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Gene – Environment Interplay, Family Relationships, and Child Adjustment

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Abstract

This paper reviews behavioral genetic research from the past decade that has moved beyond simply studying the independent influences of genes and environments. The studies considered in this review have instead focused on understanding gene – environment interplay, including genotype – environment correlation (rGE) and genotype × environment interaction (G × E). Studies have suggested that rGE is an important pathway through which family relationships are associated with child adjustment. Also important are direct causal influences of family relationships on child adjustment, independent of genetic confounds. Other studies have indicated that genetic and environmental influences on child adjustment are moderated by different levels of family relationships in G × E interactions. Genetically informed studies that have examined family relations have been critical to advancing our understanding of gene – environment interplay.

Keywords

childhood/children; family; marriage and close relationships; parenting

Well-established literature documents that the emotional quality of family relationships is linked to child-adjustment outcomes. For example, one of the most studied family relationships is the parent – child relationship. Numerous studies have indicated that parental warmth and support are linked to better outcomes in children, and harsh and negative parenting tied to the development of children's behavioral and emotional problems (e.g., Crosnoe & Cavanagh, 2010; Demo & Cox, 2000; Fletcher, Steinberg, & Williams-Wheeler, 2004). Marital problems, including the dissolution of marriage and marital conflict, have also been tied to an increased likelihood of children developing adjustment problems (Amato, 2010; Cummings & Davies, 2002; Kouros, Merrilees, & Cummings, 2008). What is less clear from this work is the extent to which family relationships are linked to child adjustment through gene – environment interplay effects (e.g., Demo & Cox, 2000), including genotype – environment correlation (*r*GE) and genotype × environment interaction (G × E).

Until fairly recently, family relationships have been conceptualized in purely environmental terms without consideration of the role of the family members' heritable characteristics in directly influencing family relationships. Beginning in the 1980s, however, genetically informed samples of twin pairs were used to examine genetic and environmental influences on family relationships (e.g., Rowe, 1981, 1983). Because twins vary in regard to genes shared (identical [MZ—monozygotic] twins share 100% of their genes and fraternal [DZ—dizygotic] twins share 50%, on average) and, when reared together, also share environments, twin studies are commonly used to disentangle genetic and environmental influences. Typically, genetic influences, shared environmental influences (i.e., nongenetic influences that make family members similar), and nonshared environmental influences (i.e., non-genetic influences that make family members different, including measurement error) are estimated in behavioral genetic studies. This approach can be used to examine constructs like parenting, as first done by Rowe (1981), noted above.

When genetic influences on family relationships are identified, this is not an indication that an individual's genes directly impact the way that she is treated by her family members. Rather, genetic effects indicate that family relationships are influenced, at least in part, from an individual's heritable characteristics (*r*GE). We will describe how *r*GE operates in detail later. Early behavioral – genetic studies and many subsequent investigations have demonstrated that genetic influences contribute to family relationship constructs (e.g., Kendler & Baker, 2007; Reiss, 1995). Yet most behavioral genetic studies examining family relationships have found that shared and nonshared environmental influences explain as much or more variance as do genetic influences. Shared environmental influences on parenting indicate that parenting behavior is consistent across twins regardless of their genetic similarity. Nonshared environmental influences on parenting represent child-specific parenting that is not due to genetic differences in the twins. More recently, research has moved beyond the independent contributions of genes and the environment to understand how gene – environment interplay may operate. There is now strong evidence that family relationships arise from a complex interplay of genes (or family members' heritable characteristics) and the environment.

In this paper, we review literature from the past decade focused on understanding the role of gene – environment interplay in shaping family relationships and the association between family relationships and child adjustment. Two broad types of gene – environment interplay have been examined in this work, including *r*GE and G × E. Accumulating evidence suggests that *r*GE is a pathway through which parenting behaviors and marital conflict are linked to child adjustment outcomes; thus, we review this work first. Next, we review studies focused on G × E, where measures of family relationships are considered as moderators of genetic and environmental influences on child adjustment. We then describe research that has assessed how *r*GE is moderated by the environment (i.e., *r*GE × E). Avenues for future research examining how gene – environment interplay operates to shape family relationships and child adjustment are then presented. Finally, we address how behavioral genetic studies can inform prevention research (two fields that have been traditionally separate) to improve family relationships and child development.

Genotype – Environment Correlation

Studies demonstrating genetic influences on family relationships provide evidence of genotype – environment correlation. Genotype –environment correlation refers to individuals' heritable characteristics evoking or creating the emotional quality of their social world (Plomin, DeFries, & Loehlin, 1977; Scarr & McCartney, 1983). Given the numerous genetically informed studies that have demonstrated the contribution of genetic influences on family relationships (e.g., Kendler & Baker, 2007), it is clear that *r*GE is important. Therefore, the purpose of this section is to review research focused on understanding the role of *r*GE. We first present an emerging literature concentrated on disentangling the different types of *r*GE (i.e., passive and evocative *r*GE) shaping parenting behaviors. Briefly, passive *r*GE is the result of a parent and child sharing both genes and environments (e.g., Kendler, 1996). For example, a child may inherit both a tendency toward negative emotionality from a parent and be exposed to negative emotionality in her relationship with the parent. Thus, a child may be treated more negatively by the parent because of the parent's heritable negative emotionality. Alternatively, evocative *r*GE occurs when a child's heritable characteristics evoke a particular response from the social environment (e.g.

McGue, Elkins, Walden, & Iacono, 2005; Plomin, McClearn, Pederson, Nesselroade, & Bergeman, 1989). For example, a child high in emotional reactivity may evoke more negative responses from her parent and, in turn, more negative parenting than a child with a more easy-going temperament. (Another type of *r*GE, active *r*GE, results when a child actively seeks out environments that are associated with his heritable characteristics. For example, a child who is musically gifted for genetic reasons may ask his parents for music lessons. This review, however, focuses on passive and evocative *r*GE, as a child cannot select his parents.)

Several creative methodological tools have been used to help specify the type of *r*GE involved (i.e., passive or evocative or both). These include comparing findings from child-based and parent-based designs, bivariate biometric models, longitudinal biometric models, the Children of Twins (CoT) design, and the Extended Children of Twins (ECoT) design—all described in more detail below. Next, we review genetically informed research that has assessed how marital problems, including marital conflict and parental divorce, are associated with child adjustment. This research has concentrated on distinguishing the direct effects of the marital relationship on child adjustment problems from the effects of passive *r*GE. In this case, passive *r*GE refers to genetic influences that contribute to the correlation between marital difficulties and child adjustment. Methodological techniques that have been used to examine these associations include the CoT design and the adoption design.

Parenting

Accumulating studies using genetically informed strategies have examined how both parents and children influence parenting behaviors (e.g., Crosnoe & Cavanagh, 2010). These studies have often used univariate biometric models that disentangle the genetic, shared environmental, and nonshared environmental influences on a given variable, including parenting. When univariate biometric models have been used to examine parenting, genetic influences have been indicated, suggesting the influence of *r*GE (e.g., Kendler & Baker, 2007). Information about the type of *r*GE involved can be gleaned depending on whether children's genes or parents' genes are the unit of measurement. In research where children vary in their genetic relatedness (i.e., a child-based twin design), children's genes are the unit of measurement. Thus, genetic influences on parenting in a child-based design suggest that a child's heritable characteristics influence the way her parents treat her as in evocative *r*GE. Shared or non-shared environmental influences, or both (but not genetic influences), on the same parenting measure in a parent-based design suggest that evocative *r*GE may be operating. This is possible because a child's heritable characteristics influence the types of behaviors evoked from the parent independent of the parent's characteristics.

Alternatively, in research where the parents vary in their genetic relatedness (i.e., a parent-based twin design), the parents' genes are the unit of measurement. Thus, genetic influences on parenting in a parent-based design suggest that a parent's heritable characteristics are influencing the way he parents his child as in passive *r*GE. If shared or nonshared environmental influences, or both (but not genetic influences), on the same parenting measure are also found in a child-based design, passive *r*GE is suggested. This is possible because heritable characteristics of the parent influence the way the parent treats the child independent of the characteristics of the child. Therefore, an important strength of comparing child- and parent-based studies is that differences between these studies help to clarify whether evocative or passive *r*GE is operating. It is also likely that both or neither is operating.

A set of studies, comparing results from compatible child- and parent-based samples, attempted to specify the roles of both passive and evocative *r*GE on parental positivity, monitoring, negativity, and control (Neiderhiser et al., 2004; Neiderhiser, Reiss, Lichtenstein, Spotts, & Ganiban, 2007). Findings suggested that maternal positivity and monitoring occur as a result of the mothers' heritable characteristics, but maternal control and negativity occur in response to the adolescents' heritable characteristics (Neiderhiser et al., 2004). This was indicated by the detection of passive *r*GE for mothers' positivity and monitoring, but primarily evocative *r*GE for mothers' negativity and control (Neiderhiser et al., 2004). Some evidence indicated that both passive and evocative *r*GE were occurring simultaneously for mothers' behaviors (i.e., mothers' negativity). Many of these findings were consistent for fathers' parenting (Neiderhiser et al., 2007). Yet there were also some notable differences in mothers' and fathers' behaviors. In particular, whereas mothers' positivity was primarily ascribed to passive *r*GE, fathers perceived themselves as parenting more positively in response to their adolescents' heritable characteristics as in evocative *r*GE. The converse was true for negativity, with evidence of both passive and evocative *r*GE for fathers' reports of their negative parenting and primarily evocative *r*GE for mothers' negativity. A limitation of these two studies is that although it is possible to compare and contrast the findings from the child- and parent-based studies, they are not nested. Differences in the pattern of findings for these two samples can only suggest which types of *r*GE may be operating. It is only by examining a sample that allows for child-and parent-based analyses within the same study that conclusions can be drawn with confidence. Nevertheless, these studies represent an important step in advancing our understanding of the role of *r*GE processes influencing parenting.

Parenting and child adjustment

Other work has used bivariate biometric models with child-based designs to examine genetic and environmental influences on associations between measured environments and child adjustment. This type of analysis also helps to clarify if *r*GE is operating and, in longitudinal designs, can help to specify the direction of effects. Bivariate biometric models are an extension of univariate models because they allow for the assessment of genetic and environmental contributions to two related variables. That is, bivariate models assess the extent to which genetic and environmental influences contributing to one variable (e.g., parenting) also influence a second variable (e.g., child adjustment). When bivariate models are used to examine how parenting is associated with child adjustment, the findings can help delineate the pathways underlying this association. Genetic influences contributing to the correlation between parenting and child adjustment indicate that heritable characteristics influencing parenting also impact child adjustment. As mentioned previously, this is best explained by evocative *r*GE in child-based designs. Specifically, a child's heritable characteristics evoke a response from her parent and influence her own adjustment. Both shared and nonshared environmental influences indicate environmental influences on child development, independent of genetic confounds (*r*GE), suggesting that family relationships have a causal influence. At the same time, shared and nonshared environmental influences suggest different pathways through which family relationships influence child development. Specifically, shared environmental influences on these associations illustrate that consistent parenting behaviors across siblings in the same family also influence similarities in the adjustment of each child. Thus, family-wide parenting behaviors lead to siblings' similar development. Evidence for shared environmental influences is consistent with the assumptions of much research on the impact of parenting on child functioning. Shared environmental effects could be due to factors like similarity in parenting and socioeconomic status. The presence of shared environmental influences within a child-based design can also be evidence of passive *r*GE. That is, a parent's heritable characteristics may contribute to consistent parenting of both siblings and both siblings' adjustment regardless of their genetic relatedness. Finally, nonshared environmental influences reflect that parenting behaviors unique to each child contribute to differences in the adjustment of each child. Nonshared environmental influences that contribute to the correlation between parenting and child adjustment may be due to things like differential parenting, child age and gender, and idiosyncratic factors in the child (e.g., an illness or injury).

Findings from such studies have often shown that genetic influences account for a large proportion of the correlation between parenting and child adjustment, with the remaining covariance being ascribed to varying degrees to shared or nonshared environmental effects, or both (e.g., Burt, Krueger, McGue & Iacono, 2003; Reiss, Neiderhiser, Hetherington, & Plomin, 2000). These findings are consistent across different dimensions of parenting and child adjustment, including parental warmth and positive child adjustment and parental negativity and child adjustment problems. The genetic effects illustrate that evocative *r*GE plays an important role in shaping the association between parenting and child adjustment. For example, a child's heritable characteristics may elicit parental negativity, which in turn may shape his adjustment problems.

To further clarify how both parents and children contribute to parenting behaviors and child adjustment, researchers have taken advantage of longitudinal biometric models using child-based designs (e.g., Burt, McGue, Krueger, & Iacono, 2005; Jaffee, Caspi, Moffitt, & Taylor, 2004). These longitudinal models are a creative extension of the bivariate biometric models, as they afford the assessment of genetic and environmental contributions to family quality and child development over time. Longitudinal models can also examine the bidirectional effects of parenting and child development. Specifically, it is possible to assess the degree to which parenting and child adjustment both influence and are influenced by each other. One such study demonstrated a bidirectional association between parent – child conflict and child externalizing behaviors over time, such that these variables independently predicted one another three years later (Burt et al., 2005). Parent – child conflict also exerted a direct environmental influence on children's externalizing behaviors, whereas these behaviors influenced parent – child conflict for genetic reasons. Another investigation sought to delineate the pathways underlying the association between parental physical maltreatment and children's antisocial behavior 2 years later (Jaffee et al., 2004). Results demonstrated that physical maltreatment prospectively predicted antisocial behavior, was not influenced by genetic factors, and was an environmental risk for the development of antisocial behavior. Therefore, findings suggest that physical maltreatment plays a causal role in the development of children's antisocial behavior; preventing maltreatment could prevent the development of this problem behavior. Findings from the bivariate and longitudinal biometric models illustrate that children's heritable characteristics influence parents' behaviors and child adjustment both concurrently and over time. The longitudinal studies also implicate parental negativity and physical maltreatment as direct environmental influences on child adjustment over time, independent of children's heritable characteristics.

A powerful approach for examining whether passive *r*GE is a mechanism through which parenting behaviors are linked to child adjustment is the children-of-twins (CoT) design (Rutter, Pickles, Murray, & Eaves, 2001; Silberg & Eaves, 2004). The CoT design compares differentially exposed offspring of MZ and DZ twins. A child of an MZ twin shares 50% of his genes with his parent and 50% with his parent's co-twin (the child's aunt or uncle). Conversely, a child of a DZ twin shares 50% of his genes with his parent and 25% with his parent's co-twin (like any niece or nephew and aunt or uncle pair). This design can thus help to distinguish direct environmental influences of parenting, passive *r*GE, and those unmeasured shared environmental factors making the parent co-twins similar (D'Onofrio et al., 2003; Rutter et al., 2001). Results from one such study revealed that offspring of twins who were exposed to harsh physical punishment from parents had greater antisocial problems compared to their cousins who were exposed to less harsh parenting (Lynch et al., 2006). Findings suggest a direct causal link between harsh physical punishment and children's problem behaviors. At the same time, the power to detect evocative *r*GE in the

CoT design is relatively weak because the offspring cousins share 25% and 12.5% of their genes, respectively. Given such a modest variation in the cousins' degree of genetic relatedness, the effects of children's genotypes influencing parenting are difficult to detect with reasonable sample sizes. Still, findings also underscore the value of the CoT model for disentangling mechanisms underlying the association between parenting and child adjustment.

More recently, a novel extension of CoT, the Extended Children of Twins (ECoT) model, combined multiple samples to facilitate the estimation of both evocative and passive *r*GE (Narusyte et al., 2008). The ECoT extends the CoT design to incorporate children who are twins within a single nested model. In this way, the ECoT design is able to capitalize on the full range of genetic variance for estimating the effects of the parents' genes (using the twin parents) as well as for estimating the effects of the children's genes (using the child-based twin sample as well as the cousin pairs from the parent-based twin sample). Thus, the ECoT design can distinguish evocative from passive *r*GE. The ECoT model includes two phenotypes: one describing parenting and one reflecting child adjustment. Both parenting and child adjustment are influenced by genetic, shared environmental, and nonshared environmental influences. Samples of twins who are parents and their children and samples of children who are twins and their parent(s) are used in this design. As such, reciprocal paths between parenting and child adjustment can be examined, and the genetic and environmental contributions to these reciprocal effects can also be estimated. When genetic influences contributed by the parent influence parenting and parenting, in turn, influences child behavior, passive *r*GE is indicated. In contrast, evocative *r*GE is indicated when genetic influences contributed by the child account for child behavior that in turn influences parenting (Figure 1).

Narusyte and colleagues (2008) applied this model to detect the direction of influence between maternal emotional overinvolvement and child internalizing behaviors. Findings revealed that genetic effects contributed by the child influenced internalizing behaviors, which in turn contributed to maternal emotional overinvolvement, suggesting the role of evocative *r*GE. Passive *r*GE was not involved, however, for genetic effects contributed by the mother influenced emotional over involvement, but emotional overinvolvement did not influence child internalizing behaviors in turn. Therefore, maternal emotional over involvement can be understood as a response that is evoked from the child's heritable internalizing behaviors. A noteworthy limitation to this study is that the ECoT model requires large sample sizes for detailed analyses of family relationships. Although these data were corrected for child gender, separate analyses on the relationships between mothers and their sons or daughters may illustrate that different processes are involved depending on child gender. Different processes may also be involved for fathers' behaviors. Unfortunately, splitting the samples by parent and child gender would reduce the robustness of the outcomes substantially and therefore was not done. The ECoT model is, however, important for disentangling evocative *r*GE and passive *r*GE.

In summary, creative and advanced methodological genetically informed approaches have been used to understand how parenting behaviors and the associations between parenting behaviors and child adjustment arise. Specifically, this work has helped to differentiate direct environmental contributions, passive *r*GE, and evocative *r*GE. Research has demonstrated the role of passive and evocative *r*GE for different dimensions of parenting (i.e., warmth, negativity, monitoring, and control) and for different reporters. Parenting behaviors (i.e., warmth, negativity, and emotional overinvolvement) are also linked to child adjustment both concurrently and over time through evocative *r*GE pathways. In addition, parental negativity and physical maltreatment exert direct environmental influences on child development over time.

Marital relationship and child adjustment

Aspects of marital problems, including marital conflict and parental divorce, have consistently been found to be associated with child adjustment problems (e.g., Amato, 2010; Cummings & Davies, 2002). Different explanations may account for the association between marital conflict or divorce and child adjustment problems. Marital conflict or divorce may directly lead to decrements in child adjustment. Alternatively, some parents may have heritable characteristics such as aggression and antisocial behavior that increase their risk of marital conflict and divorce. These heritable characteristics may also be passed onto their children, increasing the children's risk of problem behaviors (e.g., Amato, 2010). To understand the underlying pathways, researchers have used the CoT design to differentiate passive *r*GE from the direct influence of marital problems on child adjustment (e.g., D'Onofrio & Lahey, 2010). Interestingly, different mechanisms appear to be operating depending on whether the measured marital variable is marital conflict or parental divorce. For instance, one investigation has indicated that the children of MZ twins who were differentially exposed to varying levels of marital conflict had similar rates of antisocial problems (Harden et al., 2007). In contrast, the antisocial behavior of the children of DZ twins was associated with differences in marital conflict within the twin family, implicating the role of passive *r*GE. Further, research has demonstrated a direct effect of parental divorce on child adjustment in general (not necessarily twin) samples, including behaviors such as psychopathology, earlier initiation of sexual intercourse, emotional difficulties, and substance use (D'Onofrio et al., 2005, 2006, 2007).

Researchers have also examined the pathways underlying the association between parental divorce and child adjustment using prospective designs of adoptive and biological families. Adopted children do not share genes with their adoptive parents. Thus, evidence that adopted children whose adoptive parents divorce have higher rates of adjustment problems than adopted children whose adoptive parents do not divorce illustrates that parental divorce exerts a direct environmental influence on child adjustment problems. In other words, the impact of divorce on children appears to be due to a direct environmental effect, not simply due to the fact that parents and children share genes (i.e., passive *r*GE). Additional information about the role of passive *r*GE and the direct effects of divorce is gained by adding information about biologically related children and their parents. Specifically, if the association between biological parents' divorce and biological children's adjustment is greater than the association between adoptive parents' divorce and adopted children's adjustment, passive *r*GE is implicated. Conversely, if the magnitude of these associations is comparable among biological and adoptive families, passive *r*GE can be ruled out and the environmental influence of divorce is illustrated. Using this approach, one study has shown that parental divorce exerts a direct environmental influence on children's problem behaviors and substance use independent of passive *r*GE (O'Connor, Caspi, DeFries, & Plomin, 2000). This is consistent with the results from studies by D'Onofrio and colleagues (2005, 2006, 2007). Another study of adoptive and biological families incorporated the timing of parental divorce into the analyses (i.e., parental divorce that preceded or occurred after the child's birth). The authors reasoned that passive *r*GE is implicated if biological children exhibit delinquency even if their biological parents' divorce preceded their birth (Burt, Barnes, McGue, & Iacono, 2008). Conversely, the direct environmental influence of parental divorce is suggested if child delinquency is present only in response to divorce exposure and does not vary by adoption status. Consistent with the latter explanation, results suggested that it was the experience of parental divorce, and not passive *r*GE, that explained the association between divorce and child delinquency. Thus, evidence from this research is consistent with the assumptions of much of the literature about the impact of parental divorce on child adjustment (e.g., Amato, 2001). In contrast, this work indicates the importance of understanding how parents' heritable characteristics contribute to their marital conflict and their child's adjustment via passive *r*GE. What is unclear from these studies is whether children's heritable characteristics evoke their parents'marital conflict or divorce.

Genotype × Environment Interaction (G × E)

This section includes a review of behavioral genetic research that has used twin or adoption designs to examine how family relationships can influence child development through Genotype × Environment interaction (G × E). We will focus on parenting as the family relationship moderator, consistent with the majority of G × E – focused studies that have examined family relationships and child adjustment. For instance, recent research has addressed the extent to which differences in genetic, shared environmental, and nonshared environmental influences on child adjustment are moderated by varying levels of parenting behaviors, typically described as G × E (e.g., Purcell, 2002). Another strategy for examining G × E is to use an adoption design in which children are adopted at birth by genetically unrelated adoptive parents. If both adoptive families and birth parents are assessed, preferably longitudinally, the direct environmental effects of the rearing environment (indexed by adoptive parents' behaviors and characteristics), genetic factors (indexed by the biological parents' behaviors and characteristics), and their interactions on child functioning can be disentangled. This design can be used to examine environmental moderation of genetic factors or genetic moderation of the environment.

Studies that have considered family relationships as moderators of genetic and environmental influences on child adjustment have often focused on the moderating role of parenting behaviors. One such investigation assessed whether parental negativity and warmth moderated genetic and environmental influences on adolescent antisocial behavior and depressive symptoms (Feinberg, Button, Neiderhiser, Reiss, & Hetherington, 2007). Both parental negativity and warmth were found to moderate genetic influences on aggressive and nonaggressive forms of antisocial behavior. Specifically, genetic influences assumed a greater role for adolescent antisocial behavior when parenting behaviors were more negative or less warm. This indicates that genetic effects have a stronger influence on antisocial behavior in the presence of parental negativity and lack of warmth. In contrast, nonshared environmental effects on adolescents' depressive symptoms increased in the context of greater parental negativity. As such, experiences of parental negativity unique to each sibling take on an increasingly important role with increasing levels of parental negativity. This study suggests that parenting moderates genetic and environmental influences on child adjustment problems and different influences are moderated depending on the type of child adjustment problems being measured.

Another investigation addressed the moderating effects of parental monitoring on the genetic and environmental influences on adolescent smoking (Dick et al., 2007). Findings revealed that when parental monitoring was high, genetic influences on adolescent smoking were low and shared environmental influences were high. The reverse was true when parental monitoring was low. This illustrates that if parents closely monitor their adolescents, any genetic propensity towards smoking becomes less important, only coming into play when parental monitoring is low.

Yet a third study examined whether the effect of physical maltreatment on the risk for conduct problems was stronger among those who were at high genetic risk for conduct problems using a sample of 5-year-old twin pairs and their families (Jaffee et al., 2005). Children's genetic risk was estimated from their co-twins' conduct disorders. Findings showed that the effect of maltreatment on conduct disorders was highest among those at high genetic risk. Thus, therapeutic interventions should prioritize efforts toward children who are exposed to physical maltreatment and who are at high genetic risk for conduct disorders. Considered together, these studies underscore the importance of taking different measured aspects of the environment and different aspects of child adjustment into account when examining the effects of G × E.

Whereas the above-mentioned studies focused on adolescent adjustment, more recent studies seeking to understand infant and toddler development have taken advantage of a prospective adoption design, where infants are adopted at birth and placed with unrelated adoptive parents (Leve, Neiderhiser, Scaramella, & Reiss, 2008). One such study assessed the interaction between adoptive parents' structured parenting and genetic risk for psychopathology (as indexed by birth parents' psychopathology) on toddlers' adjustment problems (Leve et al., 2009). Findings showed that the effects of structured parenting on toddler adjustment problems varied as a function of genetic risk for psychopathology. Specifically, structured parenting was beneficial for toddlers at high genetic risk for psychopathology but was positively related to behavior problems for those toddlers at low genetic risk. Thus, children at genetic risk for psychopathology benefit from more structured environments, whereas children at low genetic risk benefit from less structured environments. This is consistent with the differential susceptibility model, which states that those who are most susceptible to adversity because of their genotype are also the most likely to benefit from supportive or enriching environments or the absence of adversity (Belsky et al., 2009). The second study investigated the effects of the parenting environment (indexed by adoptive parents' depressive symptoms and responsiveness) and genetic risk of depression (reflected by biological parents' major depressive disorder) on the development of fussiness between 9 and 18 months of age in adopted children (Natsuaki et al., 2010). Results revealed that children at genetic risk showed higher levels of fussiness at 18 months of age when adoptive mothers had been less responsive at 9 months of age. In contrast, children at genetic risk did not show increased levels of fussiness at 18 months in the context of high levels of adoptive mothers' responsiveness. These findings suggest that genetic risk of depression is accentuated by unresponsive caregiving. Considered together, twin and adoption studies focused on G × E effects have shown that parenting behaviors can moderate genetic and environmental influences on child adjustment; genetic factors can also moderate the influence of parenting on child adjustment.

Genotype – Environment Correlation × Environment Interaction (*r*GE × E)

A newer step in gene – environment interplay research has been to address how *r*GE effects are moderated by the family environment (i.e., *r*GE × E). One such study that used a prospective adoption design examined how adoptive parents' overreactive parenting is shaped by infant temperamental positive affectivity, birth and adoptive parent personality, and adoptive parents' marital quality (Hajal et al., 2008). The following three questions were addressed within this study: (a) Are there genetic influences on infant positive affectivity—indicated by an association between birth parent and infant positive affect? (b) Is adoptive parent overreactive parenting related to birth parent positive affectivity, suggesting evocative *r*GE? (c) Does poorer marital quality moderate evocative *r*GE differently for adoptive fathers and mothers? Results indicated that adoptive fathers' overreactive parenting was predicted by birth mothers' personality in families with high levels of marital warmth only, suggesting evocative *r*GE × E. For adoptive mothers, overreactive parenting was linked to aspects of infant temperament that were unrelated to birth mother personality. Thus, findings not only suggest distinct patterns of genetic and environmental influences on mothers' and fathers' overreactive parenting but also provide an elegant step in the delineation of the synergistic effects of *r*GE and G × E.

Conclusion

That the emotional quality of family relationships, including the parenting behaviors and marital quality, are linked to child adjustment outcomes has been well established (e.g., Amato, 2010; Cummings & Davies, 2002; Demo & Cox, 2000; Kouros et al., 2008). There is now evidence that family relationship quality is associated with child adjustment through the interplay of genes and the environment. In this paper, we reviewed literature from the past decade that has employed behavioral genetic strategies to assess two broad types of gene – environment interplay, including *r*GE and G × E, as well as the synergistic effects of *r*GE and G × E (i.e., *r*GE × E).

Many of these studies have focused on understanding the pathways through which parenting behaviors are associated with child adjustment. To delineate the mechanisms involved, an array of methodological approaches has been used to examine *r*GE. These approaches include comparing findings from child-based and parent-based designs, bivariate biometric models, longitudinal biometric models, the CoT design, and the ECoT design. Despite the differences in these approaches, a clear pattern of results has emerged in which parenting behaviors are influenced by passive and evocative *r*GE. In addition, studies using child-based designs have underscored the importance of children's heritable characteristics for evoking parenting behaviors and shaping the children's own adjustment. Parenting behaviors also exert direct environmental influences on child development over time. Future research should continue to employ longitudinal investigations to delineate the bidrectional effects of a wide variety of parenting behaviors and child adjustment outcomes over the course of the life span. More studies are also needed to identify the specific characteristics of family members contributing to the development of family relationship quality and child adjustment. Also, research that assesses family relationships and child adjustment at different times in development (i.e., infancy, childhood, and adolescence) are needed to delineate how different types of *r*GE and direct environmental effects unfold longitudinally. The continued employment of the CoT and ECoT designs is necessary to distinguish passive *r*GE from environment-plus-passive *r*GE, evocative *r*GE, and the environment alone. Because findings using the ECoT model are new, it will be important to replicate these results using different samples. Future studies should also examine how these effects are moderated by child and parent gender and age.

Using the CoT model, as well as samples of biological and adoptive families, another body of research has used novel approaches to understand how marital problems are tied to child adjustment problems. This work has produced another clear pattern of results in which marital conflict is linked to child adjustment problems via passive *r*GE, but parental divorce directly impacts child adjustment problems. Future studies should focus on the assessment of how positive aspects of the marital relationship (i.e., marital satisfaction) are tied to positive child adjustment. In addition, methodological approaches that can be used to examine the contribution of evocative *r*GE to the marital relationship and child adjustment should be employed, including child-based longitudinal models and the ECoT design.

Genetically informed research using twin or adoption designs has also focused on how family relationships moderate genetic and environmental influences on child adjustment through G × E. For example, there is now evidence that parental negativity, warmth, and monitoring moderate genetic and environmental influences on adolescents' antisocial behavior, depressive symptoms, and smoking. Genetic factors have also been shown to moderate the environmental effects of parenting on the adjustment of young children. Specifically, toddlers at genetic risk for psychopathology benefit from more structured environments, whereas toddlers at low genetic risk benefit from less structured environments. Evidence also indicates that children's genetic tendencies toward depression are accentuated by unresponsive caregiving. Similar to the future directions we have proposed for *r*GE-focused research, an important future direction within G × E-focused studies is to understand how family relationships operate to shape child adjustment at different developmental stages. Another future direction is to explore different mechanisms through which environmental factors moderate genetic effects on development, such as the environmental context triggering negative genetic predispositions, compensating for negative genetic predispositions, preventing genetically influenced behaviors, and enhancing adaption (Shanahan & Hofer, 2005). Finally, researchers have begun to explore how *r*GE and G × E operate together to shape family relationships and child development, and more studies are needed to delineate how these complex processes influence different family relationships and development.

Until fairly recently, research in behavioral genetics and in prevention science has been conducted independently, with little effort to use findings across areas to inform interpretation or design. There have been recent reviews and calls to action (e.g., Jaffee & Price, 2007; Leve, Harold, Ge, Neiderhiser, & Patterson, 2010; Reiss & Leve, 2007), as well as at least one empirical report (Brody, Beach, Philibert, Chen, & Murry, 2009), that have attempted to combine findings from genetic studies with prevention science as well as more general developmental research to advance our understanding of mechanisms. Research focused on understanding the interplay of genes and environments has the potential to inform prevention and intervention research by helping to better specify where to target interventions (e.g., Leve et al.). Although there has been a great deal of focus on G × E, studies of *r*GE also can provide directions for intervention research. For example, if passive *r*GE is found to best explain the impact of a mother's positive parenting on her child's internalizing behavior, a strategy focused more on changing the child's behavior than on mother's parenting may be more effective. Alternatively, when we find evidence of evocative *r*GE, parent training, where a parent is taught to respond differently to her child, could be a viable approach to changing the child's behavioral outcomes. Moreover, there is a growing recognition that those who are most susceptible to adversity because of their genotype may also be the most likely to benefit from supportive or enriching environments, including preventative interventions (Belsky et al., 2009). At this point, using the findings of genetic research to direct intervention on an individual level is not feasible. We suggest, however, that using findings from genetically informed research can help to guide intervention strategies. Most importantly, genetic research, especially behavioral genetic research, underscores the need to consider individual differences and highlights how approaches that allow for differences among individuals are likely to be most effective.

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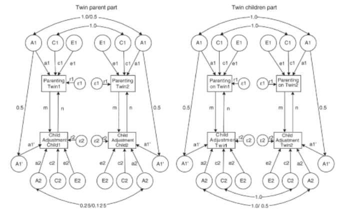

Figure 1.

Extended Children-of-twins model (ECoT).

Note: The model is described in two parts: for twin parents and for twin children. Phenotypes Parenting and Child Adjustment are denoted in rectangles. Genetic (A) and environmental (C, E) influences are depicted in circles. The Parenting phenotype is influenced by genetic (A1), shared (C1), and nonshared environment (E1), while child adjustment is influenced by genetic (A1′ and A2), shared (C2), and nonshared environmental effects (E2). Measurement error ($\varepsilon1$ and $\varepsilon2$) contributes directly to the variance of both phenotypes. In the twin parents part, the genetic effects correlate by 1.0 or .5, depending on the twin zygosity. Shared environment (C1) correlated perfectly for both MZ and DZ twins. Genetic effects for children, or cousins, correlate by .25 or .125, depending on the zygosity of the parents. Shared environmental effects are uncorrelated because the cousins do not share the family. In the twin children part, genetic and shared environmental effects correlated perfectly for the parenting phenotype, because there was always the same parent rating both twins. For children, genetic effects correlated by 1.0 or .5 for MZ and DZ twins, respectively, and shared environmental effects correlated perfectly for both zygosity groups. Paths *m* and *n* denote reciprocity in the relationship between the phenotypes. Path *m* reflects direct environmental effect of Parenting on Child Adjustment, whereas path *n* denotes evocative processes in the relationship. Significant paths *m*, *a*1′ and *a*1 will indicate passive *r*GE, and evocative *r*GE will be suggested by significant *n*, *a*1′, and/or *a*2. Copyright © 2010 by the American Psychological Association. Reproduced with permission from Narusyte et al. (2008). The use of APA information does not imply endorsement by APA.