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ORIGINAL RESEARCH

Gene×Environment Interactions in Early Externalizing Behaviors: Parental Emotional Support and Socioeconomic Context as Moderators of Genetic Influences?

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Abstract This study uses longitudinal population-based samples of young siblings to examine the effects of two hypothesized moderators of early externalizing behaviors: parental emotional support and family socioeconomic status. The first sample, a twin sample from the Early Childhood Longitudinal Study-Birth Cohort (ECLS-B), was composed of approximately 600 twin pairs measured on externalizing at ages 4 and 5. Results indicated stronger genetic influences on externalizing at lower levels of parental emotional support but higher levels of socioeconomic status; only the latter interaction remained significant when the two moderators were simultaneously modeled. These moderation effects were not replicated in our analyses of the National Longitudinal Survey of Youth-Child Supplement (CNLSY) data, which contained 1939 pairs of full and half siblings measured on externalizing at ages 4–5 and ages 6–7. Our results highlight the need for replication in quantitative behavior genetics research on externalizing behaviors. Potential causes for non-replication are discussed.

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Introduction

Externalizing refers to a constellation of behaviors that deviate from social norms, such as aggression, disobedience, and delinquency. Early externalizing behaviors are associated with increased risk for a variety of long-term maladaptive outcomes, including academic failure (Arnold 1997), later socioemotional maladjustment (Campbell et al. 2000; Moffitt 1993; Moffitt et al. 2002), and poor economic outcomes (Moffitt 1993; Moffitt et al. 2002), all of which eventually incur high costs to society (Cohen 1998). The etiology of early externalizing behavior is complex. Some commonly studied factors associated with externalizing behaviors include genes (Rhee and Waldman 2002; van Hulle et al. 2007), temperament (Campbell et al. 2000; Moffitt 1993), parenting style (McCarty et al. 2005; McLoyd and Smith 2002; Stormshak et al. 2000), and socioeconomic status (SES; Barry et al. 2005; Murray et al. 2010). Researchers are increasingly interested in investigating how individual (e.g., genes, temperament) and social (e.g., parenting, socioeconomic status) risk and protective factors interact to affect the development of externalizing behaviors (e.g., Bakermans-Kranenburg et al. 2008; Foley et al. 2004; Propper et al. 2007; Sonuga-Barke et al. 2009; Tucker-Drob and Harden 2013).

Continuing this integrative approach, the current article focuses on parenting style and SES as factors that may interact with genetic propensities for externalizing behaviors. A number of previous studies have detected gene×parenting and gene×SES interactions on externalizing behaviors; however, the direction of these detected interactions have been inconsistent, with some studies reporting that genes play a less important role at higher levels of positive parenting (e.g., DiLalla et al. 2009; Feinberg et al. 2007) or higher SES (e.g., Nobile et al. 2007), while others reported the opposite pattern (e.g., Brody et al. 2009; Leve et al. 2009; Tuvblad et al. 2006). In the following sections, we first review the extant genetic and socialization literatures on externalizing behaviors, and then describe the utility of a gene×environment interaction approach.

Genetic and Environmental Contributions

Numerous studies have indicated that externalizing behaviors in childhood are substantially, although not entirely, heritable. For instance, Rhee and Waldman (2002) meta-analyzed 51 twin and adoption studies and found that genes explained an average of 32 % of the variance in externalizing behaviors, with environmental factors accounting for the remaining 68 %. Environmental influences on externalizing can be conceptualized along a continuum ranging from proximal to distal. On the proximal end of the continuum are parents, who act directly upon their children. On the distal end of the continuum is the larger social context. Larger social contexts do not act directly on children, but instead encompass collections of proximal environments (e.g., availability of nurturing resources, parenting style of their caregivers, and type of peers they are likely to associate with or be exposed to). In this way, proximal social factors, such as parenting, can be thought of as mediators of more generalized distal social factors, such as SES. However, because proximal factors encompass collections of very many different proximal factors, it is possible for distal factors to have aggregate effects that differ in direction or magnitude from the specific effect of an individual proximal factor.

Parental Socialization as a Protective Factor

Emotionally supportive parents can be defined as those who are sensitive to their children's needs, reason with their children, and show their children affection. Through constructive parent–child interactions, parental emotional support is thought to facilitate children's internalization of social values and norms (Patterson et al. 1990) and development of behavioral, cognitive, and emotional self-control (Belsky and Beaver 2011; Bradley and Corwyn 2008; Eisenberg et al. 2005; Patterson et al. 1990). For example, children of parents who show high emotional support may learn to be more sensitive to social cues before acting, whereas children of parents who show low emotional support may act impulsively without regards to social cues. Socially accepted values and skills play an important role in children's psychosocial adjustment (Eisenberg et al. 2001, 2005; Garside and Klimes-Dougan 2002), and children who are deprived of such socialization have been shown to be at risk for externalizing behaviors (Stormshak et al. 2000; Zimmerman et al. 2005). For example, McLoyd and Smith (2002) followed a group of 4- and 5-year-old children for 6 years and found that higher levels of parental emotional support were associated not only with lower levels of externalizing behaviors at any given time, but also with a slower rate of increase in externalizing behaviors. This protective effect of supportive parents on externalizing development is evident even after controlling for the initial rate of behavioral problems (Denham et al. 2000) and other biological and contextual variables (McCarty et al. 2005).

Socioeconomic Advantage as a Protective Factor

SES is a widely studied index of the quality of larger social contexts. Higher SES is consistently associated with lower levels of externalizing behaviors (Barry et al. 2005; Dodge et al. 1994; Keiley et al. 2000; Murray et al. 2010), and this relation is likely to be mediated by more proximal mechanisms. Socioeconomic advantage is not only associated with higher resources, but also with higher quality care provided by individuals in children's immediate environment (Conger et al. 1992; Dodge et al. 1994). Moreover, higher SES parents allocate more time and effort in providing their children a nurturing environment (Kalil et al. 2012). Thus, the effects of SES on externalizing may be partially accounted for by differences in parenting.

Genetic Vulnerability and Resilience

One mechanism through which early social contexts may influence the development of externalizing behaviors is by modulating the effects of genes on early externalizing behaviors. In other words, one may expect gene×parenting and gene×SES interactions on early externalizing behaviors. However, different theoretical perspectives predict different directions of such interactions. Here, we review three such perspectives.

Diathesis-Stress Hypothesis

The diathesis-stress hypothesis holds that environmental stressors provide the opportunity for vulnerability genes to be activated (Monroe and Simons 1991). For example, in a twin study, Feinberg et al. (2007) found that genes explained a greater portion of the variance in externalizing behaviors among early adolescents who received less parental warmth. Edwards et al. (2010) found that at higher levels of physically harsh parenting, early adolescents with low MAO-A activity displayed higher levels of externalizing behaviors than those with high MAO-A activity; at lower levels of physically harsh parenting, all adolescents showed similar levels of externalizing behaviors. Foley et al. (2004) found similar results when they examined the interaction between MAO-A activity and negative parenting, which was defined by parental neglect, exposure to interparental violence, and inconsistent parental discipline. Some studies on G×SES interaction in externalizing behaviors have also provided support for the diathesis-stress hypothesis. For example, Nobile et al. (2007) observed a higher level of externalizing behaviors only among preadolescents with risk alleles of DRD4 and 5-HTTLPR who were also raised in low SES homes; these alleles were not associated with externalizing behaviors among children raised in higher SES homes.

Social Push Hypothesis

Raine (2002)'s social push hypothesis predicts a G×E interaction in precisely the opposite direction to that predicted by diathesis-stress hypothesis. This hypothesis holds that genetic influences on behavioral problems should be most active among individuals situated in minimal risk environments, whereas high-risk environments are thought to overwhelm genetic predispositions. In support of this hypothesis, Lahey et al. (2008) found that infant temperament, conceptualized as a surrogate for genetic risk, was associated with early conduct problems only for children whose parents showed a higher degree of responsiveness to their needs. Similarly, in a twin study, Button et al. (2008) found that genes explained a greater portion of variations in externalizing behaviors among adolescents who received less maternal punitive discipline. Finally, also in a twin study, Tuvblad et al. (2006) found a greater genetic contribution to externalizing behaviors among adolescents who were raised in higher SES homes than those who were raised in lower SES ones.

Differential Susceptibility Hypothesis

Instead of conceptualizing genes as conferring risk or vulnerability, the differential susceptibility hypothesis focuses on individual differences in susceptibility to environmental influences (Belsky 2009; Pluess and Belsky 2010). Accordingly, individuals with "susceptibility genes" are predicted to be more likely to engage in externalizing behaviors when exposed to contextual adversity but less likely to engage in such behaviors when raised in a nurturing environment. Therefore, this hypothesis predicts that genes have a greater contribution to externalizing behaviors among both individuals exposed to contextual adversities and those exposed to more favorable environments, with the smallest genetic effects in "average" environments. Consistent with the differential susceptibility hypothesis, Bakermans-Kranenburg and van IJzendoorn (2006) found that preschoolers with DRD4-L displayed more externalizing behaviors when raised by mothers who were insensitive to their needs but fewer externalizing behaviors when raised by mothers who were sensitive to their needs; such association between maternal sensitivity and externalizing behaviors was not observed among preschoolers with DRD4-S. Van Aken et al. (2007) observed similar results when they used temperament (i.e., inhibitory control, frustration, activity level, and soothability) as surrogates for genetic risk in a toddler sample.

Current Status of G×E Research on the Development of Early Externalizing Behaviors

Despite the fast accumulating evidence for G×E interactions in externalizing behaviors, the actual patterns of interactions obtained have been inconsistent across studies. Given the lack of focus on close replication studies, it is currently unclear whether these differences result from substantively meaningful differences in the genes, environments, and/or outcomes measured in the different studies. For example, genetic propensities have been indexed by candidate genes, the amount of variance explained by a latent genetic factor, matching characteristics in biological parent(s), or infant temperament. Similarly, the operationalization of parenting has included diverse constructs such as sensitivity and physical discipline, and various studies have focused on externalizing behaviors at developmental stages ranging from infancy through early adulthood. It is currently unclear whether G×E interaction effects are robust across changes in measurement and sampling. Moreover, given social contexts are hardly independent of each other, as in the case of parenting and SES, studying an individual social moderator without accounting for covarying ones might have conflated potentially distinct effects and contributed to the inconsistency across studies. Examining moderation effects of parenting and SES simultaneously and replicating analyses with an independent but comparable sample, as we do in the current study, is therefore one promising attempt to understand the inconsistency in the current G×E literature on externalizing behaviors.

Current Study

To address the inconsistency in the current G×E literature on externalizing behaviors, we conducted similar analyses

Table 1 Sample statistics

	ECLS-B			CNLSY		
	Full sample	MZ	DZ	Full sample	FS	HS
Age at time 1 (*M*/*SD*)	4.41/.34	4.40/.34	4.41/.34	5.03/.57; 4.99/.56	5.03/.57; 4.99/.56	5.04/.56; 4.99/.55
Race/ethnicity (%)						
Caucasian	62.26	56.99	64.48	59.26; 59.26	64.92; 64.92	34.17; 34.27
Latino/Hispanic	15.61	19.35	14.03	19.39; 19.34	19.22; 19.22	20.17; 19.94
African American	15.76	12.37	17.19	21.35; 21.35	15.87; 15.87	45.66; 45.79
Asian	1.75	3.23	1.13	–	–	–
Others	4.62	8.06	3.17	–	–	–
Parental education level (%)						
<High School	9.55	12.90	8.14	15.88; 14.18	13.78; 12.14	25.21; 23.25
High School	18.79	19.35	18.55	39.30; 36.62	38.37; 35.90	43.42; 39.78
Some College	28.50	31.18	27.38	21.92; 22.90	22.31; 22.95	20.17; 22.69
College or Beyond	43.15	36.56	45.93	20.42; 20.42	23.45; 14.60	7.00; 8.40

For the CNLSY sibling sample, statistics for sibling 1 are followed by those for sibling 2, separated by a semi-colon

on two independent, genetically informative, longitudinal, population-based datasets. In a first series of models, we individually estimated the moderation effects of parental emotional support and SES on genetic contributions to externalizing development. We then simultaneously examined parental emotional support and SES to investigate their potentially distinct moderation effects.

Methods

Participants

The first sample was drawn from the Early Child Longitudinal Study-Birth Cohort (ECLS-B), a nationally representative study of the children born in the U.S. in 2001. We used a sample of approximately[1] 600 twin pairs and their primary caregivers. Data collected when the twins were 4 years old were treated as our time 1 data and those collected when they were 5 years old were treated as our time 2 data. Table 1 lists the descriptive statistics of this first sample.

The second sample was drawn from the National Longitudinal Study of Youth 1979-Children and Young Adults (CNLSY). We used a sample of 1939 sibling pairs and their biological mothers. The CNLSY sample consists of children of a nationally representative group of 14- to 22-year-old women who were first surveyed in 1979. Data were collected biennially since 1986 and we used data collected until 2010. Data collected when the children were 4 or 5 years old were treated as our time 1 data and those collected when they were 6 or 7 years old were treated as our time 2 data. Table 1 lists the descriptive statistics of this second sample.

ECLS-B: Zygosity

Trained observers rated the physical similarity between the twins in each pair on 6 items with a 3-point Likert scale ranging from *No difference* to *Clear difference*. Following the procedures described by Tucker-Drob et al. (2011), all items were summed up for each twin pair and this resulted in a bimodal distribution with a range of 6–18. Pairs with a sum score of 6–8 were classified as monozygotic (MZ) twins and the rest were classified as dizygotic (DZ) twins. We excluded same-sex DZ twin pairs who had medical reason(s) for their physical dissimilarity. The final ECLS-B twin sample consisted of approximately 200 pairs of MZ twins, 200 pairs of same-sex DZ twins, and 250 pairs of opposite-sex DZ twins.

CNLSY: Sibling Pairs

For families with more than two children, only the first two were included in our analyses. Following the procedures described by Rodgers et al. (1994), each child's household roster provided information for sibling pair assignment. For example, siblings who both lived with their biological father were classified as full-sibling (FS) pairs and pairs in which one lived with biological father while one did not were classified as half-sibling (HS) pairs. Pairs without clear indications were classified as unidentified-sibling (US) pairs. However, to avoid biasing our estimates for genetic influences, we did not include US pairs in our current study. Using the kinship link published in 2013

[1] Sample size of the ECLS-B twin sample is rounded up to the nearest multiple of 50 due to ECLS-B requirements.

(Beasley et al. 2013), the CNLSY sibling sample consists of 760 pairs of same-sex FS, 822 pairs of opposite-sex FS, 164 pairs of same-sex HS, 192 pairs of opposite-sex HS, and 1 HS pair without complete gender information.

Measures

ECLS-B: Parental Emotional Support

Trained coders rated on the degree of each primary caregiver's "emotional availability and physical and affective presence" (Najarian et al. 2010, p. 120) to the child during a 10-min semi-structured task called the Two Bags Task. According to the ECLS-B Psychometric Report (Najarian et al. 2010), parental emotional support is defined as "(1) providing a secure base from which the child can explore, and (2) displaying emotional support and enthusiasm for the child and his or her autonomous work" (p. 120). The Two Bags Task was adapted from the Three Bags Task used in the National Institute of Child Health and Human Development Study of Early Child Care and Youth Development. Parents were asked to read a storybook to and use Play-Doh with each of their children. The administration order of these two tasks was counterbalanced and the entire interaction for each dyad was recorded. Using these video-recordings, trained coders rated each parent's emotional supportiveness on a 7-point Likert scale ranging from *very low* to *very high*. Inter-rater reliability among the 13 trained coders was 90.8 % (Najarian et al. 2010).

CNLSY: Parental Emotional Support

Using the Home Observation Measurement of Environment-Short Form (HOME-SF), parents and trained interviewers rated different parenting items that were then grouped to create the emotional support subscale. The HOME-SF (see Menaghan and Parcel 1991; Mott 2004 for reliability and utility information) was adapted from the HOME Inventory (Bradley et al. 1994, 1996). Questions for parents included "how often do you talk to child while you are working?" and those for trained interviewers included "mother caressed, kissed, or hugged child at least once?" Each item was recoded using a dichotomous scale with higher score indicating higher level of parental emotional support. Composite scores were then standardized with respect to the full CNLSY sample to have a mean of 100 and a standard deviation of 15.

ECLS-B: Socioeconomic Status

A composite score on SES was calculated using household income and three other pieces of information on both male and female primary caregivers of each child: highest completed level of education, labor force status (i.e., working or not), and occupational prestige. Composite scores were standardized with respect to the full ECLS-B sample to have a mean of 0 and a standard deviation of 1.

CNLSY: Socioeconomic Status

Total family income was used as a proxy of SES. It included government support and food stamps but excluded income of cohabitating partner who was not married to the child's biological mother. Because data were collected over the course of 24 years, total family income of each child was adjusted to 2008 dollars using the consumer price index listed on the website of Integrated Public Use Microdata Series—Current Population Survey (University of Minnesota, Minnesota Population Center, n.d.).

ECLS-B: Externalizing Behaviors

Primary caregivers rated each twin's behaviors on a number of psychosocial/behavioral items using a 5-point Likert scale ranging from 1 = *Never* to 5 = *Very Often*. Instead of providing some scoring criteria for these items, the ECLS-B user's manual (Snow et al. 2009) recommends that researchers conduct their own item-level analyses in order to arrive at some meaningful composite scores for the dimensions of interests. Following Tucker-Drob and Harden (2013), we summed 5 items to create an externalizing behavior composite score. Four items of these five items came from the Preschool and Kindergarten Behavioral Scale—2nd Edition (see Edwards 2009; Riccio 1995 for reliability and validity information) and one item came from the Social Skills Rating System (see Van Horn et al. 2007 for reliability and validity information). Sample items include "child is physically aggressive" and "child has temper tantrums." For the ECLS-B twin sample in our study, Cronbach's alpha of these 5 items is .73 for twin 1 at time 1, .79 for twin 2 at time 1, .81 for twin 1 at time 2, and .80 for twin 2 at time 2.

CNLSY: Externalizing Behaviors

Behavioral Problem Index (BPI; see Peterson and Zill 1986 for more information on the creation of this index) was used to measure the level of externalizing behaviors each child displayed. Many of the BPI items were adapted from the widely used Child Behavior Checklist (CBCL; Achenbach 2012). Mothers rated on each child's behaviors on a 3-point Likert Scale ranging from 0 = *Often True* to 2 = *Not True*. Excluding the one item on remorse, the average score across items for the Antisocial Behavior and Headstrong subscales of BPI (see Center for Human

Table 2 Comparison of items used in measuring externalizing behaviors

ECLS-B	CNLSY
	Cheats or tells lies
	Argues too much
Child is physically aggressive	Bullies or is cruel/mean to others
	Is disobedient at home
	Is stubborn, sullen, or irritable
Child has temper tantrums	Has strong temper and loses it easily
Child destroys others' things	Breaks things deliberately
	Is disobedient at school
	Has trouble getting along with teachers
Child is angry	
Child annoys other children	

Items that are similar to each other across samples are listed side-by-side

Table 3 Skewness statistics of variables before and after transformations

	Skewness/*SE*			
	ECLS-B		CNLSY	
	Before	After	Before	After
$SES_{1,1}$	–	–	7.91/.06	−2.25/.06
$SES_{1,2}$	–	–	7.47/.06	−1.45/.06
$EXT_{1,1}$	.46/.10	−.38/.10	.85/.07	.30/.07
$EXT_{1,2}$	.75/.10	−.20/.10	.95/.07	.38/.07
$EXT_{2,1}$	.72/.11	−.19/.11	1.06/.06	.50/.06
$EXT_{2,2}$	.66/.11	−.21/.11	1.14/.06	.57/.06

The first number in the subscripts represents the time point when measurements were made and the second one represents the sibling in a pair

SES socioeconomic status, *EXT* externalizing behaviors

Resource Research 2009 for a list of items each subscale) was calculated so higher scores indicate higher levels of externalizing behaviors. Sample items include "bullies or is cruel/mean to others" and "has strong temper and loses it easily." For the CNLSY sibling sample in our study, Cronbach's alpha is .77 at time 1 and .79 at time 2. Table 2 compares the items used to measure externalizing behaviors across the ECLS-B twin sample and the CNLSY sibling sample.

Data Analyses

Data were transformed and standardized prior to model fitting. Table 3 lists the skewness statistics of these variables before and after data transformation. Scores on externalizing behaviors in both our analytic samples and SES of the CNLSY sibling sample were substantially positively skewed and were log transformed to have near normal distributions. We then z-transformed each variable based on the mean and standard deviation observed for that variable in sibling 1 at time 1.

We then fit six structural equation models (i.e., three main effects and three interactions models) to each of our analytic samples using maximum likelihood estimation in *Mplus* statistical software (Muthén and Muthén 2010) to investigate the moderation effects of parental emotional support and SES on genetic and environmental contributions to externalizing behaviors. *Mplus* uses Full-information Maximum Likelihood to handle missing data, except when the missingness is on the moderator, in which case *Mplus* does not allow for missingness and excludes such cases from analyses. In our model with only parental emotional support as the moderator, 15 % of the ECLS-B twin sample and 0 % of the CNLSY sibling sample were excluded due to missingness on parental emotional support. In our model with only SES as the moderator, 0 % of the ECLS-B twin sample and 17 % of the CNLSY sibling sample were excluded due to missingness on SES. In our final model with both parental emotional support and SES as moderators, 15 % of the ECLS-B twin sample and 17 % of the CNLSY sibling sample were excluded due to missingness on either moderator. Furthermore, for data from the CNLSY sibling sample, we used the complex survey option in *Mplus* to correct for the nonindependence of data obtained from sibling pairs who were related at the extended family level.

For parental emotional support at time 1 and externalizing behaviors at both time points, variance was modeled as a linear function of additive genes (A), shared environment (C), and nonshared environment (E). For ECLS-B data, corresponding A's were constrained to correlate at 1.0 for MZ twin pairs and 0.5 for DZ twin pairs. For CNLSY data, corresponding A's were constrained to correlate at .5 for FS pairs and .25 for HS pairs. C's represent all environmental factors that contribute to the similarity between siblings in a pair and therefore corresponding C's were constrained to correlate at 1.0 for all sibling pairs. Because E's represent environmental factors that contribute to the dissimilarity between siblings in a pair and all measurement errors, corresponding E's were independently estimated for all sibling pairs. All corresponding regression coefficients were constrained to be the same for all siblings in each model. Figure 1 illustrates our longitudinal Cholesky model. We first fit a model with main effects only to examine the population-average effect of each variance component. We next fit a model with interaction terms to investigate whether moderation effect(s) observed would act on the genetic and environmental influences at

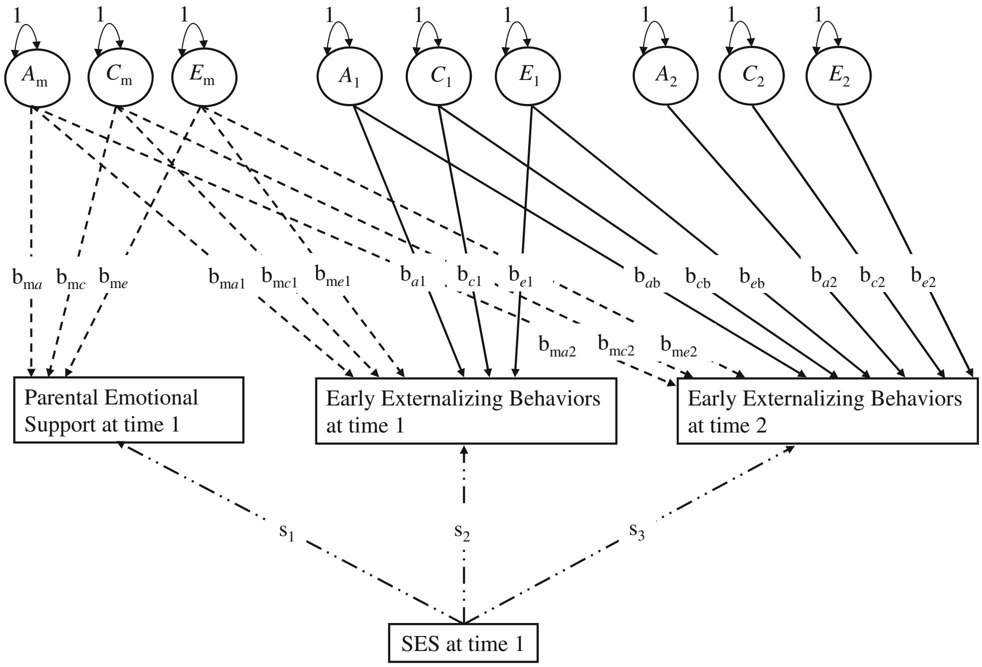

Fig. 1 A longitudinal Cholesky model of externalizing behaviors measured at 2 time points, controlling for the main effect(s) of moderator(s). Only the part for one sibling from each pair is presented. This path diagram illustrates the models we fit to the ECLS-B twin sample. The same models were fit to the CNLSY sibling sample, except SES was modeled as two observed variables, one per sibling in a pair, because the assessment year when a sibling reached 4 or 5 years old is different from that when the other one in the pair reached the same age. Parts with *solid lines* and evenly *broken lines* illustrate Model 1. Paths b_{a1}, b_{c1}, b_{e1}, b_{ab}, b_{cb}, b_{eb}, b_{a2}, b_{c2}, and b_{e2} in Model 1 each contains a main effect (i.e., b_{a10}, b_{c10}, b_{e10}, b_{ab0}, b_{cb0}, b_{eb0}, b_{a20}, b_{c20}, and b_{e20}) and an interaction with parental emotional support (i.e., b_{a1}', b_{c1}', b_{e1}', b_{ab}', b_{cb}', b_{eb}', b_{a2}', b_{c2}', and b_{e2}'). Parts with *solid lines* and *unevenly broken lines* illustrate Model 2. Paths b_{a1}, b_{c1}, b_{e1}, b_{ab}, b_{cb}, b_{eb}, b_{a2}, b_{c2}, and b_{e2} in Model 2 each contains a main effect (i.e., b_{a10}, b_{c10}, b_{e10}, b_{ab0}, b_{cb0}, b_{eb0}, b_{a20}, b_{c20}, and b_{e20}) and an interaction with socioeconomic status (i.e., b_{a1}', b_{c1}', b_{e1}', b_{ab}', b_{cb}', b_{eb}', b_{a2}', b_{c2}', and b_{e2}'). The whole figure illustrates our final model with both moderators. Paths b_{a1}, b_{c1}, b_{e1}, b_{ab}, b_{cb}, b_{eb}, b_{a2}, b_{c2}, and b_{e2} in Model 3 each contains a main effect (i.e., b_{a10}, b_{c10}, b_{e10}, b_{ab0}, b_{cb0}, b_{eb0}, b_{a20}, b_{c20}, and b_{e20}) and two interactions, one with parental emotional support (i.e., b_{a1}', b_{c1}', b_{e1}', b_{ab}', b_{cb}', b_{eb}', b_{a2}', b_{c2}', and b_{e2}') and one with socioeconomic status (i.e., b_{a1}'', b_{c1}'', b_{e1}'', b_{ab}'', b_{cb}'', b_{eb}'', b_{a2}'', b_{c2}'', and b_{e2}'')

time 1 (i.e., the paths from A_1, C_1, and E_1 to externalizing behaviors at time 1), those carried-over from time 1 to externalizing behaviors at time 2 (i.e., the paths from A_1, C_1, and E_1 to externalizing behaviors at time 2), and/or those unique to externalizing behaviors at time 2 (i.e., the paths from A_2, C_2, and E_2 to externalizing behaviors at time 2).

In Model 1 (see Fig. 1), we controlled for the main effect of parental emotional support on externalizing behaviors by regressing externalizing behaviors at both times on A, C, and E of parental emotional support. A's, C's, and E's of externalizing behaviors therefore reflect genetic and environmental contributions that are above and beyond the effect of parental emotional support. To examine the moderation effect of parental emotional support, effects of A's, C's, and E's on externalizing behaviors were allowed to vary as a function of parental emotional support. Each of the nine regression paths (i.e., b_{a1}, b_{c1}, b_{e1}, b_{ab}, b_{cb}, b_{eb}, b_{a2}, b_{c2}, and b_{e2}) of externalizing behaviors contains a main effect (i.e., b_{a10}, b_{c10}, b_{e10}, b_{ab0}, b_{cb0}, b_{eb0}, b_{a20}, b_{c20}, and b_{e20}) and an interaction with parental emotional support (i.e., b_{a1}', b_{c1}', b_{e1}', b_{ab}', b_{cb}', b_{eb}', b_{a2}', b_{c2}', and b_{e2}'). A statistically significant interaction suggests a moderation effect of parental emotional support on the corresponding genetic or environmental influences. For instance, if b_{a2}' is statistically significant, it suggests that the influence of A_2 (i.e., additive genes unique to time 2) on time 2 externalizing behaviors differs by the amount of parental emotional support a child received.

Model 2 was similar to Model 1 except parental emotional support was replaced with SES (see Fig. 1). Because SES provides information on the socioeconomic difference between families rather than siblings, we did not decompose the variance of SES in our models. For the ECLS-B twin sample, SES was modeled as a single observed variable per pair of twins because it was measured at the family level at the same time for each twin. For the CNLSY sibling sample, SES was modeled as two observed variables, one per sibling in a pair, because the assessment year when a sibling reached 4 or 5 years old is different from that when the other one in the pair reached the same age. Similar to Model 1, each of the nine regression paths (i.e.,

Table 4 Descriptive statistics of variables

	ECLS-B (*M*/*SD*/*N*)			CNLSY (*M*/*SD*/*N*)		
	Full sample	MZ	DZ	Full sample	FS	HS
$EMOSUP_{1,1}$	4.53/.95/550	4.51/.93/150	4.54/.96/400	100.86/14.70/1631	102.19/14.01/1353	94.41/16.20/278
$EMOSUP_{1,2}$	4.52/.96/550	4.53/.90/150	4.52/.98/400	97.83/15.97/1617	99.24/15.49/1316	91.66/16.57/301
$SES_{1,1}$	.12/.85/600	−.02/.88/200	.18/.83/450	46402.55/85982.42/1699	51112.72/90727.26/1402	24168.01/53369.54/297
$SES_{1,2}$				52695.78/90957.23/1793	57455.39/98455.80/1462	31672.98/38294.33/331
$EXT_{1,1}$	11.68/3.10/600	11.64/3.32/200	11.69/3.01/450	.41/.31/1347	.41/.31/1126	.44/.31/221
$EXT_{1,2}$	11.80/3.37/600	11.82/3.09/200	11.80/3.48/450	.42/.34/1430	.40/.33/1162	.49/.39/268
$EXT_{2,1}$	11.36/3.39/500	11.12/3.13/150	11.46/3.49/350	.35/.30/1795	.35/.29/1470	.39/.33/325
$EXT_{2,2}$	11.22/3.38/500	11.01/3.21/150	11.30/3.45/350	.37/.33/1670	.36/.32/1366	.41/.37/304

The first number in the subscripts represents the time point when measurements were made and the second one represents the sibling in a pair. *N*s for the ECLS-B twin sample are rounded up to the nearest multiple of 50 due to ECLS-B requirements

EMOSUP parental emotional support, *SES* socioeconomic status, *EXT* externalizing behaviors

Table 5 Correlation between variables observed in the ECLS-B twin sample

	$EMOSUP_{1,1}$	$EMOSUP_{1,2}$	SES_1	$EXT_{1,1}$	$EXT_{1,2}$	$EXT_{2,1}$
$EMOSUP_{1,2}$	.55** (.57**/.55**)	–				
SES_1	.41** (.35**/.45**)	.35** (.32**/.37**)	–			
$EXT_{1,1}$	−.06 (−.07/−.06)	−.07^ (−.10/−.06)	−.09* (−.09/−.09^)	–		
$EXT_{1,2}$	<.01 (−.03/.01)	−.06 (−.14^/−.03)	−.12** (−.16*/−.11*)	.45** (.61**/.39**)	–	
$EXT_{2,1}$	−.05 (−.13/−.03)	−.08^ (−.10/−.07)	−.16** (−.22**/−.14**)	.57** (.50**/.60**)	.26** (.46**/.19**)	–
$EXT_{2,2}$	<−.01 (−.04/.01)	−.04 (.01/−.06)	−.10* (−.10/−.11*)	.33** (.43**/.29**)	.61** (.56**/.62**)	.43** (.65**/.36**)

The first number in the subscripts represents the time point when measurements were made and the second one represents the sibling in a pair. SES was measured only once at time 1 because the twins reached the same age at the same time

EMOSUP parental emotional support, *SES* socioeconomic status, *EXT* externalizing behaviors

^ $p < .10$. * $p < .05$. ** $p < .01$. Estimates outside brackets are for the whole sample. The first estimate in each bracket is the one for MZ twins and the second one is the one for DZ twins

b_{a1}, b_{c1}, b_{e1}, b_{ab}, b_{cb}, b_{eb}, b_{a2}, b_{c2}, and b_{e2}) of externalizing behaviors contains a main effect (i.e., b_{a10}, b_{c10}, b_{e10}, b_{ab0}, b_{cb0}, b_{eb0}, b_{a20}, b_{c20}, and b_{e20}) and an interaction with SES (i.e., b_{a1}', b_{c1}', b_{e1}', b_{ab}', b_{cb}', b_{eb}', b_{a2}', b_{c2}', and b_{e2}'). A statistically significant interaction term in our second model suggests a moderation effect of SES on the corresponding genetic or environmental influences.

In Model 3, we simultaneously included both parental emotional support and SES as moderators to investigate their independent effects on genetic and environmental influences on externalizing behaviors (see Fig. 1). For the CNLSY sibling sample, similar to Model 2, SES was modeled as two observed variables, one per sibling in a pair, because the assessment year when a sibling reached 4 or 5 years old is different from that when the other one in the pair reached the same age. In this final model, each of the nine regression paths (i.e., b_{a1}, b_{c1}, b_{e1}, b_{ab}, b_{cb}, b_{eb}, b_{a2}, b_{c2}, and b_{e2}) of externalizing behaviors contained a main effect and two interaction terms, one with parental emotional support and one with SES. If any of the interactions with parental emotional support in this model is statistically significant, this suggests that parental emotional support moderates the influence of that corresponding latent factor in externalizing behaviors above and beyond the effects of SES. Similarly, if any of the interactions with SES in this model is statistically significant, this suggests that SES moderates the influence of that corresponding latent factor in externalizing behaviors above and beyond the effects of parental emotional support.

Results

Table 4 lists the descriptive statistics of the two moderators and externalizing behaviors at both time points before standardization with respect to our samples and Tables 5 and 6 list the correlation coefficients of these variables. Correlation coefficients from the CNLSY sibling sample were more consistent with previous literature on the relation between parenting and externalizing behaviors than those from the ECLS-B twin sample. For the CNLSY sibling sample, parental emotional support was positively correlated with SES, and both of these factors were

Table 6 Correlation between variables observed in the CNLSY sibling sample

	$EMOSUP_{1,1}$	$EMOSUP_{1,2}$	$SES_{1,1}$	$SES_{1,2}$	$EXT_{1,1}$	$EXT_{1,2}$	$EXT_{2,1}$
$EMOSUP_{1,2}$	.43** (.42**/.38**)	–					
$SES_{1,1}$	.16** (.14**/.13^)	.08** (.06^/.13*)	–				
$SES_{1,2}$	.14** (.12**/.25**)	.12** (.09**/.28**)	.33** (.31**/.47**)	–			
$EXT_{1,1}$	−.22** (−.21**/−.22**)	−.16** (−.15**/−.18*)	−.13** (−.13**/−.08)	−.12** (−.12**/−.21**)	–		
$EXT_{1,2}$	−.11** (−.10**/−.06)	−.20** (−.17**/−.21**)	−.07* (−.06^/−.06)	−.09** (−.09**/−.10)	.26** (.27**/.23**)	–	
$EXT_{2,1}$	−.19** (−.18**/−.17**)	−.12** (−.13**/−.07)	−.12** (−.12**/−.13*)	−.09** (−.08**/−.14*)	.55** (.58**/.39**)	.36** (.38**/.27**)	–
$EXT_{2,2}$	−.12** (−.13**/−.02)	−.15** (−.13**/−.20**)	−.08** (−.09**/−.02)	−.09** (−.09**/−.13*)	.28** (.29**/.24**)	.59** (.56**/.66**)	.30** (.31**/.22**)

EMOSUP parental emotional support, *SES* socioeconomic status, *EXT* externalizing behaviors

Note The first number in the subscripts represents the time point when measurements were made and the second one represents the sibling in a pair

^ $p < .10$. * $p < .05$. ** $p < .01$. Estimates outside brackets are for the whole sample. The first estimate in each bracket is for full-sibling pairs and the second one is for half-sibling pairs

Table 7 Main effect and interaction parameter estimates in Model 1 (parental emotional support at time 1 as moderator)

Path	ECLS-B			CNLSY		
	Main effect model	Interaction model		Main effect model	Interaction model	
		Main effect	Interaction		Main effect	Interaction
b_{a1}	**.64(±.20)**	**.78(±.16)**	−.06(±.12)	.41(±.80)	**.52(±.08)**	−.02(±.08)
b_{c1}	**.50(±.18)**	.19(±.32)	**.25(±.12)**	**.36(±.22)**	**.38(±.25)**	−.01(±.08)
b_{e1}	**.64(±.06)**	**.51(±.06)**	−.07(±.08)	**.67(±.16)**	**.68(±.16)**	**−.07(±.06)**
b_{ab}	**.69(±.37)**	**.58(±.34)**	−.02(±.12)	.42(±.82)	.50(±.51)	−.10(±.12)
b_{cb}	.11(±.31)	.19(±.27)	.01(±.16)	**.35(±.22)**	**.37(±.24)**	.01(±.14)
b_{eb}	**.23(±.10)**	**.16(±.09)**	.06(±.14)	<−.01(±.29)	.03(±.31)	.04(±.08)
b_{a2}	.39(±.55)	**.43(±.33)**	**−.17(±.18)**	**.00(±.00)**	–	–
b_{c2}	.27(±.37)	.28(±.29)	−.07(±.20)	**.00(±.00)**	–	–
b_{e2}	**.61(±.06)**	**.53(±.06)**	−.02(±.06)	**.63(±.18)**	**.64(±.18)**	−.02(±.08)

Bolded = $p < .05$. Results from the CNLSY main effects model all suggested no A_2 and C_2 effects on externalizing behaviors; therefore we dropped paths b_{a2} and b_{c2} in all the CNLSY interactions models to facilitate model convergence

negatively correlated with externalizing behaviors at both times. Similar observations were observed in the ECLS-B twin sample, except that parental emotional support was not significantly correlated with externalizing behaviors measured at either time point. For both samples, scores on externalizing behaviors were positively correlated across siblings and across times.

The main goal of the current study is to investigate moderation effects of parental emotional support and SES on the genetic and environmental influences on externalizing behaviors over time. We therefore focus our attention on the nine regression paths described above (i.e., b_{a1}, b_{c1}, b_{e1}, b_{ab}, b_{cb}, b_{eb}, b_{a2}, b_{c2}, and b_{e2}; see Fig. 1). Tables 7, 8 and 9 report parameter estimates for these nine paths in all our main effects and interactions models fitted to both samples. Results from the CNLSY main effects models all suggested no A_2 and C_2 effects on externalizing behaviors; therefore we dropped paths b_{a2} and b_{c2} in all the CNLSY interactions models to facilitate model convergence.

Our results are derived from models that did not estimate what might be described as moderated covariances (quasi-quadratic effects) between each moderator and each outcome variable. Thus we estimated 9 interactions in models with a single moderator and 18 interactions in models with both parental emotional support and SES as moderators. As van der Sluis et al. (2012) have explicated, failing to model a moderated covariance between a moderator and a phenotype, if one truly exists, can lead to false positive results in other portions of the model. While we appreciate this point, we also note that estimating these additional interactions in the, already complex, longitudinal model that we have adopted may (ironically) inflate the risk for false positive results due to increased multiple hypothesis testing and model over-fitting. We believe that

Table 8 Main effect and interaction parameter estimates in Model 2 (SES at time 1 as moderator)

Path	ECLS-B			CNLSY		
	Main effect model	Interaction model		Main effect model	Interaction model	
		Main effect	Interaction		Main effect	Interaction
b_{a1}	**.65(±.18)**	**.61(±.16)**	**.17(±.10)**	**.65(±.29)**	**.63(±.33)**	.05(±.08)
b_{c1}	**.49(±.18)**	**.45(±.18)**	**−.17(±.12)**	**.33(±.29)**	.29(±.35)	−.03(±.08)
b_{e1}	**.64(±.06)**	**.62(±.06)**	**−.08(±.04)**	**.68(±.16)**	**.71(±.16)**	**−.14(±.06)**
b_{ab}	**.74(±.25)**	**.83(±.15)**	−.07(±.12)	**.63(±.27)**	**.57(±.43)**	**−.10(±.06)**
b_{cb}	.09(±.31)	.07(±.28)	−.02(±.18)	**.30(±.27)**	**.49(±.20)**	.02(±.08)
b_{eb}	**.23(±.10)**	**.19(±.09)**	−.06(±.08)	.04(±.29)	.06(±.35)	.01(±.08)
b_{a2}	**.45(±.35)**	.15(±.33)	**.26(±.18)**	**.00(±.00)**	–	–
b_{c2}	.26(±.37)	.24(±.37)	−.04(±.24)	**.00(±.00)**	–	–
b_{e2}	**.61(±.06)**	**.58(±.06)**	−.05(±.06)	**.66(±.14)**	.32(±.47)	−.05(±.20)

Bolded = $p < .05$. Results from the CNLSY main effects model all suggested no A_2 and C_2 effects on externalizing behaviors; therefore we dropped paths b_{a2} and b_{c2} in all the CNLSY interactions models to facilitate model convergence

Table 9 Main effect and interaction parameter estimates in Model 3 (two moderators)

Path	ECLS-B				CNLSY			
	Main effect model	Interaction model			Main effect model	Interaction model		
		Main effect	Interaction			Main effect	Interaction	
			Parental emotional support	SES			Parental emotional support	SES
b_{a1}	**.64(±.20)**	**.73(±.15)**	.06(±.10)	**.12(±.10)**	.41(±.71)	.43(±.65)	<.01(±.12)	.02(±.12)
b_{c1}	**.48(±.20)**	**.33(±.25)**	−.11(±.14)	−.11(±.16)	.29(±.43)	**.40(±.29)**	−.05(±.12)	.02(±.08)
b_{e1}	**.64(±.06)**	**.52(±.06)**	−.06(±.08)	**−.07(±.06)**	**.77(±.20)**	**.74(±.20)**	−.05(±.06)	**−.09(±.06)**
b_{ab}	**.68(±.37)**	**.78(±.19)**	−.07(±.12)	−.04(±.12)	.40(±.69)	.39(±.67)	−.09(±.12)	−.02(±.06)
b_{cb}	.06(±.35)	−.08(±.32)	.01(±.18)	−.04(± .20)	.27(±.41)	**.37(±.29)**	−.04(±.12)	−.01(±.06)
b_{eb}	**.23(±.10)**	**.11(±.08)**	.02(±.12)	−.01(±.08)	.20(±.33)	.19(±.33)	.04(±.10)	−.01(±.04)
b_{a2}	.39(±.53)	.07(±.39)	.07(±.18)	**.24(±.16)**	**.00(±.00)**	–	–	–
b_{c2}	.17(±.67)	.24(±.33)	−.16(±.18)	.04(±.25)	**.00(±.00)**	–	–	–
b_{e2}	**.61(±.06)**	**.53(±.06)**	−.01(±.06)	−.05(±.06)	**.72(±.12)**	**.71(±.12)**	−.01(±.08)	−.03(±.04)

Bolded = $p < .05$. Results from the CNLSY main effects model all suggested no A_2 and C_2 effects on externalizing behaviors; therefore we dropped paths b_{a2} and b_{c2} in all the CNLSY interactions models to facilitate model convergence

the less complex models that do not include moderated covariances between moderators and phenotypes may therefore be less prone to over-fitting and be more likely to replicate across samples. As we make a particular point of the issue of replicability, we choose to report the results from these less complex models in the body of this paper. In the Online Appendix, we report results from the more complex models with moderated covariances between moderators and phenotypes. Importantly, our primary conclusion remains unaltered across modeling choices: G×E interactions detected in the ECLS-B twin sample do not replicate in the CNLSY sibling sample; E×SES interaction at time 1 was the only moderation replicated across samples.

Model 1: Parental Emotional Support

Given the protective effect of parental socialization and existing findings summarized above, we anticipated that the importance of genes and environmental factors in externalizing behaviors would vary by the amount of parental emotional support a child received. With a longitudinal Cholesky model, we also explored if parental emotional support would moderate genetic and environmental influences on externalizing behaviors at time 1, those carried over from time 1 on externalizing behaviors at time 2, and/or those unique to time 2. Figure 2 contains six panels for results comparison across samples and across times, with each panel illustrating results observed in one sample at one time point.

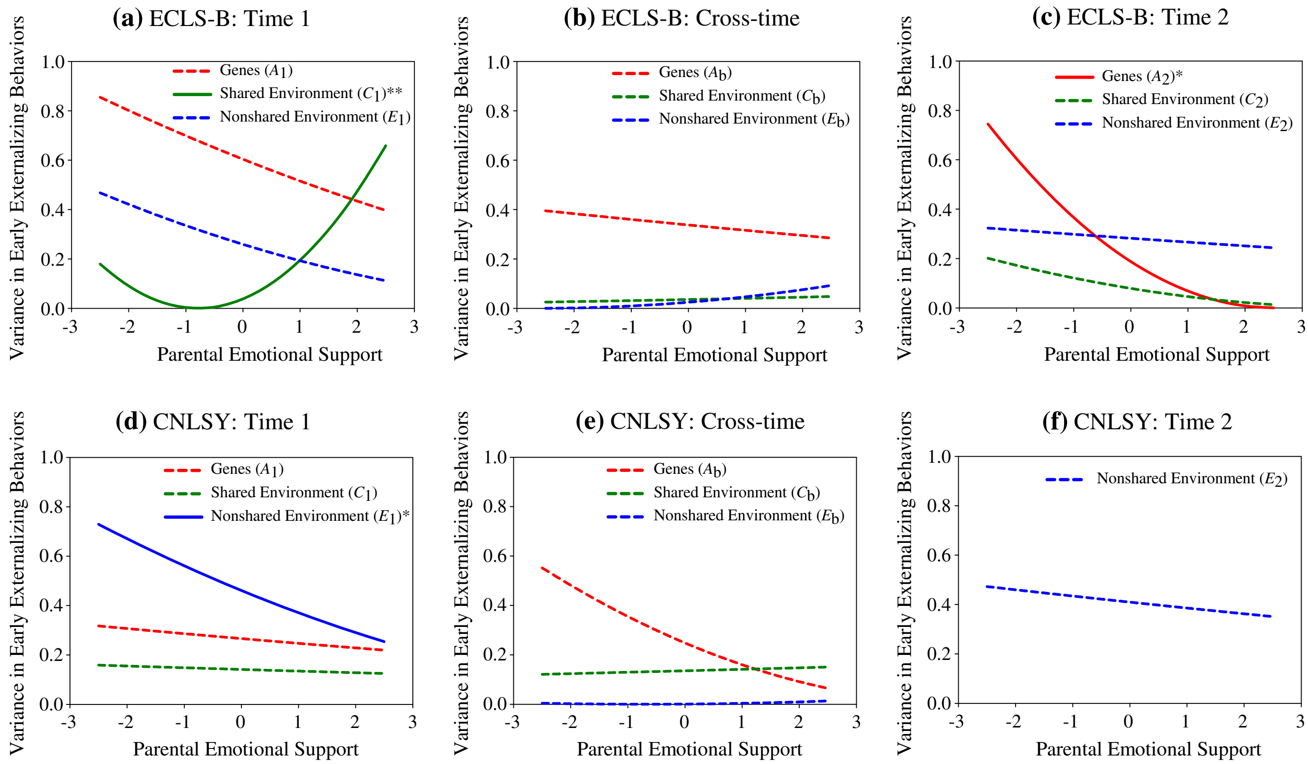

Fig. 2 Graphic representation of interactions observed from Model 1 (i.e., moderation effects of parental emotional support). *Upper panels* illustrate results from the ECLS-B twin sample while *lower panels* illustrate results from the CNLSY sibling sample. *Left panels* illustrate genetic and environmental influences at time 1, *middle panels* illustrate genetic and environmental influences at time 1 on externalizing behaviors at time 2, and *right panels* illustrate genetic and environmental influences that were unique to time 2. *Red lines* represent genetic influences, *green lines* represent shared environmental influences, and *blue lines* represent nonshared environmental influences. *Solid lines* indicate statistically significant G×E interactions. *$p < .05$. **$p < .01$. *Dashed lines* indicate statistically insignificant ones. Results from the CNLSY main effects model all suggested no A_2 and C_2 effects on externalizing behaviors; therefore we dropped paths b_{a2} and b_{c2} in all the CNLSY interactions models to facilitate model convergence (Color figure online)

ECLS-B

Our model fit the ECLS-B data well (model fit statistics from main effects model: $\chi^2(33) = 27.490$, $p = .738$, RMSEA $< .001$, CFI $= 1.000$, TLI $= 1.006$). At time 1, shared environment influenced externalizing behaviors differentially by levels of parental emotional support. C_1 accounted for 9 % of the variance of time 1 externalizing behaviors among children who received parental emotional support that was 2*SD* below sample average but for 47 % among those who received parental emotional support that was 2*SD* above sample average (see upper left panel of Fig. 2). While influence of shared environment differed by levels of parental emotional support, genes were more influential than environmental factors at time 1 ($a^2 = 60$ %, $e^2 = 26$ %) and the importance of A_1 and E_1 in externalizing behaviors remained constant at all levels of parental emotional support. In contrast, A_2 influenced externalizing behaviors differentially by levels of parental emotional support. A_2 accounted for 60 % of the variance of time 2 externalizing behaviors among children who received parental emotional support that was 2*SD* below sample average but for 0 % among those who received parental emotional support that was 2*SD* above sample average (see upper right panel of Fig. 2). Environmental influences unique to time 2 remained constant ($c^2 = 8$ %, $e^2 = 28$ %) regardless of the amount of parental emotional support a child received. Relation of externalizing behaviors across the two time points was mediated by genes. Of the total variance of time 2 externalizing behaviors, 34 % was explained by A_1 and none was explained by C_1 and E_1; and these carried-over influences remained constant regardless of the amount of parental emotional support a child received.

CNLSY

None of the interactions observed for the ECLS-B twin sample was replicated using the CNLSY sibling sample (model fit statistics from main effects model: $\chi^2(32) = 161.627$, $p < .001$, RMSEA $= .065$, CFI $= .911$, TLI $= .917$). Externalizing behaviors at time 1 was mostly

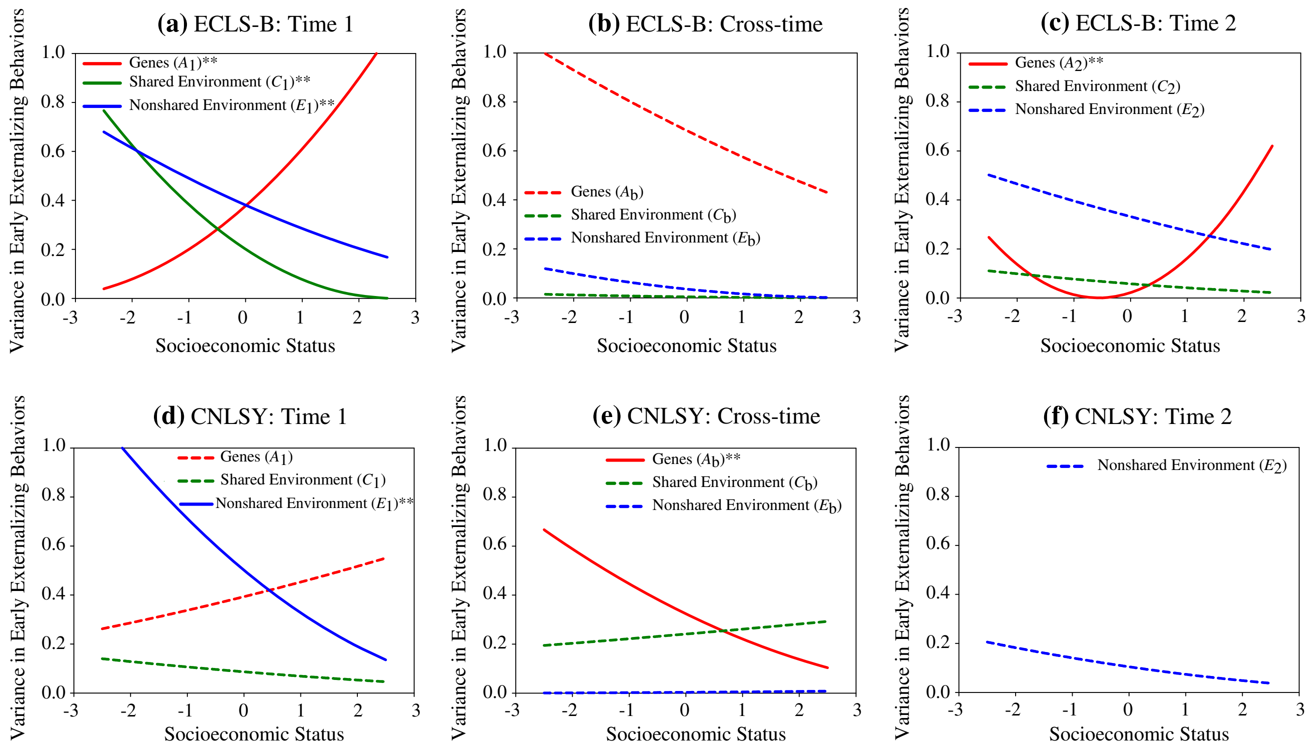

Fig. 3 Graphic representation of interactions observed from Model 2 (i.e., moderation effects of socioeconomic status). *Upper panels* illustrate results from the ECLS-B twin sample while *lower panels* illustrate results from the CNLSY sibling sample. *Left panels* illustrate genetic and environmental influences at time 1, *middle panels* illustrate genetic and environmental influences at time 1 on externalizing behaviors at time 2, and *right panels* illustrate genetic and environmental influences that were unique to time 2. *Red lines* represent genetic influences, *green lines* represent shared environmental influences, and *blue lines* represent nonshared environmental influences. *Solid lines* indicate statistically significant G×E interactions. $^{*}p < .05$. $^{**}p < .01$. *Dashed lines* indicate statistically insignificant ones. Results from the CNLSY main effects model all suggested no A_2 and C_2 effects on externalizing behaviors; therefore we dropped paths b_{a2} and b_{c2} in all the CNLSY interactions models to facilitate model convergence (Color figure online)

influenced by A_1 and E_1 ($a^2 = 27$ %, $c^2 = 14$ %, $e^2 = 46$ %). Genetic and environmental influences at time 1 remained constant at all levels of parental emotional support except for the influences of E_1, which is the only statistically significant interaction observed in this model. E_1 accounted for 67 % of the variance of time 1 externalizing behaviors among children who received parental emotional support that was 2*SD* below sample average but for 29 % among those who received parental emotional support that was 2*SD* above sample average (see lower left panel of Fig. 2). This moderation effect of parental emotional support on the influence of E_1 followed a similar trend in the ECLS-B twin sample but did not reach statistical significance. On the contrary, at time 2, E_2 explained 41 % of the variance of externalizing behaviors at all levels of parental emotional support a child received. Similar to the results observed in the ECLS-B twin sample, relation of externalizing behaviors across the two time points was mediated more by genes than environments. Of the total variance of time 2 externalizing behaviors, 25 % was explained by A_1, 14 % was explained by C_1, and <1 % was explained by E_1; and these carried-over influences remained constant regardless of the amount of parental emotional support a child received.

Model 2: SES

Using the longitudinal Cholesky model outlined above, we also examined if SES would moderate genetic and environmental influences on externalizing behaviors at time 1, those carried over from time 1 onto externalizing behaviors at time 2, and/or those unique to time 2. Figure 3 contains six panels for results comparison across samples and across times, with each panel illustrating results observed in one sample at one time point.

ECLS-B

Our model fit the ECLS-B data well (model fit statistics from main effects model: $\chi^2(23) = 24.604$, $p = .371$, RMSEA = .015, CFI = .998, TLI = .998). At time 1, influence of genes became more important while that of environments became less at higher SES. Externalizing behaviors at time 1 was more influenced by C_1 and E_1

($a^2 = 8$ %, $c^2 = 62$ %, $e^2 = 61$ %) among children from families whose SES was 2*SD* below the sample average but more by A_1 ($a^2 = 90$ %, $c^2 = 1$ %, $e^2 = 20$ %) among those from families whose SES was 2*SD* above the sample average (see upper left panel of Fig. 3). A similar $A \times$SES interaction was also observed at time 2. A_2 accounted for 14 % of the variance of time 2 externalizing behaviors among children from families whose SES was 2*SD* below the sample average but for 43 % among children from families whose SES was 2*SD* above the sample average (see upper right panel of Fig. 3). While A_2 influenced time 2 externalizing behaviors differentially by levels of SES, influences of C_2 and E_2 remained constant ($c^2 = 6$ %, $e^2 = 33$ %) regardless of the level of SES. Similar to results from Model 1, relation of externalizing behaviors across the two time points was mediated mostly by genes. Of the total variance of time 2 externalizing behaviors, 68 % was explained by A_1, 0 % was explained by C_1, and 4 % was explained by E_1; and these carried-over influences remained constant at all levels of SES.

CNLSY

The only interaction observed in the ECLS-B twin sample replicated using the CNLSY sibling sample was the moderation effect of SES on the influence of E_1 (see lower panels of Fig. 3; model fit statistics from main effects model: $\chi^2(31) = 73.362$, $p < .001$, RMSEA = .041, CFI = .956, TLI = .961). Externalizing behaviors at time 1 were influenced mostly by A_1 and E_1 ($a^2 = 39$ %, $c^2 = 9$ %, $e^2 = 50$ %) and the genetic and environmental influences at time 1 remained constant at all levels of SES, except for the influences of E_1. E_1 accounted for 96 % of the variance of time 1 externalizing behaviors among children from families whose SES was 2*SD* below sample average but for 19 % among those from families whose SES was 2*SD* above sample average (see lower left panel of Fig. 3). On the contrary, at time 2, E_2 explained 10 % of the variance of externalizing behaviors at all levels of SES. Consistent with observations in the ECLS-B twin sample, relation of externalizing behaviors across the two time points was mediated mostly by genes. Although a similar trend was observed in the ECLS-B twin sample, moderation of SES on the cross-time genetic influences reached significance only in the CNLSY sibling sample. A_1 accounted for 59 % of the variance of time 2 externalizing behaviors among children from families whose SES was 2*SD* below sample average but for 14 % among those from families whose SES was 2*SD* above sample average (see lower middle panel of Fig. 3). Of the total variance of time 2 externalizing behaviors, 24 % was explained by C_1 and <1 % was explained by E_1; and these carried-over environmental influences remained constant regardless of the level of SES.

Model 3: Parental Emotional Support and SES

Since parental emotional support and SES are positively correlated with each other and both are commonly studied factors in externalizing behaviors, differentiating their moderation effects on genetic and environmental influences on externalizing behaviors might help understand the complex etiology of behavioral maladjustment. To do this, we simultaneously included both parental emotional support and SES as moderators in our final model and examined if they had distinct moderation effects on genetic and environmental influences on externalizing behaviors. Figures 4 and 5 illustrate results on the independent moderation effects of parental emotional support and SES, respectively. Each figure contains six panels for results comparison across samples and across times, with each panel illustrating results observed in one sample at one time point.

ECLS-B

Our model fit the ECLS-B data well (model fit statistics from main effects model: $\chi^2(42) = 40.109$, $p = .554$, RMSEA $< .001$, CFI = 1.000, TLI = 1.002). Once we have accounted for the effects of SES, parental emotional support no longer interacted with any latent genetic or environmental factors in externalizing behaviors. Externalizing behaviors was more influenced by A_1 ($a^2 = 53$ %, $c^2 = 11$ %, $e^2 = 27$ %) at time 1 but more by E_2 ($a^2 = 0$ %, $c^2 = 6$ %, $e^2 = 28$ %) at time 2 (see upper panels of Fig. 4). Genetic and environmental influences at both times remained constant at all levels of parental emotional support.

In contrast to the null results on moderation effects of parental emotional support, most moderation effects of SES observed in Model 2 remained statistically significant after accounting for the effects of parental emotional support. At time 1, externalizing behaviors were influenced more by E_1 ($a^2 = 26$ %, $e^2 = 43$ %) among children from families whose SES was 2*SD* below the sample average but more by A_1 ($a^2 = 88$ %, $e^2 = 15$ %) among children from families whose SES was 2*SD* above the sample average (see upper left panel of Fig. 5). However, $C_1 \times$SES interaction was no longer statistically significant ($p = .16$) after accounting for the effects of parental emotional support. C_1 accounted for 11 % of the variance of time 1 externalizing behaviors at all levels of SES.

The $A_2 \times$SES interaction observed in Model 2 was also observed after we accounted for the effects of parental emotional support; A_2 accounted for 17 % of the variance of time 2 externalizing behaviors among children from families whose SES was 2*SD* below the sample average but for 30 % among children from families whose SES was

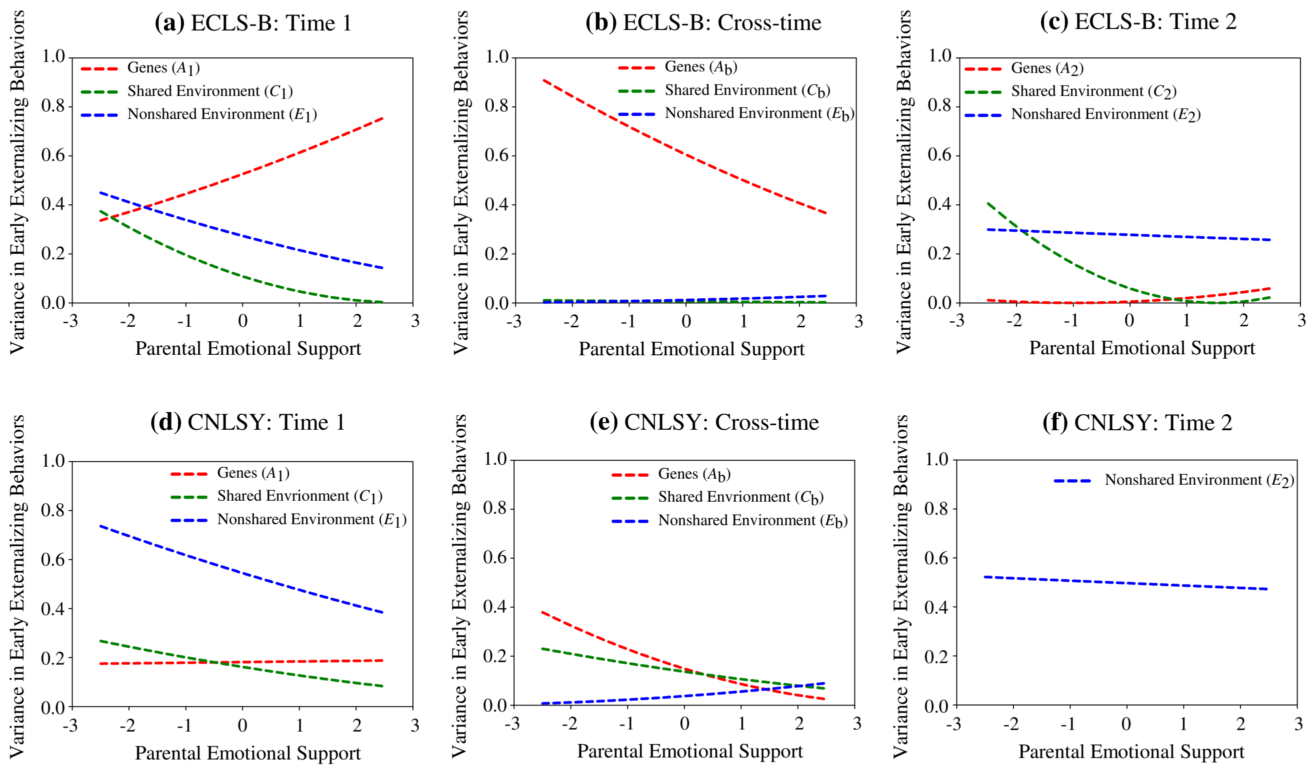

Fig. 4 Graphic representation of interactions with parental emotional support observed from Model 3 (i.e., moderation effects of parental emotional support above and beyond those of socioeconomic status). *Upper panels* illustrate results from the ECLS-B twin sample while *lower panels* illustrate results from the CNLSY sibling sample. *Left panels* illustrate genetic and environmental influences at time 1, middle panels illustrate genetic and environmental influences at time 1 on externalizing behaviors at time 2, and *right panels* illustrate genetic and environmental influences that were unique to time 2. *Red lines* represent genetic influences, *green lines* represent shared environmental influences, and *blue lines* represent nonshared environmental influences. *Solid lines* indicate statistically significant G×E interactions. $^*p < .05$. $^{**}p < .01$. *Dashed lines* indicate statistically insignificant ones. Results from the CNLSY main effects model all suggested no A_2 and C_2 effects on externalizing behaviors; therefore we dropped paths b_{a2} and b_{c2} in all the CNLSY interactions models to facilitate model convergence (Color figure online)

2*SD* above the sample average (see upper right panel of Fig. 5). After accounting for the effects of parental emotional support, influences of environmental factors unique to time 2 on externalizing behaviors remained constant ($c^2 = 6$ %, $e^2 = 28$ %) at all levels of SES. When examining moderation effects of parental emotional support and SES simultaneously, similar to results from models 1 and 2, relation of externalizing behaviors across the two time points was mediated mostly by genes. Of the total variance of time 2 externalizing behaviors, 61 % was explained by A_1, 1 % was explained by C_1, and 1 % was explained by E_1; and these carried-over influences remained constant regardless of the amount of parental emotional support a child received or the level of SES.

CNLSY

The only interaction observed in the ECLS-B twin sample that replicated using the CNLSY sibling sample was the moderation effect of SES on the influences of E_1 (model fit statistics from main effect model: $\chi^2(53) = 176.946$, $p < .001$, RMSEA = .054, CFI = .902, TLI = .900). The moderation effect of parental emotional support on the influences of E_1 and that of SES on the cross-time genetic influences observed in Models 1 and 2, respectively, no longer reached statistical significance when we examined the two moderators simultaneously. Externalizing behaviors at time 1 were influenced mostly by E_1 ($a^2 = 18$ %, $c^2 = 16$ %, $e^2 = 54$ %) and these genetic and environmental influences at time 1 remained constant at all levels of parental emotional support (see lower left panel of Fig. 4) and at all levels of SES, except for the influences of E_1 (see lower left panel of Fig. 5). E_1 accounted for 85 % of the variance of time 1 externalizing behaviors among children from families whose SES was 2*SD* below sample average but for 31 % among those from families whose SES was 2*SD* above sample average. Comparing results across Models 1 through 3, after accounting for the effects of SES, influences of E_1 on externalizing behaviors remained constant ($e^2 = 54$ %) at all levels of parental

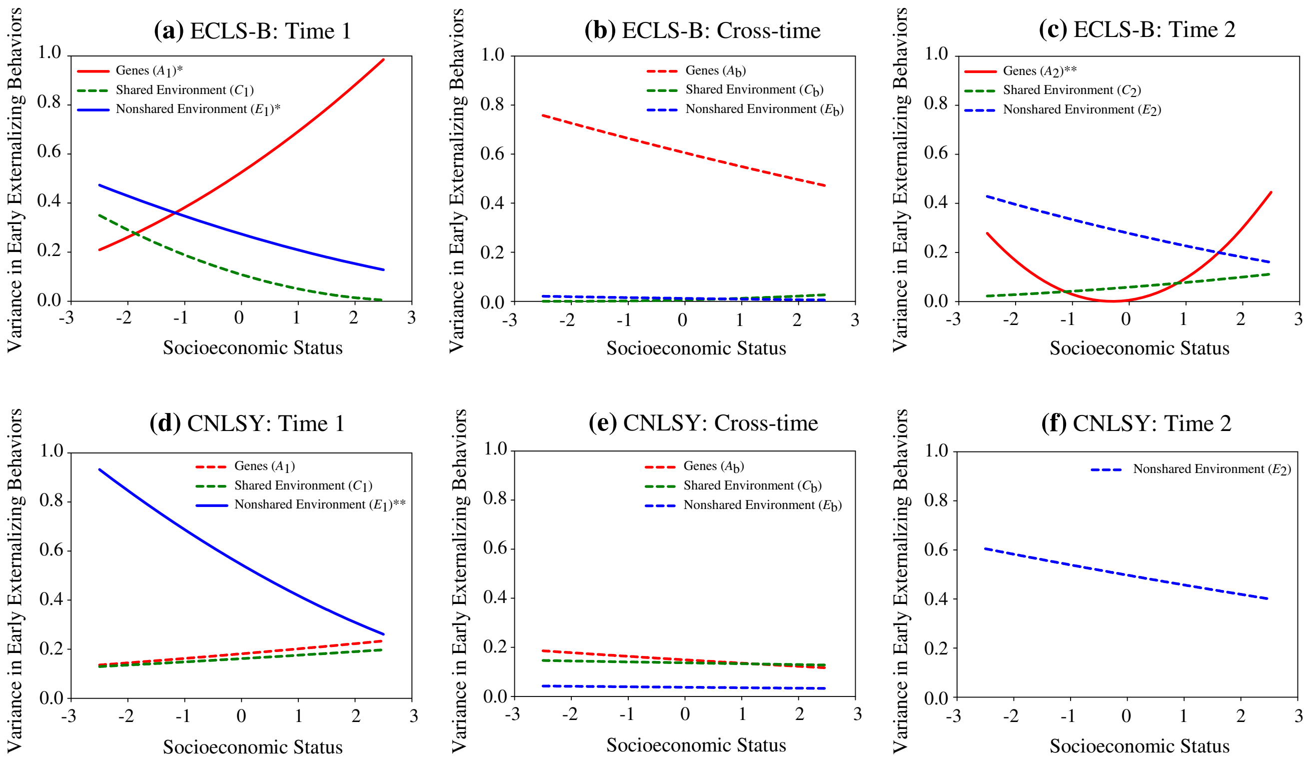

Fig. 5 Graphic representation of interactions with socioeconomic status observed from Model 3 (i.e., moderation effects of socioeconomic status above and beyond those of parental emotional support). *Upper panels* illustrate results from the ECLS-B twin sample while *lower panels* illustrate results from the CNLSY sibling sample. *Left panels* illustrate genetic and environmental influences at time 1, *middle panels* illustrate genetic and environmental influences at time 1 on externalizing behaviors at time 2, and *right panels* illustrate genetic and environmental influences that were unique to time 2. *Red lines* represent genetic influences, *green lines* represent shared environmental influences, and *blue lines* represent nonshared environmental influences. *Solid lines* indicate statistically significant G×E interactions. $^*p < .05$. $^{**}p < .01$. *Dashed lines* indicate statistically insignificant ones. Results from the CNLSY main effects model all suggested no A_2 and C_2 effects on externalizing behaviors; therefore we dropped paths b_{a2} and b_{c2} in all the CNLSY interactions models to facilitate model convergence (Color figure online)

emotional support; moderation effect of parental emotional support on the influences of E_1 observed in Model 1 seems to be driven by SES.

At time 2, E_2 explained 50 % of the variance of externalizing behaviors at all levels of parental emotional support and at all levels of SES. Consistent with findings from the ECLS-B twin sample, relation of externalizing behaviors across the two time points was mediated more by factors that contribute to greater sibling similarity. Of the total variance of time 2 externalizing behaviors, 15 % was explained by A_1, 14 % was explained by C_1, and 4 % was explained by E_1; and these carried-over influences remained constant regardless of the amount of parental emotional support a child received or the level of SES.

Discussion

To better understand the complex etiology of externalizing behaviors, researchers have increasingly turned their attention towards G×E interactions. Given the important role of parents in socializing young children and the importance of SES in various aspects of child development, indices of both parenting and social class have been viewed as promising candidate moderators of genetic influences on externalizing behaviors. While there have been a number of reports on G×parenting and G×SES interactions in the literature, the directions of these interactions have been inconsistent. It is possible that inconsistencies across studies derive from substantively meaningful differences in individuals and variables measured in the different studies. However, it is also possible that inconsistencies derive from haphazard, less systematic, reasons. Close replications are essential to distinguish between these possibilities.

The current study tested for G×E interactions involving both parental emotional support and SES. We made use of data from two population-based samples: the ECLS-B and the CNLSY. Findings on G×E interactions were inconsistent across the two samples. When examining the moderation effects of parental emotional support and SES one at a time, results from the ECLS-B twin sample indicated that genes explained more variance of externalizing behaviors at lower levels of parental emotional support and at higher levels of SES. In contrast, results from the CNLSY sibling sample indicated no evidence for G×parental emotional support interactions and decreasing cross-time genetic influences with increasing levels of SES when examining effects of our two moderators separately. When examining moderation effects of parental emotional support and SES simultaneously, there was no indication for G×parental emotional support interactions for either sample and only the G×SES interactions observed in the ECLS-B twin sample remained evident. The only interaction consistently observed across models and samples was the moderation effect of SES on the influences of nonshared environments at time 1; nonshared environments at time 1 were more influential in the development of externalizing behaviors at lower levels of SES. Although nonshared environments in our model include measurement error, if we were to interpret this consistently observed result, it implies that externalizing behaviors are more attributable to environmental factors unique to a given child among children from families of lower SES. Further investigation will be needed to support and better understand this SES×E interaction.

A number of factors may have contributed to the inconsistency of findings obtained. The first concerns differences in the measurement of parental emotional support in ECLS-B and CNLSY. Parental emotional support was measured using videotaped observational data from a semi-structured task in ECLS-B, whereas it was measured using interviewers' general observation and parents' self-report during home visits in CNLSY. Ratings of behavior during a semi-structured task may not be completely comparable to those observed passively during a home visit. In ECLS-B, observational data from a semi-structured task provide a limited scope of parent–child interactions in natural settings. In CNLSY, interviewers' presence and interactions with parents might have biased their ratings of the parents' behaviors during the home visits and parents' self-report on their levels of emotional support might have been biased by factors such as social desirability.

A second factor concerns differences in sample composition. The ECLS-B twin sample was drawn from a national representative sample of U.S. young children born in the year 2000; while the CNLSY sibling sample was drawn from a pool of children of a national representative sample of U.S. women born in the years 1957–1964, who were 14–22 years old when they were first interviewed in the year 1979. Thus, the CNLSY sibling sample is not necessarily representative of the U.S. young children population to the same extent as the ECLS-B twin sample. Using a sibling design involving different birth cohorts may have also obscured the replication of G×E interactions across the two samples. Siblings in CNLSY reached the same age in different years, and data were collected on these siblings over a course of 24 years from 1986 to 2010. Data collected in different years may not be comparable and hence may affect the validity of results obtained in CNLSY. For example, siblings from different birth cohorts may experience different upbringing either simply due to the passage of time (i.e., similar exposures but experienced at different times) or to inevitable and normal changes in environment with time. Additionally, total family income reported when a child was 4 or 5 years old might not be comparable across survey years due not only to inflation, but also to differences in the experience of social class across historical time. We attempted to eliminate issues associated with inflation by adjusting the reported amount of total family income to 2008 dollars. However, we were not able to correct for more qualitative differences in social class, for instance, that result from changes in social and educational policy over time. It is therefore possible that the inclusion of multiple birth cohorts in the CNLSY sibling sample has obscured some G×E interactions that would have been otherwise observed.

Third, there were differences in social exposures between kinship groups, particularly between the FS and HS pairs in the CNLSY sibling sample. For example, marital stability in the families of FS and HS pairs in the CNLSY sibling sample may differ substantially because, for HS pairs, they were born to their shared biological parent in the context of separate relationships; whereas for FS pairs, they shared the same pair of biological parents. Because of such fundamental difference between these sibling types, HS pairs were more likely than FS pairs to have been exposed to marital instability such as ending of relationship or divorce, infidelity, and undesired changes in family structure. Consistent with past literature on the inverse association between marital instability and SES (Cutright 1971; Galligan and Bahr 1978; Goode 1951; Jalovaara 2003; Tzeng and Mare 1995), we observed that parental educational attainment and household income were also lower among HS pairs than FS pairs. These differences in social status between FS and HS pairs in the CNLSY sibling sample might have also obscured some G×E interactions that would have been otherwise observed.

To a lesser extent, differences in parental educational attainment and household income were also observed between MZ and DZ twins in the ECLS-B twin sample. The use of fertility treatments such as in vitro fertilization is generally more prevalent among parents with higher educational attainment and household income due to its cost, which may explain the slightly higher educational attainment and household income among DZ than MZ twins. Additionally, when comparing these group differences in social status across our two analytic samples, these indices were higher for the group with greater genetic relatedness (i.e., FS pairs) in the CNLSY sibling sample but the group with lower genetic relatedness (i.e., DZ pairs) in the ECLS-B twin sample. This reversed association between SES and genetic relatedness across the ECLS-B twin sample and the CNLSY sibling sample may have contributed to the inconsistent findings on G×E interactions across samples in the current study.

Finally, confounds associated with racial/ethnic composition may have obscured our results. For instance, in the CNLSY sibling sample, FS pairs were approximately 65 % Caucasian but HS pairs were approximately 34 % Caucasian. In the ECLS-B twin sample, proportions were more comparable across MZ and DZ twins: 57 and 64 % Caucasian, respectively. Thus, sibling comparisons in the CNLSY sibling sample inadvertently act as racial/ethnic comparisons. Moreover, racial/ethnic minority status in the United States is strongly correlated with environmental disadvantages. This adds to the concern mentioned earlier that differences in social status between FS and HS pairs in the CNLSY sibling sample might have also obscured some G×E interactions that would have been otherwise observed. It also means that the G×SES findings obtained in the ECLS-B twin sample may reflect, in full or in part, differences in heritability across racial/ethnic groups.

If we were to interpret our ECLS-B results, it appears that environmental moderators that are positively correlated in the population and that are both commonly interpreted as "good" environments may moderate genetic influences differently. Specifically, G×parental emotional support interaction observed in the ECLS-B twin sample is consistent with the pattern predicted by the diathesis-stress hypothesis. That is, genes had a less influence on a child's level of externalizing behaviors at higher levels of parental emotional support. This is consistent with the view that parental emotional support facilitates at-risk children's development of self-control (Belsky and Beaver 2011; Bradley and Corwyn 2008; Eisenberg et al. 2005; Patterson et al. 1990) and hence their inhibition of externalizing behaviors. Despite the strong positive correlation between parental emotional support and SES, the direction of the G×SES interaction observed was the opposite of that of G×parental emotional support interaction. The pattern of G×SES interaction observed in the ECLS-B twin sample is consistent with the pattern predicted by the social push hypothesis. That is, genes had greater influences on a child's level of externalizing behaviors at higher levels of SES. This is consistent with the view that externalizing behaviors are explained more by genes among children raised by parents with more resources and fewer life constraints because environmental risk is minimal in nurturing environments. Though parents with more socioeconomic resources tend to show more positive parenting such as emotional support (Conger et al. 1992; Dodge et al. 1994) and these two factors are both negatively correlated with externalizing behaviors (Barry et al. 2005; Keiley et al. 2000; McLoyd and Smith 2002; Murray et al. 2010; Stormshak et al. 2000), results from the ECLS-B twin sample indicate that parental emotional support and SES moderate genetic contributions to externalizing behaviors in different ways. Different patterns of moderation effects by positively correlated moderators could therefore be a promising factor to consider in future investigation of G×E interactions.

Our study demonstrated that research on G×E interactions in externalizing behaviors is indeed complicated. We modeled interactions using sophisticated quantitative methods; we controlled for the effects of gene-environment correlations, child genetic and non-genetic influences on parental emotional support, and we employed a longitudinal approach that controlled for previous levels of externalizing behaviors. Yet, despite these strengths, we found inconsistent results across samples. Thus, patterns of G×E interactions on externalizing development vary remarkably across studies, even when strong methods are applied.

Conclusion

Our study demonstrated that G×E interaction research on externalizing behaviors is still in its early stage and existing findings, including ours, should be considered tenuous until a more consistent set of results can be obtained across samples. This is a good example of the inconsistency in the current G×E interaction literature on externalizing behaviors. We are among the first few to examine covarying social moderators simultaneously and to use two population-based samples in studying G×E interaction effects on externalizing behaviors. Our results raise the possibility that strongly and positively correlated contextual factors may modulate genetic influences on externalizing behaviors differently, and that G×E interactions may differ across studies. Future quantitative behavior genetics research on externalizing behaviors should examine the impact of covarying social moderators on the patterns of G×E interactions observed and conduct replication studies to better understand how findings may vary by subtleties in the environment and construct indices. Even non-replications can be informative to researchers in refining our understanding of G×E interaction effects on externalizing behaviors.

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Conflict of Interest Amanda K. Cheung, Kathryn Paige Harden, and Elliot M. Tucker-Drob declare that they have no conflict of interest.

Human and Animal Rights and Informed Consent All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2000 (5). Informed consent was obtained from all patients for being included in the study.

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