0.49$ for mothers). Parental genetic effects were not important for Externalizing Problems in fathers' subsample, suggesting that passive rGE is less likely to explain this association. Child specific genetic factors contributed to Externalizing Problems by 45%, but since the evocative path could be dropped from the model, the hypothesis of evocative rGE was not supported. Instead, the association tended to be explained by direct environmental effects, as paternal Criticism significantly contributed to the variance of Externalizing Problems ($m^2=0.28^2=0.08$ or 8%). For mothers, parental genetic factors explained 11% ($.33^2$) of the variance, whereas Parental Criticism contributed by 1% to the variance of Externalizing Problems ($m^2=(-.09)^2=0.01$). Given such a minor effect of Parental Criticism on Externalizing Problems, some part of the association between maternal Criticism and Externalizing Problems seems to be merely explained by genetic correlation rather than passive rGE. The role of evocative rGE seemed to be more prominent, primarily due to a larger effect of Externalizing Problems on maternal Criticism (9%).

In sum, the pattern of findings for fathers suggests that paternal criticism influence Externalizing Problems in adolescents through direct environmental processes: higher levels of critical remarks from fathers tend to increase level of externalizing behavior problems in adolescents. For mothers, on the other hand, some degree of the association is explained by a genetic correlation, while a larger portion is accounted by evocative rGE. That is, maternal criticism towards the adolescents appears to be evoked by adolescent externalizing behavior.

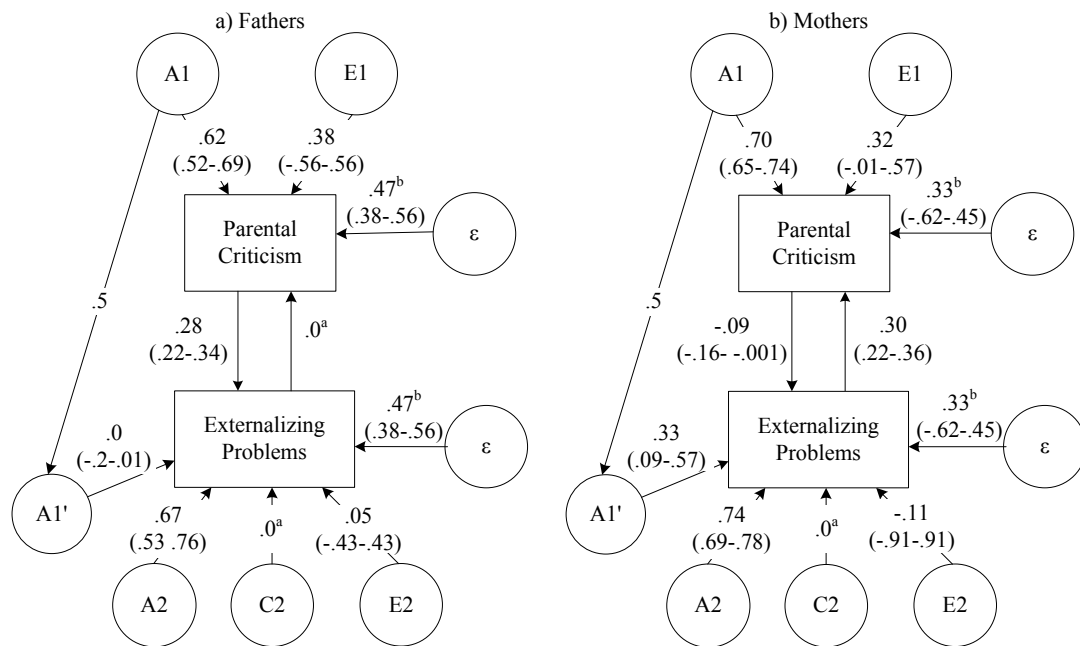


Figure 9. Best-fitting ECOT model for fathers (a) and mothers (b). Note: ^a Parameter was fixed to zero; ^b The estimate is squared.

ETIOLOGY OF THE DEVELOPMENT OF ANTISOCIAL BEHAVIOR

In Paper IV, the levels of externalizing and antisocial behavior were measured at ages 8-9, 13-14, 16-17, and 19-20 years. The model-fitting procedure revealed that the data were explained in the best and the most parsimonious way by the Common Pathway model (result of model-fitting comparison not shown) (Figure 10). The pattern of common genetic and environmental influences on the latent factor, labeled as *Persistent Antisocial Behavior*, was similar for both males and females. The common latent factor was mainly explained by genetic effects (69%), with moderate shared environmental (25%) and less influential nonshared environmental (6%) effects.

For males, age-specific variance was mainly accounted by nonshared environmental influences, ranging from approximately 30% to 65% at each measurement occasion. In addition, the variance of externalizing behavior at age 8-9 was also influenced by genetic effects (72%), and for antisocial behavior at age 13-14 there were some shared environmental effects, 25%.

For females, age-specific genetic and nonshared environmental effects contributed significantly to each variable. There were also some measurement-specific shared environmental influences (C_s) for antisocial behavior at age 13-14 years.

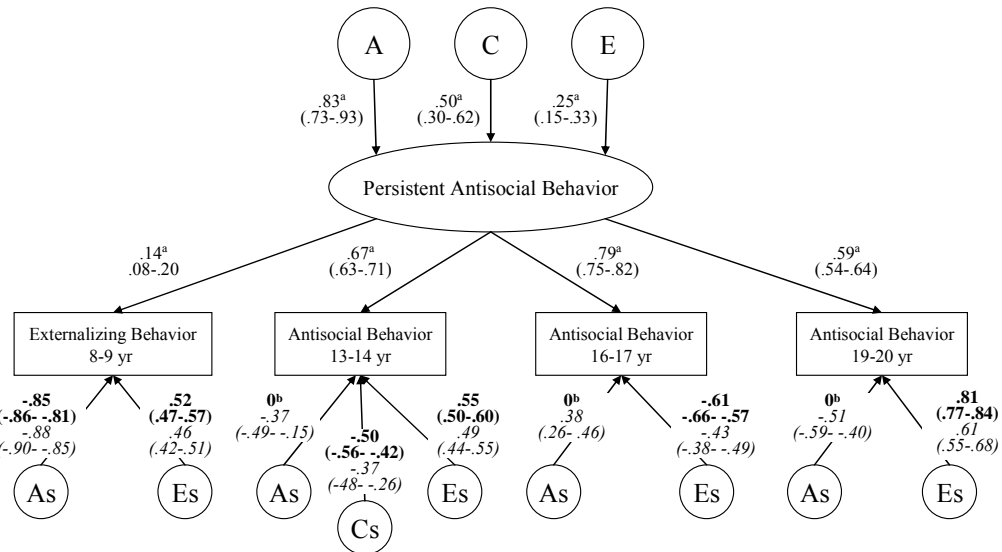


Figure 10. Standardized parameter estimates of the Common Pathway model for males (in bold) and females (in italics). ^a Estimates are the same for males and females; ^b Parameter was fixed to zero.

DISCUSSION

This thesis aimed to increase our understanding about the mechanisms involved in the development of the association between adverse parental behavior and behavior problems in adolescents. The main findings concern aspects of etiology of antisocial behavior as well as the role of genotype-environment correlation in the association between parenting practices and adolescent maladjustment.

DEVELOPMENT OF ANTISOCIAL BEHAVIOR

Findings of Paper IV revealed that the development of externalizing and antisocial behavior from childhood to early adulthood may be defined by a latent persistent antisocial behavior, for both males and females. This latent factor is to a large extent influenced by genetic effects, with a lesser influence of environmental effects.

These results are in agreement with earlier reports of longitudinal studies on externalizing and antisocial behavior (Bartels et al., 2004; Jacobson et al., 2002; Silberg et al., 2007; van Beijsterveldt, Bartels, Hudziak, & Boomsma, 2003). In these studies, the stability of antisocial behavior throughout the development was reported to be influenced by genetic and/or shared environmental factors. However, the development of antisocial behavior was usually followed in shorter time periods, either from childhood to adolescence or from adolescence to adulthood. Findings that the persistent antisocial behavior seems to last from childhood to early adulthood is an important contribution to our knowledge about etiology of antisocial behavior.

Evidence for common genetic and/or common shared environment on the persistent antisocial behavior is in line with Moffitt's developmental taxonomy. According to it, persistent antisocial behavior is associated with individual level risk factors, for example, neurodevelopmental impairment and adverse family environment that may be mediated through genetic and/or shared environmental influences.

Genetic effects contributed to the variance of the latent factor of persistent antisocial behavior by almost 70%. Genetic effects on antisocial behavior are generally thought to act indirectly through temperament and personality traits, such as impulsivity, stimulation-seeking, or fearlessness (Raine, 2002). On the other hand, genetic influences may also be explained by biological markers or endophenotypes. These include, for example, low resting heart rate, low cortisol or serotonin levels (Caspi et al., 2002; Moore, Scarpa, & Raine, 2002; Ortiz & Raine, 2004; Popma & Raine, 2006). Another approach to understand the underlying genetic mechanism in antisocial behavior includes gene identification. Despite the interest in gene identification studies of human behavior, this research is still in its infancy, particularly with regard to studies of antisocial behavior. Only a few studies have to date reported findings of an association between genes (MAO-A, COMT, and CHRM2) and some form of externalizing behavior (Brunner, Nelen, Breakefield, Ropers, & van Oost, 1993; Caspi et al., 2008; Dick et al., 2008; Thapar, O'Donovan, & Owen, 2005). Finally, it is important to note that genetic influences on the antisocial behavior may also include the effect of evocative rGE.

In addition to a strong evidence of genetic effects, a shared environmental factor was also found to explain the persistent antisocial behavior that lasts from childhood to early adulthood. Shared environment accounted for about 25% of the total variance in both males and females. There are different factors that may explain shared environmental experiences. Family-related risk factors may include poor child-rearing practices or adverse family environment (Farrington, Barnes, & Lambert, 1996). Outside the family, belonging to the same delinquent group is attributable to peer-related factors (Farrington & Loeber, 2000). Finally, shared environmental effects may be explained by contextual factors, such as neighborhood disadvantage (Sampson, Raudenbush, & Earls, 1997). Again, shared environmental influences may be inflated due to the passive rGE. The role of passive and evocative rGE in the development of antisocial behavior as in relation to parenting is further discussed in the next sections.

Familial factors, that is, genetic and shared environmental influences, accounted for over 90% of the total variance of the persistent antisocial behavior throughout the development. This contrasts the findings of the meta-analysis of twin and adoption studies, where the familial factors were reported to explain 57% of the total variance of antisocial behavior (Rhee & Waldman, 2002). Larger impact of genetic factors on the persistent antisocial behavior may depend on the fact that, contrary to cross-sectional studies, the common pathway model partitions measurement error away from variance in the latent persistent antisocial behavior factor. However, part of the time-specific nonshared environmental effects may also reflect true time-specific environmental effects, consistent with the adolescence-limited trajectory.

GENOTYPE-ENVIRONMENT CORRELATION

Papers I, II, and III addressed, directly or indirectly, the question of rGE in the association between adverse parental behavior and adolescent behavior problems. Both Paper I and III have examined the parental criticism and antisocial behavior, although using different study designs. In Paper II, the performance of the ECOT model was demonstrated by studying emotional overinvolvement in mothers and adolescent internalizing problems.

Parental criticism and antisocial behavior

Heritable child aggression precedes parental criticism and antisocial behavior

Findings of Paper I suggested that the association between parental criticism and antisocial behavior in adolescents is explained by genetic effects emanating from children. Further, these genetic effects were partly mediated by earlier expressed adolescent aggression.

Results of the bivariate Cholesky decomposition showed that genetic contributions to the association between Parental Criticism and SRD explained, in principle, all of the phenotypic correlation. The environmental effects were less important for the association. These findings partly confirm the results from previous studies showing that genetic effects originating from the child are important for the association between negative parenting and antisocial behavior (Jaffee et al., 2004; Neiderhiser et al., 1999; Pike et al., 1996). The genetic contributions to the association suggest that parental criticism may vary as a consequence of heritable traits in child. That is, inherited child characteristics may evoke

parental criticism, which, in turn, is related to further adolescent behavior problems. This type of process is consistent with evocative genotype-environment correlation.

The trivariate analyses revealed that about half of the association between Parental Criticism and SRD could be explained by the genetic effects contributing to the adolescent aggression measure 3 years earlier. It is important to note, that an equally large proportion of the genetic contributions to the association was independent of Aggression. The results suggest that the origins of the association between negative parenting and antisocial behavior may partly be found in previously expressed aggression in childhood. In terms of evocative genotype-environment correlation, aggressive children (genetics) tend to receive more critical comments from their parents (environment) leading to further more serious behavior problems in adolescence. This sequence of events is also consistent with coercive cycles described by Patterson (1980). These cycles appear when aggressive children receive less effective parenting, which in turn leads to more severe behavior problems.

About half of the genetic contributions to the association between Parental Criticism and SRD were not mediated by earlier measured Aggression. These genetic factors may be attributable to other potential mediators. That is, some other heritable child traits that may elicit more critical parental behavior and that influence the development of antisocial behavior. For example, psychopathic personality traits, such as grandiose/manipulative or callous/unemotional, are highly heritable and are good predictors of the later antisocial behavior (Larsson, Andershed, & Lichtenstein, 2006).

Genetic effects on the association that were unexplained by Aggression could also be attributable to passive rGE. Passive rGE appears mainly because of gene overlap between the family members together with common environmental experiences. Gene overlap (r_g) between Aggression and Parental Criticism was about 50%. This suggests that parenting is not only environmental factor for children, but there might also be a pleiotropic relationship between genes contributing to parenting style and genes contributing to vulnerability for child's aggression. Accordingly, the interpretation of the results as evocative genotype-environment correlation could instead be a manifestation of genes shared between parents and children. However, the shared environmental influences on Parental Criticism were rather modest. It therefore less likely that passive genotype-environment correlation could entirely explain the results.

The ECOT model

The ECOT model can be used to examine the genotype-environment interplay in the association between parental behavior and child adjustment. The ECOT model combines data from two different studies and therefore can make the maximal use of studies with moderate sample sizes, which is what is usually available in studies with detailed measures of parenting and child adjustment. By applying the ECOT model, it is possible to test for three possible processes involved in the association: (a) the direct influence of parenting on child adjustment, which is independent of the parent's or child's genotype; (b) passive genotype-environment correlation; (c) evocative genotype-environment correlation. The results of the simulations revealed that the ECOT model was stable and recovered the true parameter values with high precision. The model was robust to different variance structures

and was able to adequately recover both the presence and absence of the evocative and nonevocative paths when passive or evocative rGE was present or absent. The ECOT model also performed well when small effects of rGE were present. In general, the ECOT model is a reliable tool for disentangling different types of rGE, at least when having descent sample sizes and when there is no evidence for shared environmental influences in the parenting phenotype

Different mechanisms explain adverse mothering and fathering in relation to adolescent externalizing behavior

The findings of evocative rGE in Paper III suggest that mothers seem to be more critical as a response to the adolescents' behavior. Some part of this association was also attributable to genetic correlation between maternal criticism and adolescent externalizing problems. On the other hand, fathers' criticism tended to affect their adolescents' externalizing behavior by environmental mechanisms.

The findings of different processes involved in the association between mother or father-child relationships and externalizing problems in adolescents are consistent with the results of earlier non-genetically informative studies. A meta-analysis performed by Rothbaum and Weisz (1994) revealed that the association between parental caregiving 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, are more involved with their children. A more involved parent is more likely to get more influenced by or have a greater influence on the child. Thus, maternal criticism as a response to the behavior of their children and environmental effect among fathers may possibly reflect 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 tend to create more opportunities for mothers to get exposed to conflicts with their child that eventually may elicit critical mothering. 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.

Different maternal and paternal involvement was also discussed in a recent qualitative Swedish study of involved fatherhood (Forsberg, 2007). In this report, despite their ambitions to follow the gender-equal childcare and household work, middle-class fathers were found not to be involved with their children to the same degree as the mothers. Absence of gender-equality in parental involvement is explained by a tendency that fathers are more child-centered (i.e., playing and talking to the children) rather than being responsible for childcare and household work (Bekkengen, 2002). This interpretation is consistent with the official statistics about part-time working parents (25% were mothers and 5% were fathers) and parental benefits drawn due to child sickness (64% of mothers and 36% of fathers) in Sweden (Statistics Sweden, 2006). Compared to the results of Paper

III, fathers that are less involved in care of externalizing children might be more critical than mothers, which, in turn, promote problem behavior.

Findings consistent with evocative rGE in the association between maternal criticism and externalizing behavior problems were reported in several earlier studies (Burt, McGue, Krueger, & Iacono, 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 parents' negativity and adolescent antisocial behavior (Larsson, Viding, Rijdsdijk, & Plomin, 2008; Pike et al., 1996), as well as mothers' negativity itself (Neiderhiser et al., 2004). In a report by Burt and colleagues (Burt et al., 2005) the relationship between mother-child conflict and child externalizing behavior was 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).

Evidence for evocative rGE in mother-adolescent relationships is in line with the coercion theory suggested by Patterson (Patterson, 1980) According to this theory, aggression in children may be reinforced by the behavior of their parents, which, in turn, further elevates 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 Paper III is that child externalizing behavior tends 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". That is, being heavily 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 results of Paper III, 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.

Findings reported in Paper I suggested that the association between parental criticism and antisocial behavior was explained by evocative rGE. In Paper III, the evocative rGE was shown to be relevant for maternal but not paternal criticism. The discrepancy in findings may depend on the fact that the number of fathers that participated in TCHAD study was rather small as compared to the number of participating mothers. The results of Paper I may therefore be more reflective of the association between maternal criticism and adolescent antisocial behavior.

Adolescent internalizing problems evoke emotional overinvolvement in mothers

In Paper II, the ECOT model was applied to examine the processes involved in the association between maternal EOI and internalizing problems in adolescents. The results suggested that the association was likely to be primarily regulated by evocative rGE. That is, mothers, experiencing their children as anxious, withdrawn, or depressed, tended to get

more emotionally overinvolved in their parenting. Findings consistent with the evocative nature of this association were also reported in two earlier studies. A study by Reitz, Dekovic, and Meier (2006) found that adolescents who showed higher levels of internalizing problems were parented with higher involvement, which further increased the problem behavior 1 year later. A different evocative effect was reported in a study by Brennan and coauthors (2003), where nondepressed and emotionally overinvolved mothers seemed to have a protective effect for child behavior problems.

In the same study of Brennan and coauthors (2003), depressed and emotionally overinvolved mothers were, on the other hand, associated with decreased levels of resilient outcomes in youths. This finding may be consistent with passive rGE, where problem behavior in children could depend on both inherited genetic liability to depression and overprotective parenting. Similarly, passive rGE may explain the results of Hirshfeld et al. (1997), in which high maternal EOI was associated with separation anxiety disorder only in children of mother with a history of anxiety disorders. Rather contradictory suggestions of the type of rGE underlying the association between maternal EOI and internalizing problems in children may reflect the importance of the mother's previous psychopathology. That is, different processes may be involved in the development of the association depending on the earlier maternal depression or other disorders.

Evidence for evocative rGE was also suggested in a report by Moberg and coauthors (Moberg, Lichtenstein, Forsman, & Larsson, submitted) where the association between parenting and internalizing behavior problems were examined longitudinally. However, the evocative processes were found to be influential only for the development of internalizing problems among girls. For boys, environmental factors were more important. Further research is obviously needed to clarify sex-differences in the genotype-environment interplay.

In sum, findings of Paper I, II and III suggest that mechanisms involved in the association between negative mothering and adolescent behavior, both internalizing and externalizing, are consistent with evocative rGE. Evidence for evocative rGE in the association between negative parenting and externalizing problems has been a common pattern of results in a number of previous studies. However, findings of evocative processes underlying internalizing problems are rather innovative. Nevertheless, suggestions of the similar mechanisms involved in the development of externalizing and internalizing problems are not unexpected. Internalizing and externalizing problems were shown to often appear and develop together (e.g., Capaldi, 1991; Gilliom & Shaw, 2004; Lilienfeld, 2003). Also, several genetically informative studies have identified a common genetic liability underlying the covariation between these types of problem behavior (e.g., Pesenti-Gritti et al., 2008; Jaffee, Moffitt, Caspi, Taylor, & Arseneault, 2002; O'Connor, McGuire, Reiss, Hetherington, & Plomin, 1998).

METHODOLOGICAL CONSIDERATIONS

The equal environment assumption

The twin method assumes that environmentally caused similarity for the studied trait is roughly the same for both MZ and DZ twins reared in the same family (Plomin et al.,

2001). If this assumption does not hold, the greater resemblance among MZ twins, as compared to DZ twins, may be attributable not only to hereditary but also to environmental effects. As a result, the heritability estimates become biased upwards. One way to test the validity of the equal environment assumption (EEA) is to examine whether the trait of interest is influenced differently by perceived versus correct twin zygosity. That is, fraternal twins that view themselves as monozygotic may also expect to be more similar or be treated more similarly by others. EEA has been tested in several studies and was found to be tenable for a number of psychiatric disorders (e.g., major depression, generalized anxiety disorder, phobia, and alcohol dependence) (Kendler, Neale, Kessler, Heath, & Eaves, 1994), including childhood and adolescent psychopathology (e.g., anxiety disorder, attention-deficit/hyperactivity disorder, oppositional defiant and conduct disorders, and aggression) (Cronk et al., 2002; Derks, Dolan, & Boomsma, 2006).

In this thesis, the EEA was tested for externalizing problems and antisocial behavior in the TCHAD sample. Twins that perceived themselves of a different zygosity, did not differ significantly from the twins with “correctly” perceived zygosity, either for externalizing behavior or for antisocial behavior ($p > 0.19$ for both misperceived MZ and DZ twins). The EEA seems therefore to hold for both these phenotypes in TCHAD sample.

Assortative mating

The twin method also assumes random mating in parent generation. Non-random or assortative mating refers to phenotypic similarity between mates, which is indicated by a significant correlation between spouses for a particular trait (Maes et al., 1998). Assortative mating tends to increase the resemblance between DZ twins and thereby bias heritability estimates downward and shared environmental estimates upward. The magnitude of assortative mating has been reported to be modest for major psychiatric disorders as well as antisocial behavior (Maes et al., 1998; Maes, Silberg, Neale, & Eaves, 2007; Taylor, McGue, & Iacono, 2000). However, a few studies found a significant effect of assortative mating for self-reported antisocial behavior (Krueger, Moffitt, Caspi, Bleske, & Silva, 1998) and violent offending (Frisell, Lichtenstein, & Langstrom, submitted).

In the TCHAD sample, parents of the twins participating were asked to retrospectively report their antisocial behavior in their early twenties. A correlation between mothers and fathers on antisocial behavior was found to be 0.15 ($p < .01$), possibly indicative of an effect of assortative mating in the TCHAD sample. The estimates of heritability and shared environmental estimates might therefore be somewhat biased in Paper I and IV. Also, the effect of passive rGE could be underestimated in Paper II and III. However, the limited number of parents responding at wave 4 of TCHAD should also be kept in mind.

Generalizability to singletons

It is sometimes questioned whether the results coming from twin samples are generalizable to the general population. Twins, as compared to singletons, usually experience different intrauterine and family environments and therefore may also differ in the development of various diseases. A number of studies showed that twins and singletons experience similar rates of psychiatric disorders as well as behavioral and emotional problems (Moilanen et

al., 1999; Pulkkinen, Vaalamo, Hietala, Kaprio, & Rose, 2003; van den Oord, Koot, Boomsma, Verhulst, & Orlebeke, 1995).

Aspects of the ECOT model

Cross-sectional data

In this thesis, the ECOT model was applied to analyze cross-sectional data. The findings of Paper II and III therefore reflect only a particular time in the development of parent-child relationships. However, the heritability of, for example, antisocial behavior is widely reported to change over time. Thus, it is highly expectable that the association between negative parenting and adolescent antisocial behavior is due to different mechanisms at different time-points, too. This hypothesis is partly supported by two earlier longitudinal studies of the relationships between negative parenting and adolescent adjustment over time (Larsson et al., 2008; Burt et al., 2005). Their findings suggested that the association is of bidirectional nature, influenced by both evocative and environmental processes (Larsson et al., 2008; Burt et al., 2005). The ECOT model could be further extended to a longitudinal model to gain more knowledge on what mechanisms are more influential at particular periods of the development of parent-child relationships.

The longitudinal version of the ECOT model could also help to distinguish between rGE and GxE in the association between negative parenting and adolescent problem behavior. A study by Feinberg and colleagues (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 the observed association between maternal criticism and adolescent antisocial behavior in Paper III.

Dyadic parental treatment

In contrast to individual parental traits, dyadic parental phenotypes are aggregated parental behavior influenced by both parents. For example, both parents tend to be involved and participate in marital conflict or divorce. The effect of dyadic parental phenotypes on child adjustment could be examined by applying the children-of-twins design. However, children-of-twins models including only one parent were suggested to be applied with caution when studying this type of phenotypes. Specifically, for dyadic parental treatment measures, this type of models is unable to reliably differentiate between the direct environmental effect and association due to genetic effects (Eaves, Silberg, & Maes, 2005). In Paper II and III, neither emotional overinvolvement nor parental criticism are directly defined as dyadic measures (i.e., influenced by both parents). However, it is possible that these measures are to some extent affected by the other parent's behavior. The results of Paper II and III should therefore be replicated by including both parents in the analyses.

Definition of passive rGE

In Paper III, the ECOT estimation results showed that genetic effects contributing to maternal criticism added significantly to the explanation of externalizing behavior in

adolescents. In other words, some genes seemed to be important for both of these phenotypes in both generations. Such pattern of a genetic correlation without any environmental effect of parents on children is sometimes interpreted as a passive rGE (e.g., Price & Jaffee, 2008). However, 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, personal communication; 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 the genetic overlap between parents and their children is referred to as a genetic correlation (Eaves, personal communication), rather than rGE.

FUTURE DIRECTIONS

During the past decades the number of studies investigating differences in mothering and fathering has remarkably increased. However, there is still a need of further genetically informative studies that have a possibility to investigate the mechanisms involved in the development of mother-child and father-child relationships. Research also indicates that the association between harsh parental disciplines and child problem-behavior is strongest for the same-gender parent-child relationship. Processes involved in each parent-child dyad could successfully be examined in large longitudinal studies, employing data collected not only on twin but also on sibling families.

Findings of Paper III suggests that parenting training programs for mothers might be more effective if they focused on changing the way mothers respond to their children, whereas it might be a more successful strategy to attempt to change parental behavior in general in programs for fathers. Thus, specific aspects of parenting that needs to be covered in mothering and fathering programs should be investigated in future reports. For example, more knowledge on the origins of the paternal involvement in childcare could be gained by examining whether father's negativity is mediated by, for example, less knowledge about child development or age-specific behaviors (Nix et al., 1999).

A substantial amount of research has focused to identify the biological markers (i.e., endophenotypes) for antisocial behavior. Low resting heart rate, low cortisol or serotonin levels were found to explain variability in levels of antisocial behavior. Studies of endophenotypes are also important to understand the development of the association between negative parenting and antisocial behavior. For example, a recent study reported that the association between harsh parenting and externalizing behavior in children was stronger among children with lower skin conductance level reactivity (i.e., less sensitive to aversive or punishing circumstances) than compared to children with higher levels of this marker (Erath, El-Sheikh, & Mark Cummings, 2009). Finding evidence for other moderators of the association between negative parenting and antisocial behavior will help to identify the more vulnerable group of children and, hopefully, to improve prevention strategies for antisocial behavior.

CONCLUSIONS

- Persistent antisocial behavior that lasts from late childhood to early adulthood is to a large extent influenced by familial factors in both males and females;
- Genetic contributions to the association between parental criticism and adolescent antisocial behavior are partly explained by earlier expressed adolescent aggression;
- The ECOT model was shown to be a reliable tool to examine genotype-environment interplay in the association between parental behavior and child adjustment;
- Mothers tend to get more emotionally overinvolved in their parenting as a result of internalizing behavior problems in their children;
- Different processes explained the association between parental criticism and adolescent externalizing behavior, in mothers and fathers. Externalizing behavior problems in adolescents tended to elicit critical behavior in mothers. In contrast, paternal criticism was shown to affect the development of adolescent externalizing behavior in a direct environmental way.

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