The Relationship Between Parental Emotional Warmth, Self-Control, and Adolescent Prosocial Behavior: Polygenic Moderation and Parental Differences

Authors: Nie Yangang, Chen Pei, Wang Linxin, Yu Chengfu, Li Zhenhua, Nie Yangang

Date: 2024-06-15T00:00:00+00:00

Abstract

This study constructed an "Environment × Polygene—Endophenotype—Behavior" theoretical framework and conducted a half-year longitudinal study with 880 middle school students to investigate the mediating role of self-control in the relationship between parental emotional warmth and adolescent prosocial behavior. Furthermore, employing a polygenic additive score research paradigm, we examined how genes from the dopamine, serotonin, and oxytocin systems (COMT gene rs6269, HTR2A gene rs6313, OXTR gene rs53576, OXTR gene rs2254295, and OXTR gene rs2254298) moderate this mediating mechanism and tested for parental differences therein. The results demonstrated that: (1) After controlling for baseline levels of prosocial behavior, parental emotional warmth not only positively predicted prosocial behavior but also exerted an influence on prosocial behavior through self-control; (2) The interaction between polygenic additive score and parental emotional warmth could not directly predict prosocial behavior, but rather impacted prosocial behavior via self-control, with no parental differences observed in this mechanism. Among adolescents with higher polygenic additive scores, parental emotional warmth significantly and positively predicted self-control, which subsequently influenced prosocial behavior; conversely, among adolescents with lower polygenic additive scores, this mediating pathway was not significant. These findings elucidate how the effects of parental emotional warmth on adolescent self-control and prosocial behavior vary depending on polygenic additive scores, thereby contributing to a deeper understanding of the mechanisms underlying prosocial behavior.

Full Text

Parental Emotional Warmth, Self-Control, and Adolescent Prosocial Behavior: The Moderating Role of Multilocus Genetic Profile Scores and Parental Gender Differences

NIE Yangang[1], CHEN Pei[1], WANG Linxin[2], YU Chengfu[1], LI Zhenhua[1]

(1 Department of Psychology, Research Center for Adolescent Psychology and Behavior, School of Education, Guangzhou University, Guangzhou 510006, China)
(2 Beijing Key Laboratory of Applied Experimental Psychology, National Demonstration Center for Experimental Psychology Education (Beijing Normal University), Institute of Developmental Psychology, Beijing Normal University, Beijing 100875, China)

Abstract

This study constructed a theoretical framework of "Environment × Polygene–Endophenotype–Behavior" and conducted a six-month longitudinal study with 880 middle school students to examine the mediating role of self-control in the relationship between parental emotional warmth and adolescent prosocial behavior. Further, using a multilocus genetic profile score research paradigm, we investigated how genes from the dopamine, serotonin, and oxytocin systems (COMT gene rs6269, HTR2A gene rs6313, OXTR gene rs53576, OXTR gene rs2254295, and OXTR gene rs2254298) moderate this mediating mechanism and tested for parental differences. Results showed that: (1) After controlling for baseline prosocial behavior, parental emotional warmth not only positively predicted prosocial behavior but also influenced prosocial behavior through self-control; (2) The interaction between multilocus genetic profile scores and parental emotional warmth did not directly predict prosocial behavior but rather influenced prosocial behavior through self-control, and this mechanism showed no parental differences. Specifically, among adolescents with higher multilocus genetic profile scores, parental emotional warmth significantly positively predicted self-control, which in turn affected prosocial behavior; whereas among adolescents with lower multilocus genetic profile scores, this mediating pathway was not significant.

These findings elucidate how parental emotional warmth influences adolescent self-control and prosocial behavior differently depending on multilocus genetic profile scores, contributing to a deeper understanding of the mechanisms underlying prosocial behavior.

Keywords: prosocial behavior, parental emotional warmth, self-control, multilocus genetic profile scores, parental differences

1. Introduction

Prosocial behavior refers to actions that benefit others and promote positive social relationships (Eisenberg et al., 2006). As a marker of positive social functioning, individual prosocial behavior is crucial for building a harmonious society. As the foundation of adolescent social competence and moral development, prosocial behavior also promotes adolescents' social adaptation and reduces the risk of internalizing and externalizing problems (Liu et al., 2024; Zondervan-Zwijnenburg et al., 2022). Behavioral genetics research has shown that both genetic and family environmental factors underlie prosocial behavior (Knafo-Noam et al., 2018). Although scholars have recently explored the mechanisms of prosocial behavior, the specific mechanisms through which environmental and genetic factors interactively influence prosocial behavior remain underdeveloped. Most existing research has focused on the interactive effects of parental practices and single genes on adolescent prosocial behavior, while studies from a polygenic perspective that further explore endophenotype mechanisms are particularly lacking.

According to socialization models of prosocial behaviors, parental behavior provides an important foundation for prosocial development, and various individual internal factors such as cognitive-emotional traits and values are closely associated with prosocial behavior (Eisenberg & Mussen, 1989; Eisenberg & Spinrad, 2014). Social cognitive models of prosocial behaviors further emphasize that individuals' internal social-cognitive and emotional processes serve as mediators and bridges between parenting and prosocial behavior, with clarifying these mediating mechanisms offering new perspectives for cultivating prosocial behavior. Moreover, recent research has called for examining the interactive effects of multilocus genetic profile scores (MGPS) and environmental factors on adolescent psychological and behavioral development, which can address the low reliability of previous single-gene findings while also increasing genetic explanatory power (Lin Xiaonan et al., 2023; Starr & Huang, 2019; Zhang & Belsky, 2020). Therefore, this study examines the mediating effect of self-control in the relationship between parental emotional warmth and adolescent prosocial behavior. Building on this, we construct cumulative scores for dopamine, oxytocin, and serotonin system genes to investigate whether the interaction between parental emotional warmth and MGPS influences adolescent prosocial behavior through self-control.

1.1 The Relationship Between Parental Emotional Warmth and Adolescent Prosocial Behavior

Socialization models of prosocial behaviors emphasize that parents, as central figures in adolescents' social interactions, provide an important psychological foundation for the formation and development of prosocial behavior through their parenting styles (Eisenberg & Mussen, 1989; Eisenberg & Spinrad, 2014). Parental emotional warmth refers to parents' attention to children's emotional needs and their provision of care, responsiveness, comfort, and support during parent-child interactions (Baumrind, 1991). Research indicates that emotionally warm parenting helps children gradually develop the resources needed for self-regulation and environmental adaptation, fostering positive interpersonal interaction tendencies and promoting prosocial behavior (Buckley et al., 2023; Williams & Berthelsen, 2017). Conversely, parents lacking emotional warmth show low responsiveness to children's needs, resulting in poorer emotional expression abilities in children that hinder prosocial development (Carlo, White, et al., 2018).

Influenced by Confucian family values and traditional gender division of labor, mothers bear primary responsibility for child-rearing and family education, spending significantly more time interacting with children than fathers. Correspondingly, some previous studies have only examined maternal parenting effects on prosocial behavior, emphasizing mothers' more important role in adolescent development (Davis et al., 2018; Vaughan et al., 2021). However, other research suggests that one parent's exclusive interaction with the child does not mean that only that parent exerts influence (Ward & Lee, 2020). With rapid social and cultural changes, fathers have become increasingly involved in children's socialization processes, sharing parenting responsibilities and obligations with mothers (Bianchi & Milkie, 2010; Li, 2020). Numerous studies have shown that both fathers and mothers significantly predict adolescent social development (Daniel et al., 2016; Lee et al., 2018). Most current scholars examine paternal and maternal emotional warmth as a combined construct and have confirmed significant associations between parental emotional warmth and adolescent prosocial development (Buckley et al., 2023; Kil et al., 2023; Quan et al., 2021). Only a few studies have examined paternal and maternal emotional warmth separately without further comparing whether their effects differ (Wang et al., 2023; Wong & Konishi, 2023). Based on these considerations, this study examines the mechanism through which parental emotional warmth influences adolescent prosocial behavior development and tests whether this mechanism shows parental differences.

1.2 The Mediating Role of Self-Control

According to socialization models of prosocial behaviors, prosocial behavior depends not only on parental practices but is also closely associated with individual internal cognitive-emotional factors such as self-regulation (Eisenberg & Mussen, 1989; Eisenberg & Spinrad, 2014). Social cognitive models of prosocial behaviors further hypothesize that positive parenting promotes cognitive-emotional processes related to prosocial characteristics, which in turn influence prosocial behavior. In other words, individuals' internal social-cognitive and emotional variables may be important mediators through which parental emotional warmth affects adolescent prosocial behavior (Bandura, 1986; Carlo, Streit, & Crockett, 2018; Eisenberg et al., 2015). Emotionally warm parenting creates a supportive interactive environment that facilitates children's internalization of social norms and rules and helps them construct their own behavioral regulation mechanisms, thereby promoting self-control development (Cai Xuebin et al., 2022; Li, Willems, et al., 2019). According to the self-control process model of altruistic behavior, self-control is an important internal psychological process in prosocial behavior that can inhibit self-interested impulses and promote prosocial actions (Fei Dingzhou et al., 2016). Individuals with high self-control can effectively regulate their attention processes in response to social environmental changes, adopt a "decentration" perspective, show greater concern for others' needs in interpersonal interactions, and consequently exhibit more prosocial behavior (Zhang & Wang, 2020). Empirical research has shown that positive parenting significantly promotes adolescent self-control development, which in turn enhances adolescent prosocial behavior (Eisenberg et al., 2019; Ferschmann et al., 2023). Li, Yu et al. (2023) also noted that self-control can mediate the relationship between parent-child attachment and adolescent prosocial behavior. These theoretical and empirical clues suggest that self-control may be a key window for understanding how parental emotional warmth influences prosocial behavior. Therefore, this study examines the mediating role of self-control in the relationship between parental emotional warmth and prosocial behavior.

1.3 The Moderating Role of Multilocus Genetic Profile Scores

Behavioral genetics research suggests that the process through which parental emotional warmth influences adolescent prosocial behavior via self-control may be moderated by genetic factors (Knafo-Noam et al., 2018). Previous research suggests that gene-environment interactions may not directly encode behavioral phenotypes (Caspi & Moffitt, 2006; Zhang Wenxin et al., 2021). Compared with external behavioral phenotypes, intermediate endophenotypes are more closely associated with genetic foundations and can more directly and strongly reflect the influence of gene-environment interactions (Rommelse et al., 2008; Zhang et al., 2020). Examining endophenotype mechanisms of environment-gene interactions on behavior is more conducive to revealing the full picture of psychological and behavioral development. Therefore, this study constructed an "Environment × Polygene–Endophenotype–Behavior" framework to investigate whether the interaction between parental emotional warmth and MGPS can influence self-control and subsequently predict prosocial behavior.

Numerous studies have shown that serotonin, oxytocin, and dopamine system genes play important roles in the expression of phenotypes related to self-control, impulsivity, and delayed reward (Davies et al., 2015; Stamatis et al., 2020; Stoltenberg et al., 2012). Specifically, the serotonin receptor (5-HTR) gene regulates serotonin concentration in the synaptic cleft by mediating serotonin reuptake in the presynaptic membrane (Lesch, 2007), thereby affecting self-control resources needed for environmental adaptation (Stamatis et al., 2020). The oxytocin receptor (OXTR) gene encodes OXTR, which regulates reward-related responses, including self-control and addictive behaviors, by acting on mesolimbic dopaminergic activity (Damiano et al., 2014; Kemp & Guastella, 2010). The catechol-O-methyltransferase (COMT) gene encodes a key metabolic enzyme that degrades catecholamines (including dopamine and norepinephrine), reducing dopamine concentration in the synaptic cleft and thereby affecting impulse inhibition and self-control processes (Van Heel et al., 2020).

Theoretical and empirical research further shows that interactions between environmental factors and 5-HTR, OXTR, and COMT genes can significantly predict the development of specific phenotypes. According to the environmental sensitivity model, the interaction pattern between environment and genes essentially reflects individual differences in environmental sensitivity. That is, individuals carrying sensitivity genes show unstable psychological and behavioral responses to environmental changes—they are more susceptible to negative environments and show more maladaptive problems, but also benefit more from positive environments and show more adaptive outcomes (Pluess et al., 2018). Existing research provides preliminary evidence for this interaction pattern. For example, serotonin regulates individual responses to environmental stimuli in the amygdala and medial frontal cortex connection regions (Cools et al., 2008). The HTR2A gene rs6313 has been shown to moderate the impact of maternal parenting attitudes on individual development, with individuals carrying the rs6313 polymorphism T allele showing higher sensitivity to maternal parenting (Merjonen et al., 2011). The main expression brain regions of COMT and OXTR genes are concentrated in the prefrontal cortex and limbic system, which are involved in regulating individuals' environmental sensitivity (Matsumoto et al., 2003; Tost et al., 2010). Cao et al. (2021) found in a cross-sectional study that for adolescents with the COMT gene rs4680 ValVal genotype, positive parenting positively predicted inhibitory control, which in turn reduced depression risk, whereas this mediating pathway was not significant among adolescents carrying the Met allele. The OXTR gene rs53576 interacts with maternal sensitivity to affect individuals' self-regulation, with individuals carrying the G allele showing self-regulation more susceptible to maternal sensitivity (Augustine et al., 2018).

Previous studies have selectively examined the interaction between single nucleotide polymorphisms (SNPs) and environment on adolescent socialization development, providing important directions for identifying mechanisms of individual psychological and behavioral development. However, with the advancement of research, the limitations of the "environment × single gene" paradigm have gradually emerged, mainly manifested in extremely small effect sizes, low result reliability, and inability to capture additive genetic effects (Starr & Huang, 2019; Zeng et al., 2023). Meanwhile, multiple studies have shown that genetic effects are additive, with different genetic polymorphisms potentially influencing individual development in a cumulative manner (Diekhof et al., 2021; Green et al., 2017; Plomin, 2013). In recent years, researchers have adopted the method of constructing multilocus genetic profile scores (MGPS)—selecting multiple SNPs associated with specific psychological and behavioral traits and building a cumulative index of plasticity alleles—to obtain larger genetic effects. For example, Di Iorio et al. (2017) studied cumulative scores for three SNPs related to anxiety (5-HTR2C rs6318, TPH2 rs4570625, DRD2 rs1800497) and found that stressful life events and MGPS interactively influenced anxiety and depression symptoms. Yu and Huang et al. (2020) used machine learning algorithms to screen 22 key SNPs from dopamine, serotonin, and oxytocin systems and construct an MGPS, finding that childhood maltreatment and MGPS interactively influenced negative automatic thoughts. However, to date, no study has examined the mechanisms of adolescent prosocial behavior from the perspective of MGPS within the "environment × polygene–endophenotype–behavior" framework. Therefore, this study further examines the moderating role of MGPS in the relationships among parental emotional warmth, self-control, and adolescent prosocial behavior. To reduce the risk of false positives and enhance theoretical explanatory power, we first preliminarily selected 37 genetic polymorphisms related to self-control from dopamine, oxytocin, and serotonin systems based on previous research. We then used leave-one-out cross-validation to screen key polymorphisms that significantly interacted with parental emotional warmth to influence self-control, thereby constructing the MGPS (Yu, Huang, et al., 2020).

1.4 Overview of the Study

Integrating the above discussion, this study employed a longitudinal design to examine the mediating mechanism of self-control between parental emotional warmth and prosocial behavior. Furthermore, using the MGPS research paradigm, we constructed MGPSs for dopamine, oxytocin, and serotonin systems to investigate whether parental emotional warmth and MGPS influence prosocial behavior through self-control and whether parental differences exist. We propose the following hypotheses:

Hypothesis 1: Parental emotional warmth significantly positively predicts prosocial behavior by enhancing adolescent self-control.

Hypothesis 2: Parental emotional warmth and MGPS interactively influence adolescent self-control, which in turn affects prosocial behavior.

2. Methods

2.1 Participants and Procedure

We used cluster sampling to select first-year middle school and first-year high school students from three ordinary middle schools in Guangzhou, Guangdong Province. At the first time point (T1, November 2021), we measured adolescents' parental emotional warmth, prosocial behavior, basic demographic information, and collected genetic data. Six months later (T2, May 2022), we measured adolescent self-control and prosocial behavior again. At T1, 880 adolescents participated (Mage = 14.34 years, SD = 1.50; 472 boys and 398 girls, with 10 adolescents not reporting gender). At T2, 723 adolescents remained in the study, while 157 were absent due to leave, training, or dropout. Retained and lost adolescents showed no significant differences in age, family living standards, or prosocial behavior, but differed in parental emotional warmth and gender (partial $^2 = 0.013–0.121$). Following Bandalos (2002) and previous research (Liang et al., 2023), when partial $^2 < 0.14$, the effect size is small and can be ignored. Among the 880 adolescents, 41.3% of fathers and 36.0% of mothers had bachelor's degrees or higher; 36.1% of fathers and 39.6% of mothers had college or high school education; and 22.6% of fathers and 24.4% of mothers had education below high school.

This study was approved by the Research Ethics Committee (Ethics Number: GZHU202315). Before data collection, we informed schools, parents, and adolescents about all procedures and obtained signed informed consent from both parents and adolescents. During testing, each class was administered by two trained research assistants (undergraduate/graduate students) familiar with the questionnaires and saliva collection. All participants completed questionnaires and provided saliva DNA samples in their classrooms and had the right to withdraw at any time.

2.2 Measures

2.2.1 Parental Emotional Warmth We used the parental emotional warmth subscale from the Short-Egna Minnen av Barndoms Uppfostran (s-EMBU) developed by Perris et al. (1980) and revised by Jiang et al. (2010). The subscale includes father and mother versions, each with 7 items (e.g., "I feel my father/mother tries to make my adolescent life more meaningful and colorful"). Items are rated on a 4-point scale from 1 (never) to 4 (always). Higher mean scores indicate higher levels of paternal or maternal emotional warmth. In this study, the scale showed good internal consistency (Cronbach's $\alpha = 0.92$).

2.2.2 Self-Control We used the Dual Mode of Self-Control Scale (DMSC-S) developed by Dvorak and Simons (2009) and revised by Xie et al. (2014). The scale includes 21 items divided into two dimensions: impulsive system (12 items, e.g., "I am an impulsive person") and control system (9 items, e.g., "When encountering problems, I try to solve them"). Items are rated on a 5-point scale from 1 (completely disagree) to 5 (completely agree). After reverse-scoring the impulsive system items, we calculated the mean of all items, with higher scores indicating higher self-control. In this study, the scale showed good internal consistency (Cronbach's $\alpha = 0.90$).

2.2.3 Prosocial Behavior We used the prosocial behavior subscale from the Chinese version of the Strengths and Difficulties Questionnaire (SDQ) developed by Goodman (2000) and revised by Zhang et al. (2009). The subscale includes 5 items rated on a 3-point scale from 0 (not true) to 2 (certainly true), with higher mean scores indicating higher prosocial behavior. In this study, Cronbach's α was 0.73 at T1 and 0.81 at T2.

2.2.4 Covariates Based on relevant literature on prosocial behavior (Zhang Wenxin et al., 2021), we controlled for adolescents' age, gender (0 = male, 1 = female), family economic level (1 = poor, 2 = not well-off, 3 = average, 4 = relatively wealthy, 5 = wealthy), and parental education level (1 = elementary school or below, 2 = junior high school (including incomplete), 3 = high school or technical school (including incomplete), 4 = college (including night school, TV university), 5 = bachelor's degree, 6 = graduate degree (master's or doctoral)).

2.2.5 Saliva DNA Extraction and Genotyping We collected saliva DNA samples from participants using portable saliva collectors in classroom settings. Participants rinsed their mouths with water 30 minutes before collection and avoided eating, smoking, drinking, or brushing teeth during the 30 minutes prior. During collection, participants slowly spat saliva to approximately the 2ml mark in the collection tube and tightened the cap. Genotyping was performed using SNaPshot technology on a 96-channel automatic ABI 3730xL genetic analyzer. The detection platform and genotyping technology used in this study had high reliability (genotyping efficiency > 95%). To ensure genetic data quality, we excluded SNPs with detection rates below 95% and minor allele frequency (MAF) less than 2% (Yu, Huang, et al., 2020), retaining 37 SNPs for subsequent analysis. Detailed single nucleotide polymorphism information is presented in Table 1 .

2.3 Data Analysis

2.3.1 Construction of Multilocus Genetic Profile Scores We used Python 3.7 software to perform leave-one-out cross-validation to screen key genetic polymorphisms and calculate MGPS (Yu, Huang, et al., 2020). Specifically, leave-one-out cross-validation divides participants into training sets (N–1 participants) and test sets (1 participant), with multiple iterations of training and testing to improve reliability. The procedure involved: (1) Screening key genetic polymorphisms: In the training set, we constructed interaction terms between candidate SNPs and parental emotional warmth, then regressed these interaction terms on self-control scores. If the regression coefficient was significant in 95% of iterations, the SNP was marked as a key polymorphism and included in subsequent analysis; (2) Calculating MGPS: We reverse-coded genotypes of key SNPs with significant regression coefficients less than 0, then accumulated and averaged all key SNPs' genotypes; (3) Model training: In the training set of N–1 participants, we regressed standardized parental emotional warmth scores, standardized MGPS, and their interaction term on self-control scores, selecting the regression equation with the largest R^2 through leave-one-out validation; (4) Model prediction: We input the test set's MGPS and parental emotional warmth into the best regression equation from step (3) to obtain predicted self-control scores. After N iterations, we generated predicted self-control scores for all participants. We then correlated predicted self-control scores with actual self-control scores to test the model's predictive ability.

2.3.2 Statistical Analysis We used SPSS 26.0 and Mplus 8.3 (Muthén & Muthén, 1998–2017) for preliminary data analysis and model testing. First, we conducted descriptive statistics to obtain means and standard deviations of study variables and performed correlation analysis to examine associations among variables. Second, we constructed a mediation model to test the mediating effect of T2 self-control between T1 parental emotional warmth and T2 prosocial behavior. Third, we constructed a moderated mediation model to test the moderating role of MGPS in the mediating mechanism. Fourth, we conducted simple slope tests and region of significance analysis (RoS) for the interaction between MGPS and parental emotional warmth to further verify whether the interaction pattern conformed to the environmental sensitivity model. If the pattern conformed to the model, RoS results should meet the following criteria: within $±$2 SD of parental emotional warmth, self-control should show significant differences between high and low MGPS when parental emotional warmth is extremely high or low; proportion of interaction (PoI) should be between 0.40–0.60; and proportion affected (PA) should be between 16%–84%. In all model analyses, we used bootstrap methods (N = 5000) to test the significance of moderated mediation and moderation effects and employed full information maximum likelihood estimation (FIML) to handle missing data. Fifth, we performed multi-group comparisons of the moderated mediation model to test for parental and adolescent gender differences.

3. Results

3.1 Construction of Multilocus Genetic Profile Scores

Leave-one-out cross-validation results showed (see Figure 1 [Figure 1: see original paper]) that predicted self-control scores were significantly positively correlated with actual self-control scores (r = 0.20, p = 2.33$\times 10^{-7}$), confirmingthevalidityofthemachinelearningmodel.ThestudyidentifiedfivesignificantSNPs(seeFigure2[Figure2:
= 1.37, p = 0.242, GG = 10.0%; GA = 46.0%, AA = 44.0%), rs6313 (^{2} = 2.42, p = 0.120; CC = 14.6%, CT = 44.0%, TT = 41.4%), rs53576 (^{2} = 0.01, p = 0.930; GG = 10.3%, GA = 43.7%, AA = 46.0%), rs2254295 (^{2} = 0.31, p = 0.692; CC = 8.5%, CT = 44.5%, TT = 47.0%), and rs2254298 (^{2} = 0.13, p = 0.722; GG = 48.7%, GA = 41.8%, AA = 9.5%) all conformed to Hardy-Weinberg equilibrium, with MAF > 2%. Following previous research (Cao Yanmiao & Zhang Wenxin, 2019; Stocker et al., 2017), we tested linear genetic effects for these five polymorphisms. Model results showed that the decomposition model had higher explanatory power than the linear genetic effect model, but the change in R^2 between the two models was not significant ($\Delta R^2 = 0.005$, F(10, 764) = 0.48, p = 0.904). Therefore, based on interaction term regression coefficients, we linearly coded genotypes: rs6269 (GG = 0, GA = 1, AA = 2), rs6313 (CC = 0, CT = 1, TT = 2), rs53576 (AA = 0, GA = 1, GG = 2), rs2254295 (CC = 0, CT = 1, TT = 2), and rs2254298 (AA = 0, GA = 1, GG = 2). We accumulated and averaged genotype scores across loci to obtain the MGPS, with its distribution shown in Table 2 .

3.2 Descriptive Statistics

Table 3 presents descriptive statistics and correlation analysis results. As shown, T1 parental emotional warmth was significantly positively correlated with T2 self-control, T1 prosocial behavior, and T2 prosocial behavior. T2 self-control was significantly positively correlated with T1 prosocial behavior and T2 prosocial behavior. T1 prosocial behavior was significantly positively correlated with T2 prosocial behavior. MGPS was not significantly correlated with T1 parental emotional warmth, T2 self-control, T1 prosocial behavior, or T2 prosocial behavior.

3.3 Mediating Effect of Self-Control

We constructed a mediation model with T1 parental emotional warmth as the independent variable, T2 self-control as the mediator, T2 prosocial behavior as the dependent variable, T1 prosocial behavior as the baseline, and age, gender, parental education, and family economic level as covariates. The mediation model showed good fit ($^2(10) = 4.17$, CFI = 0.93, RMSEA = 0.06, 90%CI = [0.042, 0.079], SRMR = 0.04, see Figure 3 [Figure 3: see original paper]). T1 parental emotional warmth significantly positively predicted T2 self-control (b = 0.09, SE = 0.04, p = 0.017) and T2 prosocial behavior (b = 0.08, SE = 0.03, p = 0.002). T2 self-control significantly positively predicted T2 prosocial behavior (b = 0.06, SE = 0.03, p = 0.025). The mediating effect of T2 self-control between T1 parental emotional warmth and T2 prosocial behavior was significant (effect = 0.01, SE = 0.003, 95%CI = [0.001, 0.015]).

3.4 Moderating Effect of Multilocus Genetic Profile Scores

We incorporated MGPS into the previous mediation model. The moderated mediation model showed good fit ($^2(17) = 1.99$, CFI = 0.96, RMSEA = 0.04, 90%CI = [0.017, 0.052], SRMR = 0.04). MGPS moderated the effect of T1 parental emotional warmth on T2 self-control (b = 0.38, SE = 0.09, $p < 0.001$, see Table 4) but did not moderate the direct effect of T1 parental emotional warmth on T2 prosocial behavior (b = –0.12, SE = 0.06, p = 0.064). When excluding any single polymorphism and analyzing the cumulative score of the remaining four polymorphisms, the cumulative score of any four polymorphisms significantly moderated the effect of T1 parental emotional warmth on T2 self-control (excluding OXTR rs53576: b = 0.33, SE = 0.09, $p < 0.001$; excluding OXTR rs2254295: b = 0.36, SE = 0.09, $p < 0.001$; excluding OXTR rs2254298: b = 0.36, SE = 0.10, $p < 0.001$; excluding COMT rs6269: b = 0.29, SE = 0.08, $p < 0.001$; excluding HTR2A rs6313: b = 0.30, SE = 0.08, $p < 0.001$), indicating no dominant effect of any single polymorphism.

Further simple slope tests showed that self-control levels of adolescents with high MGPS (+1 SD) increased significantly with parental emotional warmth (b = 0.22, SE = 0.05, $p < 0.001$), whereas for adolescents with low MGPS (–1 SD), parental emotional warmth did not significantly affect self-control (b

= –0.05, SE = 0.05, p = 0.338). Moderated mediation analysis indicated that among adolescents with higher MGPS, self-control significantly mediated the relationship between parental emotional warmth and prosocial behavior (b = 0.01, SE = 0.01, 95%CI = [0.003, 0.033]), whereas this mediating pathway was not significant among adolescents with lower MGPS (b = –0.00, SE = 0.00, 95%CI = [–0.014, 0.002]). Additionally, region of significance analysis showed that when parental emotional warmth values were greater than 0.293, adolescents with higher MGPS had significantly higher self-control than those with lower MGPS; conversely, when parental emotional warmth values were less than –0.044, adolescents with higher MGPS had significantly lower self-control than those with lower MGPS (PoI = 0.44, PA = 0.45). Moreover, X^2 and ZX^2 did not significantly predict adolescent self-control, indicating no nonlinear relationships. Overall, these results suggest that the interaction pattern between parental emotional warmth and MGPS on adolescent self-control in this study conforms to the environmental sensitivity model.

To further test whether the moderated mediation model showed parental differences, we calculated separate scores for paternal and maternal emotional warmth and conducted multi-group comparisons by parent gender. Results showed good model fit ($^2(34)$ = 2.05, CFI = 0.96, RMSEA = 0.04, 90%CI = [0.024, 0.048], SRMR = 0.04). Both paternal emotional warmth × MGPS (b = 0.33, SE = 0.06, $p < 0.001$) and maternal emotional warmth × MGPS (b = 0.36, SE = 0.09, $p < 0.001$) significantly predicted self-control, with no significant parental differences in the interaction effect (b = –0.03, SE = 0.13, p = 0.810). Neither paternal nor maternal emotional warmth × MGPS significantly affected prosocial behavior (b_{father} = –0.12, SE = 0.06, p = 0.058; b_{mother} = –0.10, SE = 0.06, p = 0.098). Additionally, Wang et al. (2019) noted that simply including adolescent gender as a covariate might obscure important results. Therefore, we conducted multi-group comparisons by adolescent gender. Results showed good model fit ($^2(28)$ = 1.41, CFI = 0.96, RMSEA = 0.03, 90%CI = [0.000, 0.058], SRMR = 0.053). Parental emotional warmth × MGPS significantly predicted self-control for both boys and girls (b_{boys} = 0.41, SE = 0.13, p = 0.001; b_{girls} = 0.32, SE = 0.14, p = 0.021), with no gender differences in the interaction effect (b = 0.093, SE = 0.19, p = 0.625). Parental emotional warmth × MGPS did not significantly affect prosocial behavior for either gender (b_{boys} = –0.10, SE = 0.10, p = 0.292; b_{girls} = –0.10, SE = 0.08, p = 0.233).

4. Discussion

This longitudinal study examined the mediating role of self-control between parental emotional warmth and adolescent prosocial behavior. Using the MGPS research paradigm, we investigated for the first time how the interaction between MGPS from dopamine, oxytocin, and serotonin systems and parental emotional warmth influences prosocial behavior through self-control. Consistent with our hypotheses, after controlling for baseline prosocial behavior, parental emotional warmth indirectly influenced adolescent prosocial behavior through self-control, with multisystem MGPS moderating this effect and showing no parental differences. Specifically, among adolescents with higher MGPS, parental emotional warmth had a stronger effect on self-control, which in turn influenced prosocial behavior. For adolescents with lower MGPS, this mediating effect was not significant. These results provide important evidence for understanding the associations among parental emotional warmth, cumulative effects of multiple biological system genes, self-control, and prosocial behavior, offering theoretical support for cultivating adolescent prosocial behavior.

4.1 Mediating Role of Self-Control Between Parental Emotional Warmth and Prosocial Behavior

This study found that after controlling for baseline prosocial behavior, parental emotional warmth still positively predicted prosocial behavior, consistent with previous research (Zhang Wenxin et al., 2021; Kil et al., 2023; Pastorelli et al., 2021), again highlighting parental emotional warmth as an important predictor of prosocial development. Mediation analysis showed that self-control mediated the relationship between parental emotional warmth and prosocial behavior. This result supports social cognitive theory of prosocial behavior, which posits that parental emotional warmth fosters democratic, harmonious, and relaxed family interaction atmospheres that promote children's identification and internalization of social norms and values into self-control capabilities, thereby influencing prosocial development. Previous research based on social cognitive theory has mostly explored mediating processes from self-compassion and empathy perspectives (Zhang Wenxin et al., 2021; Yu, Li, & Zhao, 2020). Meanwhile, self-control as a core indicator of antisocial behavior has been widely reported as an explanatory mechanism between family environment and antisocial behavior. Indeed, theories and research suggest that self-control helps individuals inhibit instinctive impulses and desires, and prosocial behavior requires individuals to overcome automatic self-interested cognition and emotion through self-control (Fei Dingzhou et al., 2016; Knoch & Nash, 2015). However, in-depth empirical exploration of self-control's internal mechanism in how parenting influences prosocial behavior is lacking. This study examined how parental emotional warmth influences prosocial behavior from the perspective of self-control, showing that parental emotional warmth is an external motivator for self-control, while self-control is an internal promoting resource for prosocial behavior. The findings further clarify that self-control plays an important bridging and window role between parental emotional warmth and prosocial behavior, expanding social cognitive theory of prosocial behavior and deepening understanding of the internal endophenotype mechanisms through which parental emotional warmth affects prosocial behavior.

4.2 Moderating Role of Multilocus Genetic Profile Scores

This study further found that MGPS moderated the pathway through which parental emotional warmth influences prosocial behavior via self-control. The interaction pattern between parental emotional warmth and MGPS supported the environmental sensitivity model: adolescents with high MGPS showed significantly improved self-control with increasing parental emotional warmth, whereas adolescents with low MGPS showed stable self-control less affected by parental emotional warmth. Moreover, when MGPS was higher, parental emotional warmth more easily influenced self-control and subsequently promoted prosocial behavior; when MGPS was lower, the mediating effect of self-control was not significant. This result can be explained by the cumulative genetic plasticity model, which suggests that individuals carrying more plasticity alleles are more susceptible to environmental influences (Belsky et al., 2009; Belsky & Pluess, 2009). Among the genetic loci used to construct MGPS in this study, the COMT rs6269 A allele, HTR2A rs6313 T allele, OXTR rs53576 G allele, OXTR rs2254295 T allele, and OXTR rs2254298 A allele were identified as plasticity alleles, consistent with previous single gene-environment interaction research. For example, Merjonen et al. (2011) found that individuals carrying the T allele of HTR2A rs6313 were more sensitive to maternal parenting attitudes than those carrying the C allele. Similarly, compared to their counterpart alleles, COMT rs6269 A (Bernegger et al., 2018), OXTR rs53576 G (Chen et al., 2023), OXTR rs2254295 T (Bozorgmehr et al., 2019), and OXTR rs2254298 A alleles (Kajanoja et al., 2022) have all been shown to confer higher environmental sensitivity. MGPS represents the number of plasticity alleles an individual carries, reflecting the cumulative effect of plasticity alleles. Therefore, in this study, adolescents with higher MGPS showed self-control more susceptible to parental emotional warmth.

Additionally, MGPS did not moderate the direct effect of parental emotional warmth on prosocial behavior. This may be because gene-environment interactions do not directly affect external behavioral phenotypes. Research suggests that compared with external behavioral phenotypes, intermediate endophenotypes are more closely linked to genetic foundations and more directly and strongly reflect the influence of genetic polymorphisms (Rommelse et al., 2008; Zhang et al., 2020). Previous studies have found similar results; for example, the interaction between OXTR rs53576 and positive parenting did not directly affect prosocial behavior (Zhang Wenxin et al., 2021). This study directly selected genetic polymorphisms associated with self-control, potentially reflecting the direct effect of gene-environment interactions on self-control. Thus, the interaction between parental emotional warmth and MGPS does not directly affect prosocial behavior but rather influences it through self-control.

This study innovates in the MGPS research paradigm by using a theory-driven and data-driven approach to screen key genetic polymorphisms and constructing MGPS based on the number of plasticity alleles. This paradigm avoids the risk of misusing genetic indicators to some extent, compensates for statistical defects when using categorical single-gene polymorphisms in interaction modeling, and improves statistical power (Aliev et al., 2014). The MGPS in this study explained 2.3% of variance, a modest improvement over most previous single-gene studies. Future research should expand the genetic screening range to identify more key polymorphisms and comprehensively explore the full picture of gene-environment interactions on prosocial behavior. This study is the first to investigate the internal mechanisms among parental emotional warmth, multisystem polygenic interactions, adolescent self-control, and prosocial behavior, clarifying that self-control is an important endophenotype mechanism through which MGPS and parental emotional warmth interactively affect prosocial behavior. This provides empirical support for the "environment × polygene–endophenotype–behavior" framework and offers new options and perspectives for revealing mechanisms of complex adolescent behavioral phenotypes.

4.3 Parental Differences

This study found that both paternal and maternal emotional warmth interacted with MGPS to influence prosocial behavior development through self-control, with no significant differences between their effects. This result is similar to previous findings; for example, Putnick et al. (2018) showed that paternal and maternal acceptance had equal effects on adolescent prosocial behavior, and Stocker et al. (2017) found no parental differences when comparing the interactive effects of paternal and maternal parenting quality and MGPS on adolescent psychological adjustment. Due to Confucian values, social role division, and family changes, paternal and maternal parenting may differ (Wu Yuxiao et al., 2018; Wang et al., 2023). However, research also indicates that similarities between paternal and maternal parenting patterns outweigh differences (Kuppens & Ceulemans, 2019). Parents influence each other during adolescent socialization education and gradually develop similar concepts and values in cultivating children's prosocial behavior, jointly affecting its development (Kuppens & Ceulemans, 2019). Even when one parent primarily assumes childcare responsibilities, it is difficult to exclude the influence of the other parent's parenting style (Ward & Lee, 2020). This study is the first to clarify the influence mechanism of parental emotional warmth on adolescent prosocial behavior and its parental differences from the "environment × polygene–endophenotype–behavior" perspective. The findings emphasize that fathers and mothers contribute equally to the development of adolescent prosocial behavior through emotionally warm parenting, suggesting that intervention efforts should target both parents.

4.4 Practical Implications and Limitations

Adolescents are the cornerstone of future societal development in every era, and prosocial behavior is an important medium for future harmonious social development. Clarifying the key mechanisms through which parental emotional warmth influences adolescent prosocial behavior has important practical implications for cultivating prosocial behavior. This study suggests that self-control is an important mediating pathway through which parental emotional warmth influences adolescent prosocial behavior. Kwasnicka et al. (2016) meta-analyzed 80 theories explaining behavior change and maintenance, identifying five key mechanisms affecting individuals' ability to change and maintain behavior: motivation, self-regulation, resources, habits, and environmental factors, with motivation, self-regulation, and habits all related to self-control (Stautz et al., 2018). Moreover, existing self-control intervention systems are relatively rich, and educators can invest more attention in adolescent self-control interventions to promote prosocial behavior. Additionally, the moderating pattern of MGPS indicates that parenting influences on adolescent development vary individually. Parents should adopt truly effective parenting strategies based on children's developmental characteristics, implementing "genotype-tailored" parenting. Educators should also pay attention to individual differences in adolescents' physiological characteristics (e.g., environmental sensitivity) and intervene in prosocial behavior in a targeted manner.

Several limitations warrant attention. First, this study used a two-wave design with a six-month interval, using T2 measures of self-control and prosocial behavior in model analysis, which may bias mediation effect estimates and cannot rule out reverse causality. Future research should employ longitudinal designs with more time points to examine longitudinal causal relationships. Second, this study selected 37 candidate genes from dopamine, oxytocin, and serotonin systems and screened five significantly associated loci to calculate MGPS, with limited explained variance. Future research should expand the candidate gene range to obtain more genetic information. Third, this study deepens understanding of endophenotypes mediating gene-environment interactions on behavioral phenotypes, but gene-environment interactions may influence final behavioral phenotypes through multiple endophenotypes (Rommelse et al., 2008). Future research could examine whether more biologically-based cognitive-neurobiological markers can serve as explanatory pathways for environment-gene interactions on behavioral phenotypes, enriching the "environment × polygene–endophenotype–behavior" framework. Fourth, previous research has found that different types of prosocial behavior have different internal mechanisms (Christ et al., 2016); for example, altruistic prosocial behavior is other-oriented, while public prosocial behavior is self-oriented. Future research could further explore endophenotype mechanisms through which gene-environment interactions influence different types of prosocial behavior.

5. Conclusion

Based on the hypothesis that self-control mediates the relationship between parental emotional warmth and adolescent prosocial behavior and that MGPS moderates this relationship, this study verified these propositions using appropriate paradigms. For the first time, we revealed that MGPS (COMT rs6269, HTR2A rs6313, OXTR rs53576, OXTR rs2254295, and OXTR rs2254298) moderates the effect of parental emotional warmth on adolescent self-control, which in turn influences prosocial behavior. Consistent with our hypotheses, after controlling for baseline prosocial behavior, parental emotional warmth influenced adolescent prosocial behavior through self-control, with multisystem MGPS moderating this effect. Specifically, among adolescents with higher MGPS, parental emotional warmth had a stronger effect on self-control, which in turn influenced prosocial behavior, whereas the mediating effect of self-control was not significant among adolescents with lower MGPS. This study elucidates that self-control is an important endophenotype mechanism through which parental emotional warmth and MGPS interactively influence prosocial behavior, emphasizing that complex adolescent phenotypes result from combined environmental and polygenic effects, providing new ideas and empirical evidence for understanding the "environment × polygene–endophenotype–behavior" framework.

References

Aliev, F., Latendresse, S., Bacanu, S., Neale, M., & Dick, D. (2014). Testing for measured gene-environment interaction: Problems with the use of cross-product terms and a regression model reparameterization solution. *Behavior Genetics*, 44, 165–181.

Augustine, M. E., Leerkes, E. M., Smolen, A., & Calkins, S. D. (2018). Relations between early maternal sensitivity and toddler self-regulation: Exploring variation by oxytocin and dopamine D2 receptor genes. *Developmental Psychobiology*, 60(7), 789–804.

Bandalos, D. (2002). The effects of item parceling on goodness-of-fit and parameter estimate bias in structural equation modeling. *Structural Equation Modeling*, 9(1), 78–102.

Bandura, A. (1986). *Social foundations of thought and action: A social cognitive theory.* Englewood Cliffs, NJ: Prentice Hall.

Baumrind, D. (1991). Effective parenting during the early adolescent transition. In P. A. Cowan & E. M. Hetherington (Eds.), *Family Transitions* (pp. 111–163). Hillsdale, NJ: Laurence Erlbaum Associates.

Bernegger, A., Kienesberger, K., Carlberg, L., Swoboda, P., Ludwig, B., Koller, R., … Schosser, A. (2018). The Impact of COMT and childhood maltreatment on suicidal behaviour in affective disorders. *Scientific Reports*, 8(1), 692.

Bianchi, S. M., & Milkie, M. A. (2010). Work and family research in the first decade of the 21st century. *Journal of Marriage and Family*, 72, 705–725.

Bozorgmehr, A., Alizadeh, F., Sadeghi, B., Shahbazi, A., Ofogh S., Joghataei M., … Ghadirivasfi, M. (2019). Oxytocin moderates risky decision-making during the Iowa Gambling Task: A new insight based on the role of oxytocin receptor gene polymorphisms and interventional cognitive study. *Neuroscience Letters*, 708, 134328.

Buckley, L., Atkins, T., Perera, W. & Waller, M. (2023). Trajectories of parental warmth and the role they play in explaining adolescent prosocial behavior. *Journal of Youth and Adolescence*, 53(3), 526–536.

Cai, X., Gui, S., Tang, Y., Zhang, S., & Xu, M. (2022). The impact of parenting styles on resilience of adolescent: The chain mediating effect of self-control and regulatory focus. *Psychological Development and Education*, 38(4), 505–512. [Cai Xuebin, Gui Shoucai, Tang Yiqi, Zhang Shuo, Xu Mingxing. (2022). The impact of parenting styles on resilience of adolescent: The chain mediating effect of self-control and regulatory focus. *Psychological Development and Education*, 38(4), 505–512.]

Cao, Y., Chen, G., Ji, L., & Zhang, W. (2021). Inhibitory control mediates the associations between parenting practices and depressive symptoms in adolescents: The moderating role of catechol-o-methyltransferase (COMT) gene. *Journal of Youth and Adolescence*, 50, 2079–2095.

Cao, Y., & Zhang, W. (2019). The influence of dopaminergic genetic variants and maternal parenting on adolescent depressive symptoms: A multilocus genetic study. *Acta Psychologica Sinica*, 51(10), 1102–1115. [Cao Yanmiao, Zhang Wenxin. (2019). The influence of dopaminergic genetic variants and maternal parenting on adolescent depressive symptoms: A multilocus genetic study. *Acta Psychologica Sinica*, 51(10), 1102–1115.]

Carlo, G. (2014). The development and correlates of prosocial moral behaviors. In J. G. Smetana & M. Killen (Eds.), *Handbook of moral development* (2nd ed., pp. 208–234). New York, NY: Psychology Press.

Carlo, G., Streit, C., & Crockett, L. (2018). Generalizability of a traditional social cognitive model of prosocial behaviors to U.S. Latino/a Youth. *Cultural Diversity & Ethnic Minority Psychology*, 24(4), 596–604.

Carlo, G., White, R. M. B., Streit, C., Knight, G. P., & Zeiders, K. H. (2018). Longitudinal relations among parenting styles, prosocial behaviors, and academic outcomes in U.S. Mexican adolescents. *Child Development*, 89(2), 577–592.

Caspi, A., & Moffitt, T. E. (2006). Gene–environment interactions in psychiatry: Joining forces with neuroscience. *Nature Reviews Neuroscience*, 7(7), 583–590.

Chen, P., Wang, G., Yu, C., & Nie, Y. (2023). Academic stress, self-esteem and nonsuicidal self-injury among adolescents: The moderating effect of the oxytocin receptor (OXTR) gene rs53576 polymorphism. *Current Psychology*, 43(5), 4728–4736.

Christ, C. C., Carlo, G., & Stoltenberg, S. F. (2016). Oxytocin receptor (OXTR) single nucleotide polymorphisms indirectly predict prosocial behavior through perspective taking and empathic concern. *Journal of Personality*, 84(2), 204–213.

Cools, R., Roberts, A. C., & Robbins, T. W. (2008). Serotoninergic regulation of emotional and behavioural control processes. *Trends in Cognitive Sciences*, 12(1), 31–40.

Damiano, C. R., Aloi, J., Dunlap, K., Burrus, C. J., Mosner, M. G., Kozink, R. V., … Dichter, G. S. (2014). Association between the oxytocin receptor (OXTR) gene and mesolimbic responses to rewards. *Molecular Autism*, 5, 7.

Daniel, E., Madigan, S., & Jenkins, J. (2016). Paternal and maternal warmth and the development of prosociality among preschoolers. *Journal of Family Psychology*, 30(1), 114–124.

Davies, P., Cicchetti, D., & Hentges, R. F. (2015). Maternal unresponsiveness and child disruptive problems: The interplay of uninhibited temperament and dopamine transporter genes. *Child Development*, 86, 63–79.

Davis, A.N., Carlo, G., Streit, C., Schwartz, S., Unger, J., Baezconde-Garbanati, L & Szapocznik, J. (2018). Longitudinal associations between maternal involvement, cultural orientations, and prosocial behaviors among recent immigrant Latino adolescents. *Journal of Youth and Adolescence*, 47, 460–472.

Di Iorio, C. R., Carey, C. E., Michalski, L. J., Corral-Frias, N. S., Conley, E. D., Hariri, A. R., & Bogdan, R. (2017). Hypothalamic-pituitary-adrenal axis genetic variation and early stress moderates amygdala function. *Psychoneuroendocrinology*, 80, 170–178.

Diekhof, E. K., Richter, A., Brodmann, K., & Gruber, O. (2021). Dopamine multilocus genetic profiles predict sex differences in reactivity of the human reward system. *Brain Structure and Function*, 226(4), 1099–1114.

Dvorak, R. D., & Simons, J. S., (2009). Moderation of resource depletion in the self-control strength model: Differing effects of two modes of self-control. *Personality and Social Psychology Bulletin*, 35(5), 572–583.

Eisenberg, N., & Mussen, P. H. (1989). *The roots of prosocial behavior in children*. Cambridge: Cambridge University Press.

Eisenberg, N., & Spinrad, T. L. (2014). Multidimensionality of prosocial behavior: Rethinking the conceptualization and development of prosocial behavior. In L. M. Padilla-Walker & G. Carlo (Eds.), *Prosocial behavior: A multidimensional approach* (pp. 17–39). New York, NY: Oxford University Press.

Eisenberg, N., Fabes, R.A., & Spinrad, T.L. (2006). Prosocial Development. In R.M. Lerner, W. Damon, & N. Eisenberg (Eds.), *Handbook of child psychology* (6th edn, Vol. 3, pp. 646–718). New York: Wiley.

Eisenberg, N., Spinrad, T. L., & Knafo-Noam, A. (2015). Prosocial development. In M. E. Lamb & R. M. Lerner (Eds.), *Handbook of child psychology and developmental science: Socioemotional processes* (7th ed., Vol. 3, pp. 610–656). Wiley Blackwell.

Eisenberg, N., Spinrad, T. L., Taylor, Z. E., & Liew, J. (2019). Relations of inhibition and emotion-related parenting to young children's prosocial and vicariously induced distress behavior. *Child Development*, 90, 846–858.

Fei, D., Qian, D., & Huang, X. (2016). The self-control process model of altruistic behavior: The positive effect of moral emotions under the ego depletion. *Acta Psychologica Sinica*, 48(9), 1175–1183. [Fei Dingzhou, Qian Donghai, Huang Xuchen. (2016). The self-control process model of altruistic behavior: The positive effect of moral emotions under the ego depletion. *Acta Psychologica Sinica*, 48(9), 1175–1183.]

Ferschmann, L., Overweg, I., Dégeilh, F., Bekkhus, M., Havdahl, A.S., von Soest, T., & Tamnes, C.K. (2023). Development of prosocial behavior and inhibitory control in late childhood: A longitudinal exploration of sex differences and reciprocal relations. *Child Development*, 95(1), 313–323.

Goodman, R., Ford, T., Simmons, H., Gatward, R., & Meltzer, H. (2000). Using the Strengths and Difficulties Questionnaire (SDQ) to screen for child psychiatric disorders in a community sample. *British Journal of Psychiatry*, 177(6), 534–539.

Green, C. G., Babineau, V., Jolicoeur-Martineau, A., Bouvette-Turcot, A. A., Minde, K., Sassi, R., …, & Maternal Adversity, Vulnerability, and Neurodevelopment Research Team. (2017). Prenatal maternal depression and child serotonin transporter linked polymorphic region (5-HTTLPR) and dopamine receptor D4 (DRD4) genotype predict negative emotionality from 3 to 36 months. *Development and psychopathology*, 29(3), 901–914.

Gülseven, Z., Liu, Y., Ma, T. L., Yu, M. V. B., Simpkins, S. D., Vandell, D. L., & Zarrett, N. (2021). The development of cooperation and self-control in middle childhood: Associations with earlier maternal and paternal parenting. *Developmental Psychology*, 57(3), 397–409.

Hofmann, W., Baumeister, R. F., Forster, G., & Vohs, K. D. (2012). Everyday temptations: An experience sampling study of desire, conflict, and self-control. *Journal of Personality and Social Psychology*, 102, 1318–1335.

Jiang, J., Lu, Z., Jiang, B., & Xu, Y. (2010). Revision of the short-form Egna Minnen av Barndoms Uppfostran for Chinese. *Psychological Development and Education*, 26(1), 94–99. [Jiang Jiang, Lu Zhengrong, Jiang Bijing, Xu Yan. (2010). Revision of the short-form Egna Minnen av Barndoms Uppfostran for Chinese. *Psychological Development and Education*, 26(1), 94–99.]

Kajanoja, J., Nolvi, S., Kantojärvi, K., Karlsson, L., Paunio, T., & Karlsson, H. (2022). Oxytocin receptor genotype moderates the association between maternal prenatal stress and infant early self-regulation. *Psychoneuroendocrinology*, 138, 105669.

Kemp, A. H., & Guastella, A. J. (2010). Oxytocin: prosocial behavior, social salience, or approach-related behavior? *Biological Psychiatry*, 67(6), e33–e34.

Kil, H., Gath, M., & Grusec, J. E. (2023). Dual process in parent-adolescent moral socialization: The moderating role of maternal warmth and involvement. *Journal of Adolescence*, 95(4), 824–833.

Knafo-Noam, A., Vertsberger, D., & Israel, S. (2018). Genetic and environmental contributions to children's prosocial behavior: brief review and new evidence from a reanalysis of experimental twin data. *Current Opinion in Psychology*, 20, 60–65.

Knoch, D., & Nash, K. (2015). Self-Control in Social Decision Making: A Neurobiological Perspective. In G. Gendolla, M. Tops, & S. Koole (Eds.), *Handbook of Biobehavioral Approaches to Self-Regulation* (pp. 221–234). Springer, New York, NY.

Kuppens, S., & Ceulemans, E. (2019). Parenting styles: A closer look at a well-known concept. *Journal of Child and Family Studies*, 28(1), 168–181.

Kwasnicka, D., Dombrowski, S. U., White, M., & Sniehotta, F. (2016). Theoretical explanations for maintenance of behaviour change: A systematic review of behaviour theories. *Health Psychology Review*, 10(3), 277–296.

Lee, S. J., Pace, G. T., Lee, J. Y., & Knauer, H. (2018). The association of fathers' parental warmth and parenting stress to child behavior problems. *Children and Youth Services Review*, 91, 1–10.

Lesch, K. P. (2007). Linking emotion to the social brain. The role of the serotonin transporter in human social behaviour. *EMBO Reports*, 8(1), 24–29.

Li, J. B., Willems, Y. E., Stok, F. M., Deković, M., Bartels, M., & Finkenauer, C. (2019). Parenting and self-control across early to late adolescence: A three-level meta-analysis. *Perspectives on Psychological Science*, 14(6), 967–1005.

Li, X. (2020). Fathers' involvement in Chinese societies: Increasing presence, uneven progress. *Child Development Perspectives*, 14, 150–156.

Li, Z., Yu, C., Cao, Y., Nie, Y., Tu, W., Liu, B., Ning, Z., & Chen, P. (2023). The association between parent–child attachment and prosocial behavior: A longitudinal study. *Current Psychology*, 43(3), 2432–2441.

Liang, Y., Zhou, N., & Cao, H. (2023). Stability and change in configuration patterns of various career-related parental behaviors and their associations with adolescent career adaptability: A longitudinal person-centered analysis. *Journal of Vocational Behavior*, 145, 103916.

Liu, X., Yue, J., & Yang, Y. (2024). Why So Lonely? The direct and indirect associations between developmental trajectories of fear of negative evaluation, prosocial behavior and loneliness in adolescence. *Journal of Youth and Adolescence*, 53, 1699–1710.

Merjonen, P., Pulkki-Råback, L., Lipsanen, J., Lehtimäki, T., Rontu, R., Viikari, J., … & Keltikangas-Järvinen, L. (2011). Development of adulthood hostile attitudes: Childhood environment and serotonin receptor gene interactions. *Personal Relationships*, 18(2), 184–197.

Muthén, L.K. & Muthén, B.O. (1998–2017). *Mplus user's guide* (8th ed.). Los Angeles, CA: Muthén and Muthén.

Padilla-Walker, L. M., & Christensen, K. J. (2011). Empathy and self-regulation as mediators between parenting and adolescents' prosocial behavior toward strangers, friends, and family. *Journal of Research on Adolescence*, 21, 545–551.

Padilla-Walker, L. M., Nielson, M. G., & Day, R. D. (2016). The role of parental warmth and hostility on adolescents' prosocial behavior toward multiple targets. *Journal of Family Psychology*, 30(3), 331–340.

Pastorelli, C., Zuffianò, A., Lansford, J., Thartori, E., Bornstein, M., Chang, L., … Bacchini, D. (2021). Positive youth development: Parental warmth, values, and prosocial behavior in 11 cultural groups. *Journal of Youth Development*, 16(2–3), 379–401.

Perris, C., Jacobsson, L., Linndström, H., Knorring, L., & Perris, H. (1980). Development of a new inventory for assessing memories of parental rearing behaviour. *Acta Psychiatrica Scandinavica*, 61(4), 265–274.

Plomin, R. (2013). Child development and molecular genetics: 14 years later. *Child Development*, 84(1), 104–120.

Pluess, M., Assary, E., Lionetti, F., Lester, K. J., Krapohl, E., Aron, E. N., & Aron, A. (2018). Environmental sensitivity in children: Development of the highly sensitive child scale and identification of sensitivity groups. *Developmental Psychology*, 54(1), 51–70.

Putnick, D. L., Bornstein, M. H., Lansford, J. E., Chang, L., Deater-Deckard, K., Di Giunta, L., … & Bombi, A. S. (2018). Parental acceptance-rejection and child prosocial behavior: Developmental transactions across the transition to adolescence in nine countries, mothers and fathers, and girls and boys. *Developmental Psychology*, 54(10), 1881–1890.

Quan, S., Li, M., Yang, X., Song, H., & Wang, Z. (2021). Perceived parental emotional warmth and prosocial behaviors among emerging adults: Personal belief in a just world and gratitude as mediators. *Journal of Child and Family Studies*, 31(4), 1019–1029.

Rommelse, N. N.j, Altink, M. E., Martin, N. C., Buschgens, C. J., Faraone, S. V., Buitelaar, J. K., Sergeant, J. A., & Oosterlaan, J. (2008). Relationship between endophenotype and phenotype in ADHD. *Behavioral and Brain Functions*, 4, PMC2267799.

Stamatis, C. A., Engelmann, J. B., Ziegler, C., Domschke, K., Hasler, G., & Timpano, K. R. (2020). A neuroeconomic investigation of 5-HTT/5-HT1A gene variation, social anxiety, and risk-taking behavior. *Anxiety, Stress, and Coping*, 33(2), 176–192.

Starr, L., & Huang, M. (2019). HPA-axis multilocus genetic variation moderates associations between environmental stress and depressive symptoms among adolescents. *Development and Psychopathology*, 31, 1339–1352.

Stautz, K., Zupan, Z., Field, M., & Marteau, T. M. (2018). Does self-control modify the impact of interventions to change alcohol, tobacco, and food consumption? A systematic review. *Health Psychology Review*, 12(2), 157–178.

Stocker, C. M., Masarik, A. S., Widaman, K. F., Reeb, B. T., Boardman, J. D., Smolen, A., … Conger, K. J. (2017). Parenting and adolescents' psychological adjustment: Longitudinal moderation by adolescents' genetic sensitivity. *Development and Psychopathology*, 29(4), 1289–1304.

Stoltenberg, S. F., Christ, C. C., & Highland, K. B. (2012). Serotonin system gene polymorphisms are associated with impulsivity in a context dependent manner. *Progress in Neuro-Psychopharmacology and Biological Psychiatry*, 39(1), 182–191.

Tost, H., Kolachana, B., Hakimi, S., Lemaitre, H., Verchinski, B. A., Mattay, V. S., … Meyer-Lindenberg, A. (2010). A common allele in the oxytocin receptor gene (OXTR) impacts prosocial temperament and human hypothalamic-limbic structure and function. *Proceedings of the National Academy of Sciences of the United States of America*, 107(31), 13936–13941.

Van Heel, M., Bijttebier, P., Claes, S., Colpin, H., Goossens, L., Hankin, B., V… & Van Leeuwen, K. (2020). Parenting, effortful control, and adolescents' externalizing problem behavior: Moderation by dopaminergic genes. *Journal of Youth and Adolescence*, 49(1), 252–266.

Vaughan, E. P., Frick, P. J., Ray, J. V., Robertson, E. L., Thornton, L. C., Wall Myers, T. D., Steinberg, L., & Cauffman, E. (2021). The associations of maternal warmth and hostility with prosocial and antisocial outcomes in justice-involved adolescents. *Developmental Psychology*, 57(12), 2179–2193.

Wang, M., Zheng, X., Xia, G., Liu, D., Chen, P., & Zhang, W. (2019). Association between negative life events and early adolescents' depression: The moderating effects of Catechol-O-methyltransferase (COMT) Gene Val158Met polymorphism and parenting behavior. *Acta Psychologica Sinica*, 51(8), 903–913. [Wang Meiping, Zheng Xiaojie, Xia Guizhi, Liu Didi, Chen Pian, Zhang Wenxin. (2019). Association between negative life events and early adolescents' depression: The moderating effects of Catechol-O-methyltransferase (COMT) Gene Val158Met polymorphism and parenting behavior. *Acta Psychologica Sinica*, 51(8), 903–913.]

Wang, X., Huebner, E.S., & Tian, L. (2023). Longitudinal relations among perceived parental warmth, self-esteem and social behaviours from middle childhood to early adolescence in China: Disentangling between- and within-person associations. *British Journal of Psychology*, 114(4), 969–990.

Ward, K. P., & Lee, S. J. (2020). Mothers' and fathers' parenting stress, responsiveness, and child wellbeing among low-income families. *Children and Youth Services Review*, 116, 105218.

Williams, K. E., & Berthelsen, D. (2017). The development of prosocial behaviour in early childhood: Contributions of early parenting and self-regulation. *International Journal of Early Childhood*, 49(1), 73–94.

Wong, T. K. Y., & Konishi, C. (2023). Parental warmth and guilt induction: Associations with prosocial behaviors and the mediating role of values in Chinese adolescents. *Social Development*, 33(2), e12714.

Wu, Y., Wang, P., & Du, S. (2018). The changing Chinese family structure and adolescent development. *Social Sciences in China*, (2), 98–120+206–207. [Wu Yuxiao, Wang Peng, Du Sijia. (2018). The changing Chinese family structure and adolescent development. *Social Sciences in China*, (2), 98–120+206–207.]

Xie, D., Wang, L., Tao, T., Fan, C., & Gao, W. (2014). Validity and reliability of the Chinese version of the Dual-Mode of Self-Control Scale for adolescents. *Chinese Mental Health Journal*, 28(5), 386–391. [Xie Dongjie, Wang Ligang, Tao Ting, Fan Chunlei, Gao Wenbin. (2014). Validity and reliability of the Chinese version of the Dual-Mode of Self-Control Scale for adolescents. *Chinese Mental Health Journal*, 28(5), 386–391.]

Yu, G., Li, S., & Zhao, F. (2020). Childhood maltreatment and prosocial behavior among Chinese adolescents: Roles of empathy and gratitude. *Child abuse & neglect*, 101, 104319.

Yu, M., Huang, L., Mao, J., Dna, G., & Luo, S. (2022). Childhood maltreatment, automatic negative thoughts, and resilience: The protective roles of culture and genes. *Journal of Interpersonal Violence*, 37(1–2), 349–370.

Zeng, Z., Peng, L., Liu, S., Yang, Q., Wang, H., He, Z., & Hu, Y. (2023). Serotonergic multilocus genetic variation moderates the association between interpersonal relationship and adolescent depressive symptoms. *Journal of Affective Disorders*, 340, 616–625.

Zhang, C., Ling, Y., Xiao, J., Yang, X., Yang, J., & Yao, S. (2009). Application of Chinese version of the self-report strengths and difficulties questionnaire in a sample of 832 adolescents. *Chinese Journal of Clinical Psychology*, 17(1), 8–11. [Zhang Chenchen, Ling Yu, Xiao Jing, Yang Xiaolai, Yang Juan, Yao Shuqiao. (2009). Application of Chinese version of the self-report strengths and difficulties questionnaire in a sample of 832 adolescents. *Chinese Journal of Clinical Psychology*, 17(1), 8–11.]

Zhang, Q., Cai, Z., Lhomme, M., Sahana, G., Lesnik, P., Guerin, M., Fredholm, M., & Karlskov-Mortensen, P. (2020). Inclusion of endophenotypes in a standard GWAS facilitate a detailed mechanistic understanding of genetic elements that control blood lipid levels. *Scientific Reports*, 10(1), 1–12.

Zhang, R., & Wang, Z. (2020). Inhibitory control moderates the quadratic association between resting respiratory sinus arrhythmia and prosocial behaviors in children. *Psychophysiology*, 57(4), e13491.

Zhang, W., Li, X., Chen, G., & Cao, Y. (2021). The relationship between positive parenting and adolescent prosocial behaviour: The mediating role of empathy and the moderating role of the oxytocin receptor gene. *Acta Psychologica Sinica*, 53(9), 976–991. [Zhang Wenxin, Li Xi, Chen Guanghui, Cao Yanmiao. (2021). The relationship between positive parenting and adolescent prosocial behaviour: The mediating role of empathy and the moderating role of the oxytocin receptor gene. *Acta Psychologica Sinica*, 53(9), 976–991.]

Zhang, X., & Belsky, J. (2022). Three phases of Gene × Environment interaction research: Theoretical assumptions underlying gene selection. *Development and Psychopathology*, 34(1), 295–306.

Zondervan-Zwijnenburg, M., Dobbelaar, S., van der Meulen, M., & Achterberg, M. (2022). Longitudinal associations between prosocial behavior and behavioral problems across childhood: A robust random-intercept cross-lagged panel model. *Developmental Psychology*, 58(6), 1139–1155.

Note: Figure translations are in progress. See original paper for figures.