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Gene × Environment Interactions in the Development of Preschool Effortful Control, and its Implications for Childhood Externalizing Behavior

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Abstract

This study examined the role of gene × environment interaction (G × E) in the development of effortful control (EC) and externalizing symptoms (EXT). Participants included 361 adopted children, and their Adoptive Parents (APs) and Birth Mothers (BMs), drawn from the Early Growth and Development Study. The primary adoptive caregivers' (AP1) laxness and overreactivity were assessed when children were 27-months-old, and used as indices of environmental influences on EC. Heritable influences on child EC were assessed by the BMs' personality characteristics (emotion dysregulation, agreeableness). Secondary adoptive caregivers (AP2) reported on children's EC at 54 months, and EXT at 7 years. Interactions between BM characteristics and AP1 laxness were related to EC and indirectly predicted EXT via EC. Parental laxness and EC were positively associated if children had high heritable risk for poor

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Authors' contributions:

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Jody Ganiban, Chang Liu, Lara Zapaterra, Saehee An, Leslie Leve, and Jenae Neiderhiser. The first draft of the manuscript was written by Jody Ganiban and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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The authors have no relevant financial or non-financial interests to disclose.

Ethics approval:

All study procedures involving human participants were conducted in accordance with the ethical standards of the 1964 Helsinki Declaration and its later amendments and guidance provided by the Office of Human Research Protections (National Institutes of Health, USA). This study was reviewed and approved by the Institutional Review Boards at the University of Oregon, Pennsylvania State University, and the George Washington University prior to data collection.

Consent to participate:

Written informed consent was obtained from the parents of all participants.

Code availability:

Programming code for analyses included in this paper is available upon request.

EC (BM high emotion dysregulation or low agreeableness), but negatively associated if children had low heritable risk for poor EC (BM low emotion dysregulation or high agreeableness). BM agreeableness also moderated associations between AP1 overreactivity and effortful control, and yielded a similar pattern of results. Our findings suggest that G × E is an important first step in the development of EXT via its effect on EC. Consistent with "goodness of fit" models, heritable tendencies can affect which parenting practices best support EC development.

Keywords

effortful control; externalizing behavior; G × E; childhood; adoption study

Externalizing Behavior and Effortful Control:

Externalizing behaviors such as impulsivity, hyperactivity, aggression and oppositionality are united by more fundamental problems regulating behavior, attention, and emotion (Achenbach & Rescorla, 2001). Accordingly, difficulties with self-regulation during the preschool years are thought to initiate an early starter route to long term externalizing behavior problems (e.g., Moffitt, 1993; Frick, 2012). One facet of self-regulation is effortful control, defined as "the ability to inhibit a dominant response in order to perform a subdominant response" (Posner & Rothbart, 2000, p. 434; Rothbart & Bates, 1998). Effortful control is conceptualized as a top-down process through which behavior is controlled voluntarily. It is reflected in a child's capacity to regulate behavior in service of a goal or in compliance with rules (i.e., inhibitory control) and the capacity to direct and manage attention (i.e., attentional control; Bridgett et al., 2015). Poor effortful control during early childhood is associated with higher levels of externalizing behavior problems across studies that have used parent-reports and laboratory assessments (Eisenberg et al., 2005; Eisenberg et al., 2010; Gusdorf et al., 2011; Olson et al., 2005; Olson et al., 2017). Furthermore, lower effortful control in preschool is associated with chronic levels of externalizing behavior from early to late childhood (Olson et al., 2017). Consequently, understanding factors that shape effortful control during the preschool years could be key to understanding the initiation of pathways that lead to externalizing behavior. The current study focuses on the role of gene × environment interaction (G × E) in the development of effortful control and subsequent externalizing symptoms. A prospective adoption design was used to differentiate between environmental and heritable influences on effortful control during the preschool years, and the downstream effects of G × E and effortful control on externalizing symptoms during middle childhood.

Genetic and Environmental Contributions to Effortful Control:

Rudimentary forms of effortful control are present as early as 6–7 months of age (Sheese et al., 2008); however, self-regulatory capacities improve substantially between the ages of 2½ to 3 years (Eisenberg, Spinrad, & Eggum, 2010; Gerardi-Caulton, 2000; Kochanska et al., 2001). Between the ages of 3 to 4 years, individual differences in effortful control emerge and become increasingly stable, and by the age of 4, most effortful control processes are "on line": children demonstrate inhibitory-control, attentional flexibility, and the ability to use

memory to guide behavior (Hughes & Graham, 2002; Kochanska et al., 2001). Therefore, the toddler and preschool periods demarcate a critical developmental period for effortful control.

Previous research indicates that effortful control and its components are genetically influenced during the preschool years (Gagne & Saudino, 2016; Goldsmith, Buss, & Lemery, 1997), middle childhood (Lemery-Chalfont, Doelger, & Goldsmith, 2008) and adulthood (Yamagata, 2005). Twin studies also show that environmental factors account for moderate variance in effortful control during the preschool and early childhood years (Goldsmith, Buss, & Lemery, 1997; Lemery-Chalfont, Doelger, & Goldsmith, 2008). Parenting is one likely source of these effects. Indeed, parenting interventions during the preschool years are associated with positive changes in children's subsequent effortful control capacities (e.g., Chang, et al., 2014; Somech & Elizur, 2012). Vygotsky (1978) initially proposed that parents create a scaffold upon which children can build and practice their fledgling self-regulatory skills (see also Hoffman, 2000; Kopp, 1982). In particular, parental positive control strategies, characterized by the provision of consistent structure, rules, and limit setting for their children's behavior, are associated with better effortful control (Karreman, 2006, 2009). In contrast, parental negative control strategies, including parental hostility, coercion and intrusiveness, predict lower effortful control (Bridgett et al., 2018; Karreman et al., 2006, 2008; Taylor et al. 2013). Last, parental warmth and support promote better effortful control across the toddler period (Kochanska, Murray, & Harlan, 2000; Lengua, Honorado, & Bush, 2007) and preschool years (Karreman, et al., 2008; Neppl, Shinyouung, Diggs, & Donnellan, 2020; Spinrad et al., 2012).

Gene × Environment Interaction and Effortful Control:

Although there is evidence that both genetic and environmental factors are associated with children's effortful control, relatively few studies have examined the role of G × E in its development. There are several ways in which children's heritable characteristics could affect the impact of parenting on child outcomes (Rabinowitz, 2017). For example, children who have liabilities for poor effortful control could be more adversely affected by parents' negative control strategies than children without liabilities (i.e., diathesis-stress model). Alternatively, children who have proclivities towards strong effortful control may benefit more from parents' positive control strategies than children without such predispositions (i.e., vantage sensitivity model; Pluess, 2017). Last, the Differential Susceptibility perspective proposes that genetically influenced differences in "plasticity" render some children highly sensitive to both adverse and supportive environments (i.e., high plasticity; Belsky & Pluess, 2009). In regard to effortful control, these children would thrive when parents use positive control strategies, but would also be vulnerable to the adverse effects of parental negative control. In contrast, other children may be less sensitive to both adverse and supportive environments (i.e., low plasticity), and parenting would have little impact on their development of effortful control.

Existing G × E studies have primarily taken a candidate gene approach, with particular focus on alleles related to dopaminergic activity (e.g., DRD4, DRD2, DAT1) during the toddler years (Sheese et al., 2007), preschool (Sheese et al, 2012; Smith et al., 2012), and

adolescence (Cho et al., 2016; van Heel, 2020). Three additional studies have focused on 5-HTTLPR during preschool (Kochanska, Philbert, & Barry 2009) and COMT (Val^{158}Met) during adolescence (Sulik et al., 2015; Zhao, Cao, Zhang, & Zhang (2020). In most studies, investigators utilized parent observations or parent reports of supportiveness or sensitiveness vs. unresponsiveness as environmental indicators.

Collectively, these studies support the relevance of G × E for the development of effortful control across different ages and for different polymorphisms and parenting dimensions. Nevertheless, the type of G × E observed varies across studies, with some evidence of diathesis-stress interactions (Kochanska, et al. 2009; Smith et al., 2012), vantage sensitivity (Sheese, et al., 2012; Zhao, et al (2020), and differential susceptibility (Cho et al, 2016; Sulik et al., 2015). These discrepancies are not simply due to developmental stage or to the specific polymorphism assessed. However, they could reflect small study samples (e.g., Kochanska et al., 2009; Sheese et al., 2012; Sulik et al., 2015), and methodological differences in how parenting was assessed. In addition, extant research has two general limitations. First, nearly all of the studies that have explored G × E and effortful control focus on the effects of a single gene at a time, even though there is evidence that multiple genes can moderate environmental effects on effortful control. Second, nearly all previous research has included genetically related parents and children, potentially making it difficult to disentangle the effects of parenting from genetic factors that are shared by parents and children. Therefore, additional studies that include larger sample sizes and research designs other than the candidate gene approach can further understanding of the role played by G × E processes in the development of effortful control.

The Adoption Research Design:

The adoption research design addresses some of the limitations of candidate gene G × E studies, and is well suited to examine gene-environment interplay in the development of effortful control and externalizing behavior. Within the adoption design birth parents' personality characteristics can be used as indices of children's heritable predispositions. Because personality dimensions are complex phenotypes that reflect the impact of thousands of genes rather than a single gene, this approach could provide a more comprehensive assessment of heritable predispositions towards strong versus weak effortful control and externalizing behavior than candidate gene studies. Adoption designs can also decouple the effects of environmental and heritable influences on children's behaviors: adoptive parents control children's rearing environments, but children's genetic makeup is determined by their biological parents.

Birth parents' tendencies towards neuroticism (vs. emotional stability) and agreeableness (vs. disagreeableness) are plausible indices of heritable predispositions towards effortful control. Both personality dimensions incorporate aspects of self-regulation (Digman, 1997; McCrae, 1987), and are genetically influenced (e.g., Bouchard et al., 2003; Jang et al., 1996; Loehlin, 1992). Specifically, neuroticism describes a personality continuum that ranges from the tendency to express heightened and dysregulated negative affect (i.e. anxiety, fear and frustration) at one end to strong emotional and self-regulation at the other end (McCrae, 1987). Therefore, low levels of neuroticism could reflect stronger levels

of effortful control. Accordingly, previous studies have consistently found that negative affectivity and indices of self-regulation are inversely associated, load onto the same latent personality factor (e.g., Digman, 1997; Shewark et al., 2021), and show common genetic influences (Ganiban et al, 2009). Negative affectivity and self-regulation are also intertwined across development. For example, within the current sample children's negative affectivity during preschool predicts childhood effortful control (Cioffi et al., 2021); other research groups have emphasized the importance of effortful control and/or self regulatory skills in the expression of negative affect during childhood (e.g., Ferrier, Bassett, & Denham, 2014) and adulthood (e.g., Bridgett et al, 2013). Agreeableness may also be an indicator of self-regulation and effortful control. This personality dimension captures the extent to which individuals form and maintain positive relationships with others versus express interpersonal antagonism and hostility (McCrae, 1987). During adulthood, agreeableness and effortful control are positively correlated (Jensen-Campbell et al, 2002), and it is noteworthy that agreeableness is associated with measures of conscientiousness, a general indicator of voluntary self-regulation (Digman, 1997). Furthermore, mothers' agreeableness is associated with their children's effortful control levels (Goldsmith, Losoya, Bradshaw, & Campos, 1994). Developmentally, effortful control may lay the foundation for adult agreeableness by enabling children to modulate frustration in service of cooperating with others and establishing positive relationships (Ahadi & Rothbart, 1994). Consistent with this hypothesis, Cumberland-Li, Eisenberg, and Reisler (2004) further note that children who show higher levels of effortful control or self-regulation are more likely to demonstrate skills that underlie agreeableness, including more prosocial behavior, empathy and sympathy for others. Last, effortful control and agreeableness are correlated during childhood (Cumberland-Li et al., 2004), and self-regulation during childhood is related to agreeableness during adolescence (Kochanska & Kim, 2020), and adulthood (Laursen, Pulkkinen, & Adams, 2002).

Given conceptual and empirical links between effortful control and the broader personality dimensions of emotion dysregulation and agreeableness, it is plausible that high neuroticism (i.e., emotion dysregulation) and low agreeableness index poor self-regulatory skills within adults. Therefore, birth parents with these attributes would be more likely to have offspring who are genetically predisposed to have poor effortful control skills. Conversely, children who have birth parents who show low emotion dysregulation or high agreeableness would be predisposed to have strong effortful control skills.

The Current Study:

The current study employed a prospective adoption design to examine the importance of G × E during the toddler years for preschoolers' effortful control, and its implications for subsequent externalizing behavior during early childhood. We hypothesized that children's heritable tendencies towards effortful control (as indexed by their birth mothers' personality) interact with adoptive parents' caregiving to predict effortful control. We assessed children's heritable predispositions via measures of birth mothers' agreeableness and emotion dysregulation (i.e., neuroticism) that were derived by Shewark et al. (2021) within the current sample. To assess environmental contributions to effortful control, we included measures of adoptive parents' positive control (i.e., structured versus lax parenting)

and negative control (overreactive versus calm parenting) because of their relevance for the development of effortful control in early childhood (e.g., Karreman et al., 2006). Since previous research has not clearly indicated which form of G × E is related to effortful control (i.e., diathesis-stress, vantage sensitivity, or differential susceptibility), we also examined patterns of associations between parenting and effortful control for children at high or low heritable risk for poor effortful control skills. Second, we extended previous research by examining the long term impact of G × E effects on effortful control on children's subsequent externalizing behavior. In doing so, we explored if G × E processes during the toddler period contribute to an early starter pathway for externalizing behavior that is initiated by poor effortful control skills. We hypothesized that G × E processes would indirectly predict children's subsequent externalizing behavior through their impact on effortful control.

Method

Participants

Participants were drawn from Cohort I of the Early Growth and Development Study (EGDS), which is a prospective parent-offspring adoption study. The current sample included 361 triad groups composed of birth parents, adoptive parents, and adopted children. The sample consisted of children with birthdates between January 2003 and June 2006. Median age at time of adoption was 2 days (*SD* = 12 days). Most families included opposite-sex adoptive parents (N=340), while a small number of families had same-sex adoptive parents (N=21). For parsimony, we refer to the primary adoptive caregiver as adoptive parent 1 (AP1, 97 % female), and the secondary adoptive caregiver as adoptive parent 2 (AP2, 97% male).

Forty-three percent of the children were females. Fifty-seven percent of the children were White, 11% were Black, 9% were Hispanic, and 23% were other or multi-ethnic. In regard to AP1, 91% were White, 4% were Black, 3% were Hispanic, 1% were American Indian or Asian, 1% were more than one race or race was unknown. For AP2, 90% were White, 5% were Black, 2% were Hispanic, 1% were Native Hawaiian, Pacific Islander, or Asian, 1% were more than one race, and the race of 1% was unknown The mean age of the AP1 and AP2 at childbirth was 37.78 (*SD* = 5.5) and 38.39 (*SD* = 5.8), respectively. The mean age of the birth mother (BM) at childbirth was 24.12 (*SD* = 5.9). At childbirth, nearly half of the adoptive parents were characterized as affluent and had annual gross household incomes that exceeded $100,000 and more than 70% of adoptive parents had completed a college education or higher. At childbirth, eighty-five percent of birth mothers had household income of less than $20,000 and the majority of them did not have a college degree. For a more detailed description of sampling methods and participant characteristics, please refer to Leve et al. (2019).

Measures

To minimize potential single-rater bias, we used AP1's report on parental laxness and overreactivity and AP2's report on child effortful control and externalizing behaviors. Throughout our analyses we only used BM's personality characteristics as indices of

heritable influences. We excluded birth father's characteristics because of the high rates of missing data that ranged from 66% to 72% for personality measures.

Birth Mother's personality characteristics.—BM emotion dysregulation and agreeableness were used to index heritable influences for child effortful control. Between 3 to 18 months post-partum, BM's completed a battery of personality and behavioral measures, including: (a) Fear, Frustration, Sociability, Activation Control, Attentional Control, Associative Sensitivity, and Affect Perceptual Sensitivity subscales of the Adult Temperament Questionnaire (α's .56–.77; ATQ; Derryberry & Rothbart, 1988); (b) Self-Transcendence subscale from the Temperament Character Inventory (α=.78; TCI; Cloninger, 1998; Cloninger, Svrakic, & Przybeck, 1993); (c) the Nurturance and Intimate Relationships subscales of the Harter Adult Self-Perception Profile (α's .59 – .76; HASPP; Messer & Harter, 1986); and (d) the Reward Responsiveness, Fun Seeking, and Drive subscales of the Behavioral Inhibition Scale/Behavioral Activation Scale (α's .62 – .86; BIS/BAS; Carver & White, 1994). The ATQ was assessed at 18 months post-partum. The TCI, HASPP, and BIS/BAS were assessed at 3–6 months post-partum. As described in Shewark et al (2021), confirmatory factor analysis was used to create personality composites. Four factors were identified: emotion dysregulation, agreeableness, behavioral activation, orienting sensitivity. Based upon theoretical considerations, only two factors were included in this study and used to create composite scores: emotion dysregulation and agreeableness. The following scales loaded onto the emotion dysregulation factor: attentional control (−.77), activation control (−.66), fearfulness (.58), and frustration (.56). Therefore, high scores for the emotion dysregulation composite denote a greater propensity to experience negative affect, while lower scores represent strong effortful control. Three personality scales loaded onto the agreeableness factor: sociability (.54), nurturance (.55), and competence in intimate relationships (.61). Therefore, high scores for the agreeableness composite denote better interpersonal relationships, while low scores denote interpersonal difficulties

Adoptive Parent 1's parenting at child age 27 months.—AP1 completed the Parenting Scale (Arnold et al., 1993) when children were 27-months old. This 30-item self-report questionnaire assesses parents' discipline practices, and includes two subscales: lax versus structured parenting, and overreactive versus calm parenting. Each item presents parents with a situation (e.g., "When I want my child to stop doing something") and asks them to rate the degree to which they usually respond in a "dysfunctional" (e.g., I coax or beg my child to stop) vs. "functional" (e.g., "I firmly tell my child to stop") way. Responses are made on a 7-point scale, anchored by functional parenting behaviors (1) and dysfunctional parenting behaviors (7). Importantly, values of 1–3 represent greater endorsements of functional disciplinary strategies (i.e., structured or calm parenting) relative to dysfunctional strategies, while ratings of 5–7 represent greater endorsements of dysfunctional disciplinary strategies (i.e., laxness or overreactivity) relative to functional strategies. A rating of 4 indicates that a parent uses both types of strategies equally. The laxness subscale includes 11 items that measure the degree to which a parent provides lax, permissive and inconsistent discipline versus consistent and firm structure and limit setting. The overreactivity subscale consists of 10 items that measure the degree to which a parent displays irritability, anger, or hostility versus calm or neutral responses when a

child misbehaves. Items within each subscale were averaged. Both subscales demonstrated adequate internal reliability, for laxness, a = .78, for overreactivity, a = .78.

Child effortful control at 4.5 years.—At child age 4.5 years, AP2 completed the Child Behavior Questionnaire (CBQ; Rothbart, Ahadi, Hershey, & Fisher, 2001). The CBQ produces scores on three broad temperamental factors: Extraversion/Surgency, Negative Affectivity, and Effortful Control. In the current study, we focused on the Effortful Control Factor (a = .86), which incorporates the Attentional Focusing, Inhibitory Control, and Perceptual Sensitivity subscales. This factor also includes the ability to regulate arousal effectively as reflected in the Low Intensity Pleasure and Smiling/Laughter subscales. AP2 indicated their responses on a 7-point Likert scale, ranging from 1 (*extremely untrue of your child*) to 7 (*extremely true of your child*) on the basis of the child's behaviors within the last 6 months.

Child externalizing behaviors at 7 years.—At child age 7 years, AP2 completed the Child Behavior Checklist (CBCL; Achenbach & Rescorla, 2001). The CBCL is a widely used and well-validated questionnaire measures in the assessment of child socio- and emotional problem behaviors. The CBCL produces scores on two broadband behaviors: Externalizing behaviors and Internalizing behaviors. In the current study, we focused on child externalizing broadband scale (α = .88) which consisted of 35 items that assessed rule-breaking behavior and aggressive behavior. AP2 indicated their responses on a 3-point Likert scale, ranging from 1 (*Not True*) to 3 (*Very True*) based on the child's behaviors.

Control Variables

Adoption Openness.—The current study used data from a parent-offspring adoption sample, where adoptive parents' perception of child characteristics/behaviors may be impacted by their perceived knowledge or contact with the birth parents. Thus, we controlled for adoption openness indexed by a composite score of BMs' and APs' perceived openness, ranging from very closed (i.e., the BM's and AP's have no knowledge or contact with each other) to very open (i.e., the BM's and AP's have knowledge and contact with each other), at 5–9 months post-partum (Ge et al 2008).

Perinatal Risk Index.—Perinatal risks could be associated with BM's characteristics, child effortful control and externalizing behaviors. To control for any potential effects of perinatal risks, we included BMs' obstetric complications as a covariate in the model using an index derived from birth mother's reports and coded medical records based on an adaptation of the McNeil-Sjöström Scale for Obstetric Complications (see Marceau et al., 2016; McNeil, 1995 for more details).

Child Sex.—Child sex was coded as 1 (male) or 2 (female).

Attrition Analysis

The proportion of missingness for each variable is listed below: 2.1% – 17.8% for BM's personality indicators; 13.0% for AP1's report of parenting at 27 months; 23.5% for AP2's report of child effortful control at 4.5 years; and 38.0% for AP2's report of child

externalizing behaviors at 7 years. We conducted a targeted missing data analysis to examine whether there were significant differences in the study and demographic variables across groups where the outcome variable (child externalizing behaviors at age 7) was available (n = 224) versus missing (n = 137) to index attrition using one-way analysis of variance. Study variables included birth mother's personality characteristics, AP1's laxness and overreactivity at 27 months, and child effortful control at 4.5 years. Demographic variables include child sex, adoption openness, perinatal risk index, adoptive parents' demographics (age at child's birth, household income, education), and birth parents' demographics (age at child's birth, household income, education). We found no significant differences in the study variables and demographic variables across groups where child externalizing behaviors at age 7 was available versus missing (adjusted p values = .0025). Therefore Full Information Maximum Likelihood (FIML) estimation was used to account for missing data.

Data Analysis

Prior to analyses, we compared items included within the effortful control and externalizing behavior questionnaires and determined that these scales were conceptually distinct. Next, descriptive statistics (means, standard deviations and intercorrelations) of primary theoretical variables were computed. A series of path analyses were conducted to examine: (a) if each BM's personality characteristic (i.e., emotion dysregulation and agreeableness), moderated the association between AP1's parenting behavior (laxness or overreactivity) at 27 months and child effortful control at 4.5 years; (b) if child effortful control at 4.5 years was associated with child externalizing behaviors at 7 years after controlling for BM's temperament characteristics (emotion dysregulation and agreeableness), AP1's parenting behaviors (laxness and overreactivity); and (c) if interactions between BM personality and AP1's parenting are indirectly related to child externalizing behavior via effortful control.

Separate path analyses were conducted for each combination of BM's temperament characteristics (emotion dysregulation and agreeableness) and AP1's parenting behaviors (laxness, overreactivity). For analyses that included emotion dysregulation, agreeableness was included as a covariate; likewise when agreeableness was the target characteristic, emotion dysregulation was included as a covariate. Similarly, laxness was included as a covariate for analyses that focused on overreactivity; and overreactivity was a covariate for analyses that focused on laxness. Last, child gender, adoption openness, and perinatal risks were included as covariates in all models tested. When significant moderation effects were detected, they were probed with simple slopes analysis (Aiken & West, 1991). In addition, a regions of significance test was conducted using the Johnson-Neyman technique (1936), allowing estimation of the values of AP1 parenting at which the effects of BM personality on child effortful control become significant ($p < .05$).

All analyses were conducted using maximum likelihood estimation in *Mplus 8* (Muthén & Muthén, 2015). BM's temperament characteristics and AP1's laxness and overreactivity were standardized before examining the models. The fit of the proposed model was examined on the basis of multiple criteria: the root mean square error of approximation (RMSEA), the comparative fit index (CFI), and the standardized Root Mean Square

Residual (SRMR). The model fits the data if the RMSEA is smaller than .08, SRMR is smaller than 0.08 and the CFI is larger than 0.90 (Bentler, 2007).

Results

Descriptive Analysis

Means, standard deviations, and intercorrelations among the study variables are presented in Table 1. According to the recommended cutoffs of 2 for skewness and kurtosis (George & Mallery, 2010), all study variables met the criterion for normality except for child externalizing behaviors at age 7, which is only slightly positively skewed. On average, children demonstrated moderate levels of effortful control on par with other samples (e.g., Eisenberg et al 2005), and low frequencies of externalizing behavior. The means for the laxness and overreactivity scales indicate that AP1s primarily described themselves as using more structure and limit setting strategies, rather than engaging in lax, permissive parenting, and being calm or neutral rather than overreactive to their children's misbehavior. In fact, only one parent endorsed a predominantly lax or overreactive parenting style (i.e., rating of 5 or greater on either scale). This pattern of findings is consistent with nonclinical samples (Arnold et al., 1993). AP1's laxness and overreactivity at 27-months were not correlated with child effortful control at 4.5 years (ps > .05). In regard to heritable influences on child effortful control, BM agreeableness was positively correlated with child effortful control at 4.5 years (r = .14, p = .017), while associations between emotion dysregulation and child effortful control approached statistical significance (r=.11, p<.10). BM emotion dysregulation was also negatively correlated with AP1's laxness at 27 months (r = −.12, p = .030). Moreover, BM emotion dysregulation was positively correlated with child externalizing behaviors at 7 years (r = .14, p = .034). Child effortful control at 4.5 years was negatively correlated with child externalizing behaviors at 7 years (r = – .35, p < .001). Last, girls had higher levels of effortful control compared to boys at age 4.5 (r = .24, p < .001).

Path Analysis

AP1 Laxness vs. Structuring Parenting and BM Personality—Models that included AP1 laxness and each of the BM personality characteristics demonstrated a good fit to the data: for BM emotion dysregulation, RMSEA = .049, CFI = .947, and SRMR=.031; and for BM emotion agreeableness, RMSEA = .054, CFI = .935, and SRMR=.032. In regard to covariates, child gender was associated with effortful control at 4.5 years (b=.231 to .237, p's <.001), with girls showing greater effortful control than boys. Findings related to the key analyses are described below by BM personality characteristic, and summarized in Figure 1. Please note that this Figure includes unstandardized estimates.

BM emotion dysregulation: While neither AP1 laxness nor BM emotion dysregulation was directly related to child effortful control, their interaction did predict child effortful control (b = .146, p = .001). To probe the interaction effect, we conducted a simple slopes analysis and examined the degree to which BM emotion dysregulation moderated associations between AP1 laxness and child effortful control. As depicted in Figure 2a, when BM emotion dysregulation was high (1 SD above the sample mean), AP1 laxness was

positively associated with child effortful control (b = .108, p = .018). However, when BM emotion dysregulation was low (at least 1 SD below the sample mean), AP1 Laxness was negatively associated with child effortful control (b = −.126, p = .010). An additional regions of significance test indicated that the low and high BM emotion dysregulation groups showed significantly different levels of effortful control when AP1 laxness was slightly below the mean (−.47 SD, 34.7% of the sample), and when AP1 laxness was high (1.08 SD, 13.7% of the sample). This pattern of findings suggests that both BM emotion dysregulation groups were responsive to parents' use of lax (versus structuring) parenting styles, albeit in different ways.

Furthermore, child effortful control at 4½ years was related to externalizing behavior at 7 years (b=−3.211, p=.000). Last, the interaction between BM emotion dysregulation and AP1 laxness predicted subsequent externalizing behavior via effortful control through its effect on effortful control (total indirect effect = −.470, p = .005).

Birth mother's agreeableness: Neither BM agreeableness or AP1's laxness at 27 months was associated with child effortful control at age 4.5 years. However, their interaction predicted child effortful control (b = −.127, p = .003). As depicted in Figure 2b, a simple slopes analysis indicated that the association between lax parenting and child effortful control was negative when BM agreeableness was high (i.e., 1 SD above group mean; b = −.106, p = .026), but positive when BM agreeableness was low (i.e., 1 SD below the sample mean; b = .097, p = .037). A regions of significance test indicated, that the low and high BM agreeableness groups only showed different levels of child effortful control when laxness was slightly below the sample mean (−.29 SD, 41.4% of the sample).

Child effortful control at 4½ years was related to externalizing behavior at 7 years (b = −3.223, p=.000). Last, the interaction between BM agreeableness and AP1 lax parenting was indirectly associated with externalizing behavior via effortful control (indirect effect = .409, p = .010).

AP1 Overreactivity vs. Calmness and BM Personality—Models that included AP1 overreactivity and each of the BM personality characteristics demonstrated adequate fit to the data: for BM emotion dysregulation, RMSEA = .052, CFI = .86; and for BM agreeableness, RMSEA = .046, CFI = .89. In regard to covariates, child gender was associated with effortful control at 4.5 years (b=.257 to .258, p's <.001). Findings related to the key study questions are summarized below by BM personality characteristic and in Figure 3.

BM emotion dysregulation: BM emotion dysregulation, AP1 overreactivity and their interaction were not associated with child effortful control or externalizing behavior. However, effortful control at 4½ years was related to externalizing behavior at 7 years (b = −3.298, p=.000).

***BM agreeableness*:** The interaction between BM agreeableness and AP1 overreactivity was modestly related to child effortful control (b = −.080, p = .047). Simple slope analysis indicated that when BM agreeableness was high (+1SD), overreactive parenting

was marginally and negatively associated with child effortful control (b=−.082, p=.075). However, overreactive parenting and child effortful control were not associated when BM agreeableness was low (−1 SD). Finally, child effortful control at 4½ years was related to externalizing behavior at 7 years (b = −3.269, p=.000). The indirect effect of the interaction between BM agreeableness and overreactive parenting on externalizing behavior via effortful control approached significance (total indirect effects = .26, p = .067).

Discussion

Previous research has described a pathway to externalizing behavior in which preschool effortful control predicts externalizing behavior trajectories during childhood (Olson et al., 2017). The roots of this pathway may be found during the toddler period, a time during which children are sensitive to the impact of environmental factors (Shaw et al., 2003, 2012; Sitnick et al., 2017). Within this study, children's effortful control at age 4½ years strongly predicted externalizing behavior problems at age 7 years. For every one unit increment in effortful control skills, children's externalizing behavior scores increased by approximately 3 points. This increase roughly translates into the addition of an externalizing symptom. Therefore, even small increments in effortful control have an important downstream impact on externalizing behavior. The present study used an adoption design to examine the importance of G × E processes during the toddler period for preschoolers' effortful control and externalizing behavior. Based on previous research, we expected that: (1) children's heritable predispositions towards effortful control (as indexed by their birth mothers' emotion dysregulation and agreeableness) interact with adoptive parents' caregiving (i.e., laxness, overreactivity) to predict effortful control; and (2) the interaction between heritable predispositions and parenting predicts children's subsequent externalizing behavior via its effect on effortful control.

Heritable and environmental contributions to Effortful control:

At the bivariate level, BM's agreeableness and emotion dysregulation were modestly associated with adoptive parents' ratings of children's effortful control (r's .14, −11, respectively), and indicative of heritable contributions to effortful control. These associations, are similar in magnitude to the correlation between BM's and adoptive children's performance on an objective test of attentional control, a key component of effortful control, within the same sample (Bridgett et al., 2018; Cioffi et al., 2021). In contrast, parental laxness and overreactivity at 27 months were not correlated with children's effortful control at 4½ years. The absence of significant correlations was surprising given findings from a previous meta-analysis (Karreman et al 2006). However, even within this analysis, there was heterogeneity in effect sizes. Within our study, associations between parenting and effortful control could have been attenuated by the use of different raters for each construct or by the 2½ year gap between the parenting and effortful control assessments. In addition, our sample showed restricted ranges in parenting styles. Nearly all parents endorsed functional, positive control strategies characterized by structure, limit setting, and calmness, rather than laxness or overreactive parenting. Arnold et al (1993) reported similar levels of laxness and overreactivity amongst non-clinical families when they developed the parenting scale used in the current study. Therefore, it is possible

that this scale captures general parenting styles that are relevant for clinical diagnoses, but is less sensitive to more nuanced variations in parents' behaviors that affect effortful control development. For example, in a previous EGDS analysis that utilized observational data, adoptive parents' harsh parenting (negative expressions, intrusiveness, controllingness) during structured situations at 27 months was negatively associated with children's self-regulatory capacities at 54 months (Bridgett et al., 2018).

G × E and Effortful Control:

The absence of significant correlations between parenting and effortful control could also be explained by significant G × E interaction effects. Consistent with our expectations, BM personality moderated associations between adoptive parent laxness during the toddler period and effortful control during preschool. Furthermore, BM personality × parenting interaction effects were indirectly related to children's subsequent externalizing behavior via effortful control. Specifically, children who may be genetically inclined to have strong effortful control skills (i.e., had a BM with low emotion dysregulation or high agreeableness) fared better when they experienced low levels of lax caregiving and high structure. Conversely, if children possessed putative heritable risks for poor effortful control (i.e., had a BM with high emotion dysregulation or low agreeableness), they showed higher levels of effortful control when exposed to parenting that included low levels of laxness. These findings were partially replicated for parental overreactivity: there was a trend for children who have a heritable predisposition towards strong effortful control skills (i.e., had a BM with high agreeableness) to fare better when their parents were calm versus overreactive. Collectively, our results suggest that the interaction between parenting and children's heritable characteristics affect children's emergent effortful control skills, and may play an important role in the initiation of a pathway that leads to externalizing problems. Although the effect sizes were modest, as noted previously, even small changes in effortful control can have important downstream effects on children externalizing behavior.

Our findings are generally consistent with a host of candidate gene studies that show heritable factors to moderate associations between parenting and effortful control during the preschool period (e.g., Kochanska et al., 2009; Sheese et al., 2012; Smith et al., 2012; Sulik et al., 2015). We extend this body of research by identifying G × E within an adoption study and using broad indicators of heritable tendencies. Our findings attest to the robustness of G × E as a process that contributes to effortful control development, and highlight its relevance to the emergence of externalizing behaviors.

G × E models:

Although we found that G × E in the toddler period predicts preschool effortful control, our pattern of results did not completely match those of previous candidate G × E studies. First, all children appeared to be sensitive to the effects of structured versus lax parenting, albeit the directions of associations between parenting and effortful control depended on children's heritable predispositions. Therefore, Differential Susceptibility was not observed. Second, heritable liabilities towards weaker effortful control did not translate into lower effortful control when children experienced less optimal parenting (i.e., more lax parenting). In fact, children in the putative "heritable vantage" group fared worse than children with heritable

liabilities when they experienced more parental laxness. Therefore, our findings are also inconsistent with Diathesis-Stress G × E. There was some evidence of vantage sensitivity for interactions between agreeableness and parenting: low levels of laxness or overreactivity were most advantageous for children who have a BM characterized by high agreeableness. However, the significant positive associations between lax parenting and effortful control amongst children with putative heritable liabilities imply that other processes are in play.

Rather, our findings are most compatible with the "Goodness-of-Fit" model of development, which proposes that optimal development occurs when there is a match between parents' expectations and children's capacities (Thomas & Chess, 1977). According to this framework , goodness-of-fit arises when a "person's temperament and other characteristics, such as motivations and levels of intellectual and other abilities, are adequate to master the successive demands, expectations, and opportunities of the environment" (p. 16, Chess & Thomas, 1991). In regard to the current study, children who may be genetically predisposed to show strong effortful control capacities will thrive in environments that include low levels of laxness and are highly structured. However, children who may be less inclined towards strong effortful control may benefit most from environments that are structured, but also hold somewhat flexible expectations for immediate and consistent compliance. A previous analysis from the Early Growth and Development study also supports a "goodness of fit" understanding of GxE. Specifically, Leve et al (2009) found that children's heritable characteristics affected whether structured parenting had a positive versus adverse effect on their internalizing and externalizing symptoms during the toddler period. Therefore, instead of casting heritable characteristics as indices of liabilities, vantages, or plasticity, it may be more fruitful to use heritable characteristics to anticipate which types of parenting styles will support optimal outcomes for different children.

The most likely reason why our pattern of G × E findings differ from previous research is our use of an adoption research design rather than a candidate gene approach. As described previously, the adoption design offers a more "omnigenic" approach to estimating heritable influences on behavior than candidate gene studies. Through using BM characteristics as indices of heritable effects, the adoption design assesses the combined influences of thousands of genes, rather than a single gene variant. This approach enabled us to assess the combined effects of a wide range of sensitivities, vantages, and liabilities, possibly leading to different findings from previous studies.

Another possibility is that most parents in the current study described low levels of lax and overreactive parenting. Accordingly, this may have limited our capacity to discern Diathesis-Stress or Differential Susceptibility forms of G × E. Since most previous G × E studies reported parenting in terms of standardized means (e.g., Sulik et al., 2015) or factor scores (e.g., Cho et al., 2016; Smith et al., 2012), however, it is difficult to determine if other studies also included restricted ranges of parenting. Additional explanations for discrepant findings include demographic or measurement differences across studies. Most previous research, however, has included populations similar to the current study (Smith et al., 2012; Sulik et al., 2015; Kochanska et al., 2009; Sheese et al., 2012; Van Heel et al, 2020). Several have used the same or similar measures for child effortful control and parenting measures as the current study (Sulik et al., 2015; Sheese et al., 2012; Zhao et al., 2020). Therefore,

it seems unlikely that demographic or measurement differences account for our different pattern of findings.

Limitations and Future Directions:

Methodological considerations: This study had several strengths, including an adoption research design that differentiated between the contributions of heritable and parenting factors to children's effortful control over time, different reporters for parenting and child effortful control, and its longitudinal design. However, there were also several limitations that invite further research. In particular, most parents described functional forms of parenting, including highly structured, consistent, and calm vs. lax and overreactive styles. Consequently, we were not able to examine G × E within the context of parenting adversity. Additional parenting behaviors should also be considered in future G × E studies. We focused on parental laxness and overreactivity based upon theory (Kopp, 1982; Vygotsky, 1978) and previous research (Karreman, 2006). However, in a recent analysis with the current sample, Cioffi (2020) found that observed maternal warmth during infancy served as a protective factor for the development of inhibitory control in childhood by compensating for children's earlier attentional control difficulties. Therefore, warmth may also interact with BM personality to predict children's effortful control. A third limitation is that we did not include birth fathers' personality characteristics as indices of heritable influences. Consequently, it is likely that heritable influences on children's behaviors were underestimated.

Sociodemographic considerations: Another key limitation is that our study included a high-SES community sample of mostly two-parent, adoptive families with little racial diversity. Therefore, the generalizability of our findings may be limited. Current research emphasizes the importance of contextual factors such as economic adversity and race on parenting and the development of effortful control skills. There is accumulating evidence that economic stress can adversely affect the development of effortful control (Atherton et al., 2020; Bridgett, 2015), and these effects are apparent during the preschool period (Raver, et al., 2013; Lengua et al., 2015). In part, these effects could be explained by decreased parental sensitivity and responsiveness in the face of financial stress (i.e., Family Stress Model, Conger & Donnellan, 2007). Emerging research also points to links between poverty and alterations in neural structures that underlie self-regulation, language, and memory (Noble, Houston, Brito et al., 2016). Such effects may reflect the direct impacts of family stress on the developing brain or disadvantaged home environments with lower levels of cognitive and linguistic stimulation (Brito & Noble, 2014; Noble et al al., 2016), as well as exposure to higher levels environmental toxins such as air pollution that are frequently found in impoverished neighborhoods (Margolis, Herbstman, Davis et al, 2016). Consequently, families' socioeconomic context could affect the importance and expression of gene × parenting interactions for the development of effortful control and externalizing behavior.

Children's race and ethnicity are additional factors that should be considered carefully in future research. Racial and ethnic minority status is often associated with a host of unique stressors that can affect parenting and child outcomes, including personal exposure to discrimination and oppression (Garcia-Coll, et al., 1996), and for immigrants,

acculturative stressors (Emmen, 2013). Structural racism also has a pervasive influence on the psychological and physical wellbeing of racial minorities (Williams, Lawrence, Davis, 2019). This form of racism refers to laws, practices, and institutions that provide advantages to one racial group, while simultaneously limiting resources and opportunities for other racial groups. Consequently, structural racism creates disadvantageous contexts that can deepen the stress of interpersonal racism, while also fostering and maintaining poverty and its attendant psychosocial and environmental stressors. Therefore, both race-related stressors and structural racism could influence the type of G × E observed and its importance for the development of effortful control.

Conclusions:

In summary, the current study found evidence that G × E processes during the toddler period predicts preschool effortful control, consistent with previous candidate gene studies. In addition our study indicates that children's heritable predisposition may influence the type of parenting they need to develop strong effortful control skills, rather than determine their general sensitivity to specific types of parenting. Last, we were able to demonstrate that G × E contributions to effortful control have implications for subsequent externalizing behavior. These findings suggest that G × E is an important first step in a developmental path that leads to long term externalizing behavior. Efforts to prevent or reroute children's development may benefit most from considering the fit between children's heritable tendencies and their rearing environment in early development, rather than characterizing such tendencies as stable genetic risks, vantages, or indicators of plasticity. Our findings, however, require replication in a larger study sample drawn from a more socioeconomically and racially diverse population.

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Availability of data and material:

We affirm the validity of the data included in this report. Data are available upon request.

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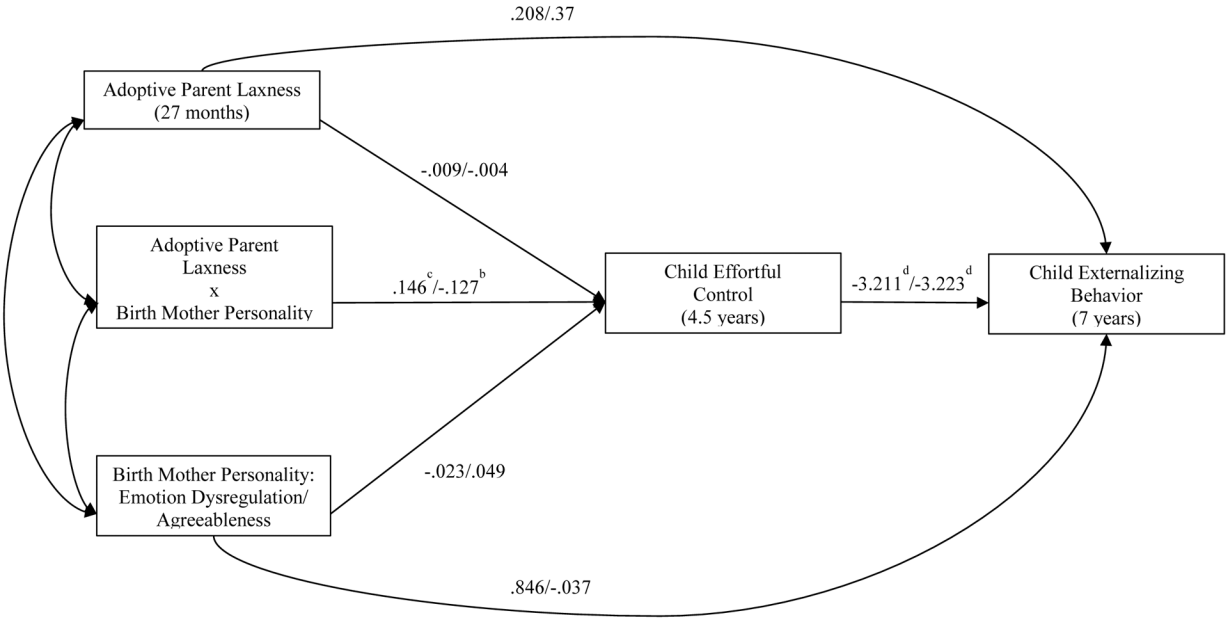

Figure 1: Associations between Birth Mother Personality, Adoptive Parent Laxness at 27 months, Effortful Control at 4.5 years, and Child Externalizing Behavior at 7 years

This figure summarizes unstandardized path estimates from models that included Birth Mother Emotional Dysregulation and Agreeableness. The first path estimates are derived from a model that included Birth Mother Emotional Dysregulation, controlling for the effects of Agreeableness, the second set of estimates are derived from a model that included Agreeableness, controlling for the effects of Emotional Dysregulation. For the sake of simplicity, covariates are not included in this Figure.

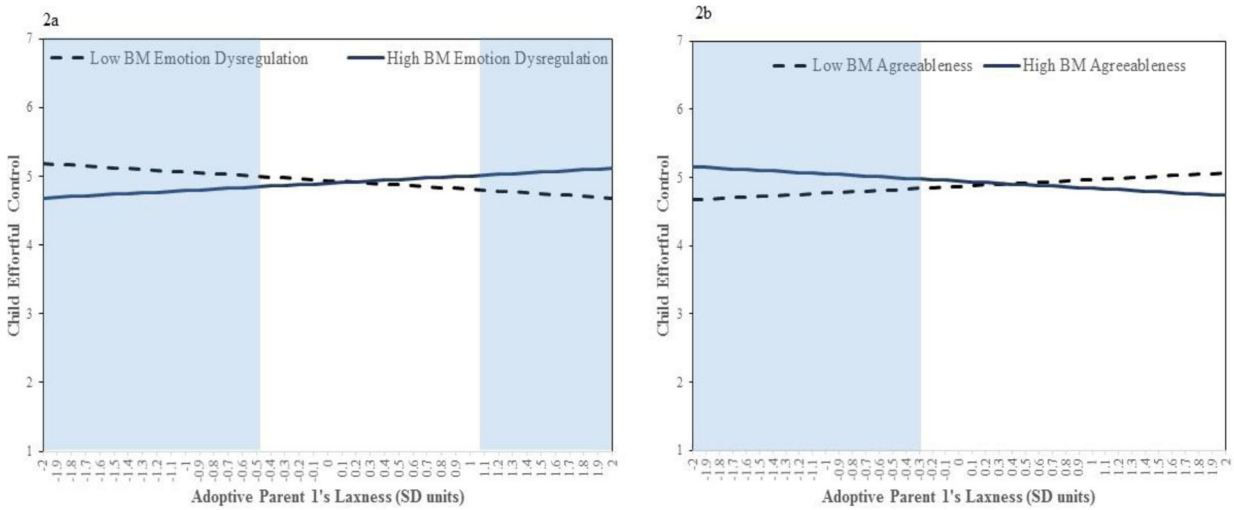

Figure 2:

Associations between AP1 Laxness and Child Effortful Control as a function of BM Emotion Dysregulation (2a) and BM Agreeableness (2b). The shaded areas in each figure represent regions of significance

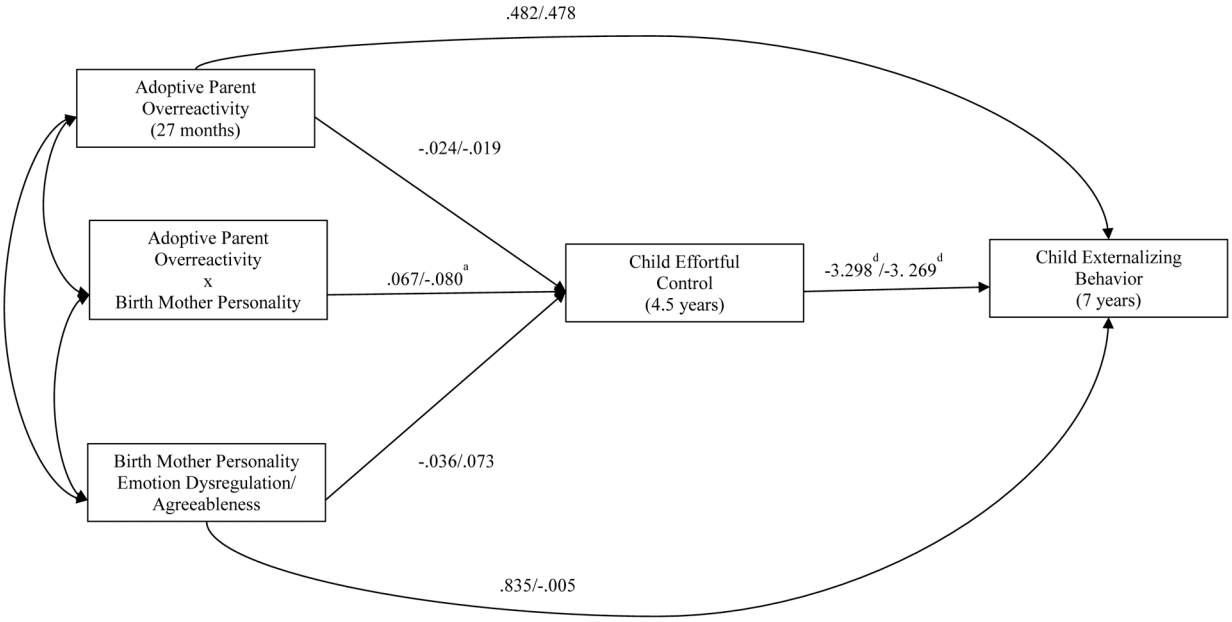

Figure 3: Associations between Birth Mother Personality, Adoptive Parent Overreactivity at 27 months, Effortful Control at 4.5 years, and Child Externalizing Behavior at 7 years

This figure summarizes unstandardized path estimates from models that included Birth Mother Emotional Dysregulation and Agreeableness. The first path estimates are derived from a model that included Birth Mother Emotional Dysregulation, controlling for the effects of Agreeableness, the second set of estimates are derived from a model that included Agreeableness, controlling for the effects of Emotional Dysregulation. For the sake of simplicity, covariates are not included in the Figure.

Please note that $^{+}p<.10$, $^{a}p<.05$; $^{b}p<.01$; $^{c}p<.001$; $^{d}p<.0001$.

Table 1

Bivariate Correlations, Means, and Standard Deviations among Study Variables

	M (*SD*)	Min	Max	Skew	Kurtosis	1	2	3	4	5	6	7	8	9
1. BM emotion dysregulation	.05 (.81)	−2.47	2.65	.01	.51	-								
2. BM agreeableness	−.01 (.78)	−2.28	1.91	−.43	−.11	−.49**	-							
3. AP1 laxness at 27 mos	2.23 (.63)	1	5.09	.48	.51	−.12*	.05	-						
4. AP1 overreactivity at 27 mos	2.09 (.59)	1	4.30	.50	−.03	−.02	.06	.34**	-					
5. Child effortful control at 4.5 yrs	5.00 (.53)	3.39	6.58	.05	.06	−.10+	.14*	−.01	−.01	-				
6. Child externalizing behaviors at 7 yrs	6.33 (5.57)	0	28.00	1.31	2.21	.14*	−.11	.05	.10	−.35**	-			
7. Child sex	1.43					.06	0	−.04	.11	.24**	−.06	-		
8. Adoption openness	.04 (.93)	−2.06	1.84	−.19	−.55	.07	0	−.02	−.05	.07	−.03	−.08	-	
9. Perinatal risks	4.55 (3.20)	0	14	.28	−.74	.02	.07	.04	.04	.01	.02	.03	.09+	-

Notes: BM = Birth Mother, AP1 = Adoptive Parent 1.

+ $p < .10$,

* $p < .05$,

** $p < .01$.