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EMPIRICAL ARTICLE

CHILD DEVELOPMENT

Disentangling genetic and environmental influences on early language development: The interplay of genetic propensity for negative emotionality and surgency, and parenting behavior effects on early language skills in an adoption study

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Abstract

Parenting and children's temperament are important influences on language development. However, temperament may reflect prior parenting, and parenting effects may reflect genes common to parents and children. In 561 U.S. adoptees (57% male) and their birth and rearing parents (70% and 92% White, 13% and 4% African American, and 7% and 2% Latinx, respectively), this study demonstrated how genetic propensity for temperament affects language development, and how this relates to parenting. Genetic propensity for negative emotionality inversely predicted language at 27 months ($\beta = -.15$) and evoked greater maternal warmth ($\beta = .12$), whereas propensity for surgency positively predicted language at 4.5 years ($\beta = .20$), especially when warmth was low. Parental warmth ($\beta = .15$) and sensitivity ($\beta = .19$) further contributed to language development, controlling for common gene effects.

Language development is a highly complex phenomenon with long-term consequences for academic success (NICHD ECCRN, 2005). Expressive vocabulary at 2 years can predict academic test performance at age 12 (Bleses et al., 2016), and differences in language skills at 4 years persist into adolescence (Bornstein et al., 2014). However, there is high variability in preschool language skills (Fenson et al., 1994), and the

Abbreviations: AF, adoptive father; AM, adoptive mother; ATQ, Adult Temperament Questionnaire; BF, birth father; BM, birth mother; CFA, confirmatory factor analysis; CFI, comparative fit index; EGDS, Early Growth and Development Study; MAR, missing at random; MCAR, missing completely at random; *r*GE, gene–environment correlation; RMSEA, root mean square error of approximation; SES, socioeconomic status; SRMR, standardized root mean square residual; TCI, Temperament Character Inventory; TOPEL, Test of Preschool Early Literacy; WEIRD, Western, educated, industrialized, rich, and democratic.

mechanisms underlying this variability remain unclear. There is strong evidence from developmental research that both parenting (e.g., Tamis-LeMonda et al., 2001) and children's temperament (e.g., Coplan et al., 1999; Slomkowski et al., 1992) are important influences on language development. However, children's temperament is influenced by prior parenting *and* existing genetic propensity, as well as interaction between the two (Putnam et al., 2002). In empirical studies of biologically related families, parenting effects are confounded by parents and children sharing genes (Plomin et al., 1977). Furthermore, parenting behavior itself can be evoked by children's genetically influenced characteristics (Narusyte et al., 2011). Research designs that can more precisely estimate parenting and temperament influences on language are thus imperative in understanding what the individual *child* brings to parent–child dynamics, which then influences their language development.

The current study examines independent and joint influences of heritable temperament characteristics and parenting on emergent language skills, from the toddler through preschool period, using a prospective adoption design (the Early Growth and Development Study, EGDS). As children in EGDS are separated from birth parents in the first days of life, relations between child and birth parent phenotypes infer genetic effects, whereas relations between children and adoptive parents infer environmental effects, unconfounded by shared genes between parent and child. Utilizing the adoption design thus allows us to cleanly delineate sources of genetic and environmental variability in early language, and identify how they operate in tandem. It also allows us to uncover how children's genetic propensity for temperament affects language development *through* its effect on parenting. More broadly, the adoption design allows us to examine how parenting behavior might enhance or diminish children's genetic propensity, as part of either natural or planned environment variation. The current study thus provides a potential platform for more precise, tailored, promotive language interventions that allow for differences in children's temperament and parenting exposure.

Influences of parenting on emergent language skills

Caregivers provide input to children from birth that influences language development. From birth, infants can distinguish between different sound contrasts in language, and over their first year, develop sensitivity to the speech sounds that they are exposed to (Conti-Ramsden & Durkin, 2012). This sensitivity of infants and exposure to their environment lays foundations for later language milestones. For example, speech perception ability at 6 months predicts early vocabulary skills at 2 years (Tsao et al., 2004). Notably, shared environment estimates in twin studies are reasonably high in infancy—approximately 59% between 6 months and 2 years (Austerberry, Mateen, et al., 2022). Non-genetic research has found that the quantity and the quality of caregiver linguistic input affects language development, and can differ by social context (Hoff, 2006).

As children progress toward learning and using words from around 1 year, research has shown effects of warm, sensitive, and harsh parenting on language development. A recent meta-analysis found significant pooled estimates between language skills at 1–6 years, and warm (r_{pooled} = .16) and sensitive (r_{pooled} = .27) parenting (Madigan et al., 2019). Warm parenting describes the degree to which caregivers feel affection and offer praise and encouragement toward their child, such as smiling and positive physical contact. Warm parenting may support language skills by promoting positive interactions, and by encouraging the use of language as a communicative tool (Hoff, 2006). Sensitive parenting broadly describes the dynamic awareness a caregiver has of a child and their level of attunement to the child's bids for interaction—such as how they respond and interact contingently with children's vocalizations, interests, and the focus of the child's gaze (Madigan et al., 2019). Sensitive parenting may help provide optimal learning conditions that appropriately scaffold the child's existing knowledge and tailor responses accordingly as part of a contingent interaction (Vygotsky, 1978). For example, scaffolding may involve encouraging joint attention to target objects (Tomasello, 2003) or adjusting language use according to the child's knowledge (Luce & Callanan, 2010) during word learning.

Conversely, few studies have examined effects of harsh caregiving, characterized by hostility, overly strict punishment, and angry responses, on language skills. However, extant studies have identified that both observed and self-reported hostility and over-reactive parenting can predict less proficient language skills throughout preschool (18 months to 3 years, Pungello et al., 2009; Tamis-LeMonda et al., 2004) and childhood (from 4.5 to 7 years; Berthelon et al., 2020). Harsh parenting may prevent children from internalizing key information during parent–child interactions due to a higher cognitive load imposed by a more hostile environment (Rothbart & Putnam, 2002), or due to the perceived unfairness of the interaction by the child (Grusec & Goodnow, 1994). Evidence suggests children can discriminate between praise and admonishment at 2 years (DesChamps et al., 2016), and verbally discuss their perception of unfairness in parental discipline at 3 years (Johnston & Saltzstein, 2016). Another possible mechanism is the reduction of learning opportunities. Self-reported harsh parenting has been associated with less child-contingent behavior and greater inflexibility in adapting to children's abilities at 5 years, relative to warm parenting (Carr & Pike, 2012).

Influences of children's genes and temperament on emergent language skills

Although environmental effects on language are important, much of this research has been undertaken in non-genetic studies. Genetically informative research suggests children's variability in early language is also influenced by genetic differences. For example, a meta-analysis of twin studies identified that expressive and receptive language skills also had low-to-moderate heritability (~17%–52%) throughout early childhood (Austerberry, Mateen, et al., 2022). Existing evidence provides clues to the contribution of genetic propensity relative to heritable language delay (Haworth et al., 2009), and influences of general intellectual performance and educational attainment (Belsky et al., 2016; Kovas et al., 2005). Birth parent intellectual performance also predicts adoptee language from 4.5 to 7 years old (Austerberry, Fearon, et al., 2022), suggesting that early language is not only heritable but also influenced by the same genes that influence intellectual and academic performance in adulthood.

However, given the complexity of language skills and the social environment in which they evolve (Tomasello, 2003), other genetic factors likely also play an important role. Plausible, but overlooked, influences of individual variability in language skills are genetic propensities for temperament. More specifically, *negative emotionality* (or 'negative temperament'), which includes susceptibility toward sad, fearful, anxious, avoidant behavior, and *surgency* (or 'positive temperament'), which includes susceptibility toward positive affect, need for social reward, approach behavior, and sociability (Rothbart & Putnam, 2002), may also contribute to language development. Negative emotionality and surgency appear heritable (Goldsmith, 1983; Iacono et al., 2008; Jami et al., 2021; Loehlin, 1992), accounting for 20%–60% of the population variability in twin studies (Saudino, 2005), with heritability estimates at ~21%–34% between 1 and 4 years (Goldsmith et al., 1997).

In non-genetic studies, greater negative emotionality has been correlated with reduced expressive vocabulary and sentence complexity in 2-year-olds (Cioffi et al., 2021; Kucker et al., 2021; Salley & Dixon, 2007) and poorer literacy in 4-year-olds (Coplan et al., 1999). Conversely, higher surgency has been correlated with larger expressive vocabulary at 2–3 years old (Bruce et al., 2022; Dixon & Smith, 2000; Kucker et al., 2021; Slomkowski et al., 1992) and with greater talkativeness in children aged 7 (DeThorne et al., 2011).

Children depend on their social and physical environment when learning language from infancy (Hollich et al., 2000; Tomasello, 2003). Pre-existing genetic propensity for temperament that influences how children interact with the early environment may thus affect language development. For example, if a child with a greater propensity toward negative emotionality is less likely to approach novel objects, they may have fewer chances to learn the names for them; a child with a propensity toward pursuing rewarding social signals may conversely seek out more opportunities. Between ~1 and 2.5 years, children acquire vocabulary rapidly, using social cues such as eye gaze and gesture (Hollich et al., 2000). Negative emotionality and surgency may affect how children attend to these cues during learning from infancy. Infants aged 11 months high in negative emotionality are less likely to engage in joint attention (Todd & Dixon, 2010), whereas infants aged 9–12 months who smile and laugh more initiate more joint attention bids (Vaughan et al., 2003). Similarly, when testing word learning in 2-year-olds, those with a shy temperament pay less attention to objects as compared to others, learning new words for target objects less accurately (Hilton et al., 2019). In sum, children with a greater genetic propensity for negative emotionality might have poorer language skills, and those with greater genetic propensity for surgency, better language skills—possibilities that remain to be fully tested. Although prior EGDS research found children with negative emotionality had lower language skills at 27 months (Cioffi et al., 2021), genetic effects of surgency have not yet been tested. Furthermore, the mechanisms underlying relations between temperament and language are unclear. In particular, prior research has not examined how parenting might enhance or diminish effects of children's genetic propensity for temperament on language development.

Possible gene–environment interplay effects on emergent language skills

Rothbart and Putnam (2002) describe temperament as an early 'biological basis' for how individuals differentially respond to and interact with their environment to affect developmental outcomes. In line with this idea, alongside direct genetic and environmental effects on language development, effects of gene–environment interplay may also be implicated (Belsky et al., 2007; Onnis, 2017). One possible source of this interplay is gene–environment correlation (rGE), which occurs when genetic differences between individuals become systematically associated with environmental exposures. For example, children have a role in 'making their own environment' through actively selecting or evoking environmental exposures (Scarr & McCartney, 1983), and if these processes are driven by a child's genetic propensities, children's genetics will become correlated with their environment (referred to as active and evocative rGE). In particular, evocative rGE might explain how genetic propensity for temperament influences language development: effects of genetic propensity toward negative emotionality and surgency may not only *directly* affect language skills but they may also *elicit* different levels of parenting that also have an impact on language skills. Accordingly, children with a genetic propensity for negative emotionality might elicit harsher parenting that interferes with language learning (Rothbart & Putnam, 2002), although there is some ambivalence in prior research. One meta-analysis highlighted that higher child negative emotionality was associated with harsher parenting in low socioeconomic status (SES) environments, and more supportive parenting in mid-high SES environments (Paulussen-Hoogeboom et al., 2007). Additionally, children with a genetic propensity for surgency behaviors such as high sociability might encourage more warmth and sensitivity from their caregivers, thus bolstering their language skills (Bornstein et al., 2020).

However, studies of biological families cannot separate roles of genes and environments when examining child outcomes due to *passive* *r*GE. As children share genes with biological parents, parents provide both 50% of their genes and the rearing environment itself, confounding associations between phenotypic parenting behavior and child characteristics (Plomin et al., 1977). Although it is widely recognized that gene–environment interplay contributes to child development, environmental effects may also be hidden within heritability estimates in twin studies—reciprocal relations between genes and environment can 'mask' the potency of environmental effects as a result of this *r*GE (Dickens & Flynn, 2001). As children's genes likely play a role in shaping their own environment, and this environment can amplify early genetic effects, these influences may be conflated with one another. This confounding means estimating genetic and environmental influences from the child's phenotype alone cannot isolate hidden environmental factors. As a result of this confounding, determining if genetic propensities for temperament evoke environmental parenting effects (evocative *r*GE) is not possible in biological family or twin studies (Jami et al., 2021)—but is possible in adoption studies, where birth parents provide estimates of genetic influences, and adoptive parents, measures of rearing environment.

Another possible source of gene–environment interplay is gene–environment interaction: parenting may moderate (enhance or diminish) the association between children's genetic propensities and their language outcomes (Belsky et al., 2007). A meta-analysis of biological family studies (Slagt et al., 2016) suggested that children with increased difficult temperament (broadly operationalized as combined surgency, negative emotionality, and effortful control traits) are both more vulnerable to harsh parenting *and* benefit from warmer, more sensitive parenting when examining internalizing, externalizing, social, and cognitive (school-age academic competence) outcomes. Applied to language development, warmer and more sensitive parenting might buffer any effects of genetic propensity for negative emotionality and surgency on language (Paulussen-Hoogeboom et al., 2007; Putnam et al., 2002). However, cleanly estimating interactions between genetic propensity for temperament and parenting requires a design that can first distinguish between these influences.

The current study

This study uses a prospective parent–offspring adoption design, the EGDS (Leve et al., 2019) to disentangle genetic influences of temperament and postnatal influences of parenting warmth, sensitivity, and harshness on early language skills. In the adoption design, postnatal environmental effects can be separated from genetic influences by using measures of birth parent to index genetic propensity, while controlling for passive *r*GE (as adoptive parents do not share genes with their children). For example, within EGDS, higher birth parent harm avoidance, fearfulness, and insecurity were associated with higher odds of increased fearfulness, irritability, distress to novelty, and reduced activity and interest across 9, 18, and 27 months of age (Beekman et al., 2015). Higher birth parent fear, frustration, and responsiveness to social reward also predicted child anger and sadness at 4.5 years (Shewark et al., 2021). Birth parent sociability also predicted child positive affect at 9 months and social competency at 6 years (Van Ryzin et al., 2015).

As well as examining direct genetic and environmental effects on child outcomes, the adoption design enables us to examine whether children's genetic propensities for temperament—indexed by birth parent measures—evoke differences in parenting (evocative *r*GE). It allows us to examine whether genetic propensity for temperament might actually elicit higher warmth and sensitivity from parents that scaffolds learning (e.g., through more contingent interactions), or harsher parenting that interferes with learning (e.g., through less opportunities to learn or increased cognitive load)—yet untested hypotheses. The adoption design also makes it possible to examine whether associations between children's genetic propensities for temperament and language outcomes are moderated by parenting warmth, sensitivity, and harshness (gene–environment interaction), again in such a way that does not confound genetic and environmental influences.

In sum, by utilizing the adoption design, this study aims to provide a clearer platform for how children can be supported by broadening our understanding of what the *child* brings to parent–child interactions, how parenting warmth, sensitivity, and harshness interact with the child's pre-existing genetic propensity for temperament, and how this complex gene–environment interplay predicts language outcomes.

Hypotheses

First, in relation to genetic effects, we predicted that *birth parent surgency* (as an index of genetic propensity) *would predict increased child language proficiency*, when controlling for known influences of birth parent intellectual performance as a separate variable within the same model. Second, in relation to environmental effects, we predicted that *higher levels of harsh parenting would predict lower child language proficiency, and higher levels of warm and sensitive parenting would predict higher proficiency*. Third, we predicted an effect of evocative *r*GE: that *genetic propensity for surgency would lead to warmer, more sensitive parenting, and genetic propensity for negative emotionality would lead to either warmer, more sensitive parenting or more harsh parenting*. Fourth, we predicted that the *parenting environment would moderate the relation between genetic influences and child phenotype*, such that effects of birth parent negative emotionality on child language would be expected to increase in the context of harsher, less warm/sensitive parenting, and that effects of birth parent surgency would be enhanced in the context of warmer, less harsh parenting, or emerge as a protective factor in the context of harsher parenting (Slagt et al., 2016).

METHODS

Our hypotheses and analyses were pre-registered on the Open Science Framework (https://osf.io/hq28s/?view_only=7caa06e044084265b58a50f18c323632; pre-registration differences: https://osf.io/gd8tw/?view_only=d9b2378ab20a439386870ec430234004).

Participants

Participants were from EGDS, a U.S.-based longitudinal prospective adoption study of 561 linked sets of participants (demographics in Table 1), which included 561 adopted children, 554 birth mothers, (BMs), 210 birth fathers, (BFs), 562 adoptive fathers (AFs), and 569 adoptive mothers (AMs)—including 41 same-sex parents and 15 additional adoptive parents entering the family following the original adoption (Leve et al., 2019). The data were collected in two cohorts: Cohort I contains 361 children with data collected between 2003 and 2013, and Cohort II contains 200 children with data collected between 2007 and 2017. A total of 45 adoption agencies in 15 states were recruited into the study and served as the recruitment source for the sample. Further details can be found in Leve et al. (2019).

Some variables in the analysis were collected in both cohorts, although some were only collected in one cohort. Figure 1 and Table 1 report the number of participants for each variable. Given the far smaller BF sample size (Figure 1; Table S1), we used the BF data only to provide semi-independent, convergent evidence for the main BM analyses. Where BF findings are similar in magnitude to BM results, this corroboration makes explanation of findings, based on fetal exposure, less likely (Rice et al., 2018).

Ethics

Ethical approval was obtained from the University of Oregon (Protocol number: 0304201400) and the Pennsylvania State University (Submission ID: CR00007591) institutional review boards. Prior to research participation, informed consent was obtained from all adult participants.

Measures

Birth parent negative emotionality

The latent variable ('negative temperament' in pre-registration) for each birth parent contained items from four pre-registered indicators that were consistent with negative emotionality effects on language (Coplan et al., 1999; Salley & Dixon, 2007) and previously used in EGDS to identify effects of birth parent on child negative emotionality (Beekman et al., 2015; Lipscomb et al., 2012). This included the harm avoidance subscale (20 items; BM: α = .86; BF: α = .83) from the Temperament Character Inventory short form (TCI; Cloninger et al., 1993), administered at 3 to 6 months post-partum. Statements are self-rated as 'True' or 'False'. Higher scores on Harm Avoidance indicate increased cautiousness, insecurity, avoidance, and fearfulness (e.g., 'I often feel tense and worried in unfamiliar situations'). Three subscales from the Adult Temperament Questionnaire (ATQ; Evans & Rothbart, 2007), administered at 18 months post-partum, were also used: Fear (7 items; BM: α = .56; BM: α = .63), Frustration (6 items; BM: α = .63; BF: α = .56), and Sadness (7 items; BM: α = .59; BF: α = .47). Statements are self-rated from 1 'extremely untrue' to 7 'extremely true'. Fear comprises uneasiness related to anticipated distress (e.g., 'I become easily frightened'). Frustration concerns irritation in response to interruptions (e.g., 'Whenever I have to sit and wait for something, I become agitated'). Sadness describes intensity, duration, frequency, rate, and amount of sadness in response to negative events (e.g., 'I often feel sad'). All factor loadings were > .30 and significantly loaded onto the latent variable (Figure 3; confirmatory factor analysis [CFA], $\chi^2(2)$ = 1.29, comparative fit index [CFI] = 1.00, root mean square error of approximation [RMSEA] = .00, standardized root mean square residual [SRMR] = .01).

TABLE 1 Birth parents, adoptive parents, and adopted children demographics.

Variable	Birth mothers	Birth fathers	Adoptive mothers	Adoptive fathers	Child
Mean age at adoption (SD)	24.4 years (6.0)	26.1 years (7.8)	37.4 years (5.6)	38.3 years (5.8)	5.6 days (12.4)
Ethnicity					
Non-Latinx White	70%	70%	92%	90%	58%
Black or African American	13%	12%	4%	5%	11%
Hispanic or Latinx	7%	10%	2%	2%	9%
Multi-ethnic	5%	5%	1%	1%	20%
Other (Asian, Native Hawaiian/Pacific Islander, American Indian/Alaskan Native, unknown)	5%	4%	1%	2%	2%
Median household income (range)	<$15K (<15K–300K)	$15K–25K (15K–>300K)	$100K–150K (<15K–>300K)	$100K–150K (<15K–>300K)	
Median education level	High school	High school	4-year college	4-year college	
Marital status					
Single	38%	38%	2%	0.2%	
Married	22%	27%	85%	87%	
Cohabiting	30%	31%	3%	2%	
Other	10%	4%	11%	12%	
Openness of adoption, *M* (SD)					0.02 (0.96)[a]
Weighted obstetric risk, *M* (SD)					16.98 (11.83)[b]

[a]Standardized composite of adoptive parent-rated adoption openness calculated as per Ge et al. (2008); sample mean score indicates perceptions 'slightly open'.

[b]Birth mother reports of perinatal risk scored using McNeil Sjostrom Scale for Obstetric Complications and weighted according to Marceau et al. (2016); sample mean score indicates risk 'generally low'.

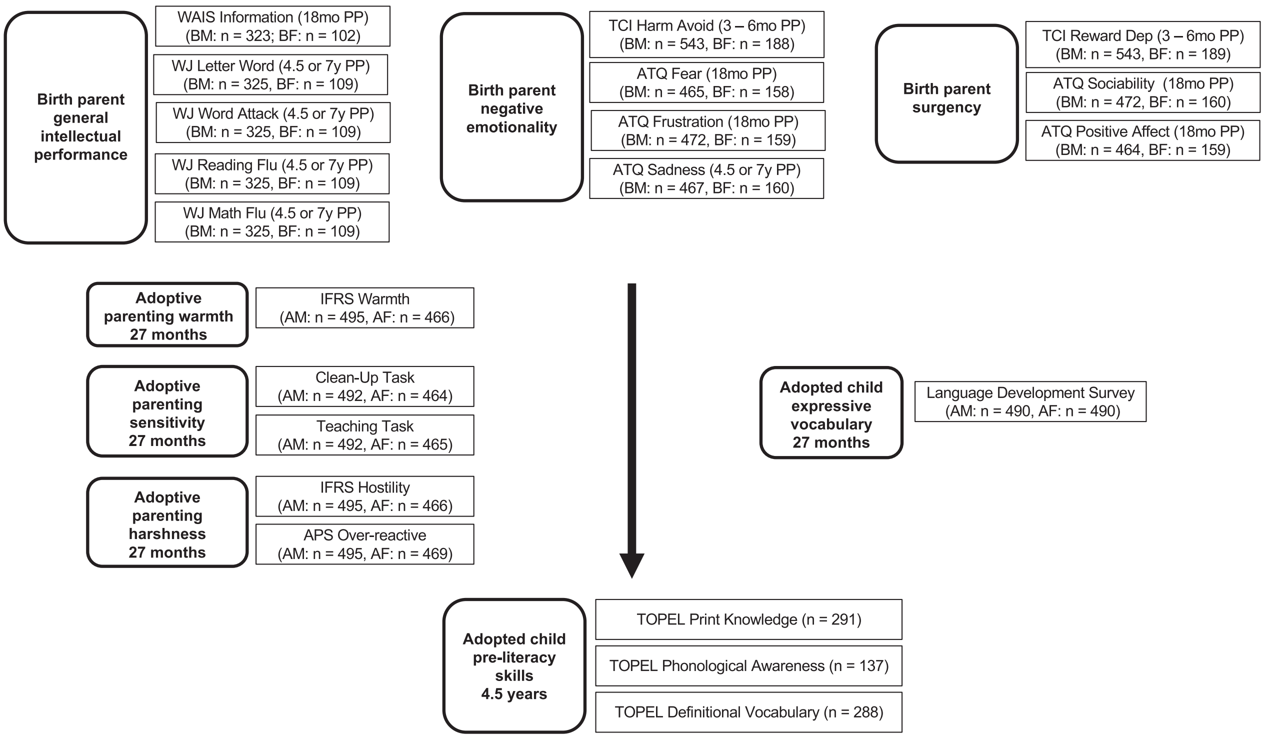

FIGURE 1 Latent and indicator variables used in structural equation models. Bold text shows latent or composite variables; regular text shows indicators. AF, adoptive father; AM, adoptive mother; ATQ, Adult Temperament Questionnaire; Avoid, avoidance; BF, birth father; BM, birth mother; Dep, dependence; Develop, development; Flu, fluency; IFRS, Iowa Family Rating Scales; mo, months; PP, post-partum; Soc, sociability; TCI, Temperament Character Inventory; TOPEL, Test of Preschool Early Literacy; y, years; WAIS, Weschler Adult Intelligence Scale; WJ, Woodcock–Johnson Achievement Tests III.

Birth parent surgency

The latent variable ('positive temperament' in pre-registration) for each birth parent contained three pre-registered indicators consistent with surgency effects on language (Dixon & Smith, 2000; Slomkowski et al., 1992) that were also used in EGDS to identify effects of birth parent surgency on adopted child surgency (Beekman et al., 2015; Van Ryzin et al., 2015). This included the reward dependence subscale (20 items; BM: α=.65; BF: α=.72) from the TCI (Cloninger et al., 1993), administered at 3 to 6 months post-partum. Higher scores on Reward Dependence indicate more warmth, tender-heartedness, and sociability (e.g., 'I like to discuss my experiences openly with friends instead of keeping them to myself'). Two subscales from the ATQ (Evans & Rothbart, 2007), administered at 18 months post-partum, were also used: sociability (5 items; BM: α=.69; BF: α=.70) and positive affect (5 items; BM: α=.61; BF: α=.42). Sociability describes enjoyment in interacting with and being among others (e.g., 'I usually like to spend my free time with people'). Positive affect characterizes the intensity, duration, frequency, rate, amount of happiness, and general enjoyment experienced by the individual and in response to events (e.g., 'It doesn't take much to evoke a happy response in me'). All factor loadings were >.30 and significantly loaded onto the latent variable (Figure 4; CFA: $\chi^2(0)$=.00, CFI=1.00, RMSEA=.00, SRMR=.00).

Birth parent general intellectual performance

The latent variable for each birth parent contained five pre-registered indicators that were consistent with non-EGDS literature on heritable general intellectual performance measures (Kovas et al., 2005) and had heritable influences on child language skills at 4.5 years in EGDS (Austerberry, Fearon, et al., 2022). This included standardized scores based on age from the Information subtest (up to 28 items based on number answered incorrectly) from the Weschler Adult Intelligence Scale III (Wechsler, 1997) administered to birth parents at 18 months post-partum. This subtest loads onto the full Verbal Comprehension factor and is considered a stable indicator of general intellectual performance. We also administered four subscales of the Woodcock–Johnson Tests of Achievement III (Woodcock et al., 2001) at 4.5 years post-partum, testing: (1) letter word identification (76 items), (2) word attack (32 items; decoding unfamiliar words); (3) reading fluency (98 items), and (4) math fluency (160 items; *T*-scores, standardized to M=50, SD=10). Scores were rescaled prior to analysis (divided by 10) to avoid convergence issues. All factor loadings were >.30 and significantly loaded onto the latent variable (Figure 3; CFA $\chi^2(4)$=23.21, CFI=.97, RMSEA=.11, SRMR=.03).

Parenting variables

Sensitive parenting

Rearing parent-sensitive and guiding behavior were observed during two tasks administered at home when the child was 27 months, consistent with the assessment of sensitivity in the wider literature (Madigan et al., 2019) and in EGDS (Van Ryzin et al., 2015) and as pre-registered. The first task was a clean-up task that required the parent–child dyad to tidy up toys they had been playing with. The second was a teaching task that required the parent and child to solve a puzzle together. Following task completion, trained examiners completed global impressions for overall parenting sensitivity and guidance (4 items, 2 per parent, and 2 per task), rated as (1) very true, (2) somewhat true, (3) hardly true, and (4) not true (15% video-coded by two independent coders; % agreement = .98; inter-rater reliability $r = .83$). Items were reverse coded prior to analysis, so higher scores indicated increased sensitive parenting. Scores on the tasks were strongly correlated (AM: $r = .68$, $p < .001$; AF: $r = .69$, $p < .001$); therefore, a mean composite was used per parent.

Warm parenting

Warm parenting was assessed when the child was 27 months old using the warmth subscale as pre-registered (4 items; AM: $\alpha = .81$, AF: $\alpha = .84$) from the IOWA Family Interaction Rating Scales (Melby & Conger, 2001). This measure is consistent with described effects in Madigan et al. (2019) and has been used in EGDS to identify effects of birth parent traits and parenting on adopted child outcomes (Cioffi et al., 2020). It is a self-reported measure of the parent's displays of affection toward the child rated on a 7-point scale from 'never' to 'always'. Higher scores indicate increased warmth.

Harsh parenting

Harsh parenting was assessed when the child was 27 months old using the over-reactivity subscale from the parenting scale (Arnold et al., 1993) and the hostility subscale from the IOWA family interaction rating scales (Melby & Conger, 2001). These measures were consistent with literature around negative effects of self-reported harsh parenting on language (Berthelon et al., 2020). Over-reactivity and hostility were strongly correlated (AM: $r = .65$, $p < .001$; AF: $r = .65$, $p < .001$) and have been utilized in EGDS previously to identify effects of birth parent temperament, parenting, and child outcomes (Liu et al., 2020). The over-reactivity subscale (10 items; AM: $\alpha = .79$, AF: $\alpha = .77$) is a self-reported measure of the parent's display of anger, meanness, and irritability. The hostility subscale (5 items; AM: $\alpha = .74$, F: $\alpha = .70$) tests self-reported parent displays of criticism and anger toward the child. Both are rated on a 7-point Likert scale from 'never to always.' A mean composite of the two subscales was used (Liu et al., 2020) as pre-registered.

Child variables

Child early language skills

At 27 months, children's language skills were assessed using the Language Development Survey (Child Behavior Checklist, Achenbach & Rescorla, 2000), used in Austerberry, Fearon, et al. (2022), Cioffi et al. (2021), and Leve et al. (2013) and as pre-registered. This is a parent-reported checklist of 310 words that children produce (AM: $\alpha = .99$, AF: $\alpha = 1.00$), and is a robust measure of expressive vocabulary (Rescorla et al., 2005). It has high test–retest reliability ($r = .97$) and concurrent validity with the MacArthur–Bates Communicative Development Inventories ($r = .95$; Rescorla et al., 2005). Raw scores were converted to percentiles reflecting performance compared to same-age peers and rescaled (divided by 10) to avoid model convergence issues. A total of 5% of the sample were ≤15th percentile, a cut-off indicating possible early language delay. Adoptive parent reports were highly correlated with one another ($r = .74$, $p < .001$); a mean composite was thus used. Where maternal data were not available, paternal data were used, and vice versa.

At 4.5 years, child language skills were assessed using the Test of Preschool Early Literacy (TOPEL), which high internal consistency ($\alpha = .86$–$.96$), test–retest reliability ($r = .81$–$.89$), strong concurrent validity ($r = .59$–$.77$), and tests emerging literacy (Lonigan et al., 2007). Three pre-registered indicators were used to create a latent variable (standardized scores) as per Austerberry, Fearon, et al. (2022): (1) print knowledge (36 items; alphabet knowledge and early decoding); (2) definitional vocabulary (35 items; oral and definitional vocabulary); and (3) phonological awareness (27 items; word elision and blending). All factor loadings were >.30 and significantly loaded onto the latent variable (Figure 3; CFA $\chi^2(0) = .00$, CFI = 1.00, RMSEA = .00, SRMR = .00).

Covariates

Child sex, adoption openness, and prenatal risk were used as covariates (Table 1) as pre-registered. Sex was coded 0 for males and 1 for females. Adoption openness may contaminate the adoption design, as it entails contact between birth and adoptive families; a mean standardized composite of adoptive parent-rated openness at 27 months postpartum was thus used as per Ge et al. (2008). This comprised perceived openness (one item rated on 7-point scale, *1 = very closed* to *7 = very open*), contact between birth and adoptive parents (six items rated on 5-point scale, *1 = never* to *5 = daily*), and knowledge of one another (five items: birth parent physical health, mental health, ethnic and cultural background, reasons for adoption, and extended family history, rated on 4-point Likert-type scale, *1 = nothing* to *4 = a lot*). BM reports of perinatal risk (pregnancy, labor, delivery, and complications at 5 months postpartum) were also used, as these may confound genetic and environmental influences on child outcomes. These were scored based on the McNeil–Sjöström scale for obstetric complications (76 items, *1 = not harmful or relevant* to *6 = very great harm*; McNeil et al., 1994) and a weighted total prenatal risk score was calculated (see Marceau et al., 2016).

Data analysis

Hypotheses were tested using *lavaan* (Rosseel, 2012) in R 4.2.0 which combines a measurement model for latent variables (CFA) with a structural equation model to test the proposed relations in Figure 2. Factor loadings >0.30 and model fit with SRMR <.08 and RMSEA <.06 were considered adequate (Hu & Bentler, 1999).

Preliminary analyses

Temperament and intellectual performance correlations have been identified as weak, with effect sizes close to zero (Poropat, 2009). However, strong correlations between birth parent temperament and general intellectual performance indicators in our data would mean the effects of these domains cannot be adequately separated. As pre-registered, we carried out preliminary analyses testing for possible relations using Pearson correlations ($p < .05$).

Main analyses on BM data

Main analyses were pre-registered and conducted on BM data, as this strategy provided the most complete dataset (sample sizes: Figure 1; Table 2). We tested our first and second hypotheses on genetic and environmental influences on language. Effects of genetic propensity for negative emotionality and surgency on child language were tested separately. We constructed models that tested effects of birth parent negative emotionality, surgency, and general intellectual performance, with two final models testing the addition of adoptive parenting variables (i.e., warmth, sensitivity, and harshness), one for mothers and one for fathers. Indirect effects of birth parent temperament and parenting were tested using bootstrapping with 1000 repetitions (Bollen & Stine, 1990). We then examined our third hypothesis around evocative effects: within final models, we tested for rGE between birth parent negative emotionality and surgency, and adoptive parenting variables. Finally, we tested interactions between BM temperament and adoptive parenting to examine our fourth hypothesis. We used Schoemann and Jorgensen's (2021) latent variables approach compatible with *lavaan*. Model fit is assessed without interactions, and then individual interactions are assessed for significance using product indicators (double mean centering). Significant interactions are probed using simple slopes: regression slopes for low (1 SD below mean), medium (mean), and high (1 SD above mean) values of the moderator are plotted and tested for significance.

Across all models, birth parent variables covaried with each other (Woodcock–Johnson reading fluency and math fluency indicators also covaried as per modification indices). Adoptive warm and harsh parenting covaried, as both contained subscales of the same measure. We included covariates for all models.

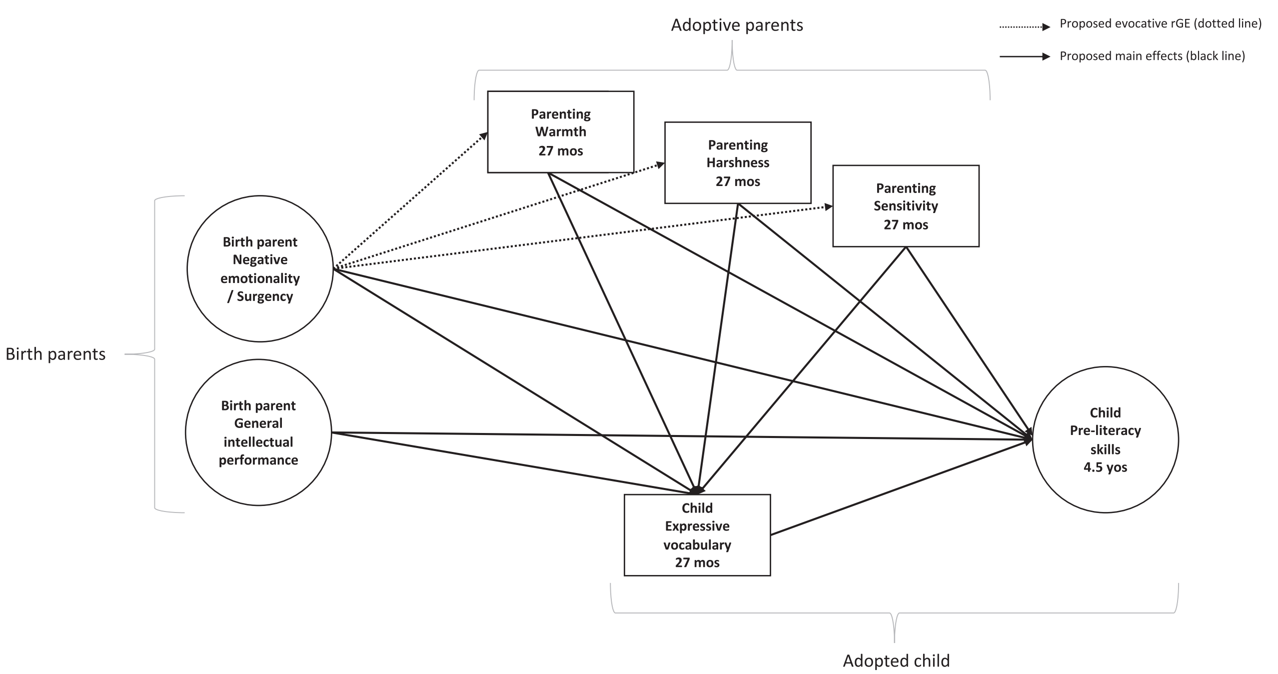

FIGURE 2 Proposed theoretical model. mos, months old; yos, years old.

TABLE 2 Bivariate correlations, means, standard deviations, and sample sizes for birth mother, adoptive parenting, and adopted child variables (see Supporting Information for birth father data).

	Variable	*M* (SD)	*n*	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	BM harm avoidance	9.15 (5.08)	543																					
2	BM fear	3.74 (0.97)	465	.40																				
3	BM frustration	3.97 (1.04)	472	.30	.40																			
4	BM sadness	4.36 (0.94)	467	.27	.45	.32																		
5	BM reward dependence	9.99 (1.77)	543	−.03	.04	−.05	.12																	
6	BM sociability	4.92 (1.17)	472	−.30	−.24	−.20	−.18	.29																
7	BM positive affect	4.54 (1.11)	464	−.31	−.28	−.35	−.27	.22	.47															
8	BM WAIS information	9.56 (2.59)	323	−.14	.02	−.09	.08	.08	.11	.11														
9	BM WJ letter word	47.76 (5.67)	376	−.07	.08	−.06	.15	.10	.06	.12	.57													
10	BM WJ reading	49.83 (7.48)	376	−.07	.06	.01	.15	.11	.02	−.01	.49	.57												
11	BM WJ math	44.22 (8.77)	374	−.08	−.01	−.02	.09	.02	−.01	−.03	.35	.44	.62											
12	BM WJ word attack	46.69 (6.72)	376	−.12	.06	−.07	.12	.09	.06	.14	.37	.71	.48	.43										
13	AM warmth	25.90 (2.25)	495	.03	.06	.10	.05	.03	.01	−.03	−.04	.04	.11	.06	.08									
14	AM task sensitivity	3.61 (0.48)	490	.06	.09	.04	.02	.00	−.03	.03	.02	.08	.04	.00	.07	.00								
15	AM harshness	0 (1.38)	495	−.02	−.04	−.03	−.02	.02	.02	−.02	.01	−.06	−.09	−.07	−.12	−.36	−.02							
16	AF warmth	25.12 (2.66)	466	−.10	−.04	−.10	−.02	.07	.07	.06	−.01	.06	.08	.05	.09	.23	.04	−.09						
17	AF task sensitivity	3.49 (0.52)	463	.03	.00	.05	−.01	−.04	−.02	.02	.03	.01	−.03	−.05	.01	.03	.58	.03	.06					
18	AF harshness	0 (1.38)	466	.04	−.01	.02	−.09	−.07	−.09	−.05	.10	.00	.02	.05	−.06	−.14	−.05	.32	−.33	−.05				
19	27 m expressive vocab	55.1 (21.0)	487	−.10	−.06	−.01	−.04	.02	.07	.13	.11	.12	.12	.03	.09	.10	.01	−.02	.04	.04	.01			
20	4.5 y print knowledge	106.76 (13.39)	291	−.03	.06	−.01	.08	.04	.11	.11	.23	.22	.25	.23	.13	.00	.10	−.09	−.15	.10	.06	.28		
21	4.5 y phono. awareness	97.76 (15.66)	137	−.02	.22	−.08	−.06	.13	.06	.12	.03	.10	.11	.02	.10	.07	.14	−.14	.17	.18	−.03	.26	.38	
22	4.5 y definition vocab	104.29 (9.94)	288	−.03	−.01	.01	.01	.07	.10	.08	.18	.09	.17	.04	.08	.11	.14	−.07	.13	.21	−.03	.33	.43	.30

Abbreviations: AM, adoptive mother; AF, adoptive father BM, birth mother; m, months; Phono., phonological; WAIS, Weschler Adult Intelligence Scale; WJ, Woodcock–Johnson Tests of Achievement III; y, years.

■ $p<.001$; ■ $p<.01$; ■ $p<.05$.

Semi-independent analyses on BF data

As pre-registered, BF data were used to provide convergent evidence for the main analyses (sample sizes: Figure 1; Table S1). BF model results focused on path coefficients rather than *p*-values, and on identifying if these were consistent with BM data, given the reduced power and sample size. The analytic approach taken for BM data was attempted, but models did not converge. CFA as per the BM data was conducted with factor score extraction to provide latent scores. These were then utilized in structural equation models as per the BM main analyses.

Missing data

Data were examined for patterns of missingness. The main source of missing data in BM models was TOPEL phonological awareness, and in BF models, it was information on BF intellectual performance. Data were not missing completely at random (MCAR; where the probability of missing is same for all cases, without systemic association between missingness of data; Little's MCAR test: $\chi^2(2297)=2538$, $p<.001$). An attrition analysis using the Missing Value Analysis function in SPSS was undertaken, which created an indicator variable for variables with missing values, which was then used to compare group means among dataset variables using a *t*-test. This attrition analysis revealed that patterns of missingness for 73% of study variables were related to observed values of one or more variables in the dataset. Although it is not possible to identify data as missing not at random (missingness of data systematically related to unobserved data) or missing at random (MAR; missingness systematically related to observed, but not unobserved data), the patterns of missing data were consistent with MAR. Full information maximum likelihood is suitable for MAR or MCAR (Enders & Bandalos, 2001) and used as per the pre-registration.

Post-hoc sensitivity analyses

We conducted six additional post-hoc analyses that were not pre-registered to identify the sensitivity of our main analyses: (1) we tested the individual effects of the three parenting separately, in case of suppression effects that obscure the relations of individual types of parenting behavior with language skills; (2) we tested for *r*GE between birth parent general intellectual performance and the three parenting variables; (3) we ran an analysis to identify if the indirect effects of BM negative emotionality and surgency, and parenting persisted to 7 years, testing the pathway in Austerberry, Fearon, et al. (2022) using 1000 bootstrapped draws of the data; (4) we tested if the main BM models held using just Cohort I, as the TOPEL was only collected in Cohort I (we prioritized including the full EGDS cohort in main analyses); (5) we conducted the same analysis undertaken for BF data (using factor score extraction) on BM data to account for any differences in analytic method; and (6) we ran the BM models with the removal of harsh parenting to test if results held, as this had low variability.

RESULTS

Preliminary analyses

There were minimal or no significant correlations between birth parent general intellectual performance and temperament (Table 2; Table S1), consistent with the literature (Poropat, 2009). We therefore proceeded with main analyses.

Negative emotionality

Main analyses on BM data

AM model

The model contained BM negative emotionality and maternal parenting as predictors, and child language as the outcome (fit: $\chi^2(124)=160.39$, CFI=.97, RMSEA=.03, SRMR=.05; Figure 3a). There was a direct effect of BM negative emotionality predicting lower child vocabulary at 27 months (with parenting, $\beta=-.15$, $p=.009$; without, $\beta=-.13$, $p=.020$). There was no direct effect of BM negative emotionality on pre-literacy skills at 4.5 years ($\beta=.07$, $p=.426$); however, the indirect effect via vocabulary at 27 months was significant ($\beta=-.08$, $p=.024$)—that is, the effect of BM negative emotionality on pre-literacy skills at 4.5 years was mediated through its effect on early vocabulary.

Children exposed to higher maternal warmth at 27 months had higher concurrent vocabulary scores ($\beta=.15$, $p=.002$). Longitudinally, maternal warmth also had an indirect effect on pre-literacy skills at 4.5 years, via earlier vocabulary at 27 months ($\beta=.03$, $p=.006$). Children exposed to more sensitive parenting at 27 months also had higher pre-literacy scores at 4.5 years ($\beta=.19$, $p=.022$). There were no other significant effects for parenting.

Consistent with Austerberry, Fearon, et al. (2022), child vocabulary at 27 months ($\beta=.41$, $p<.001$) and BM general intellectual performance ($\beta=.30$, $p<.001$), predicted child pre-literacy skills at 4.5 years, but BM general intellectual performance did not predict vocabulary at 27 months ($\beta=.10$, $p=.071$).

AF model

The model contained BM negative emotionality and paternal parenting as predictors, and child language as the outcome (fit: $\chi^2(124)=189.55$, $p<.001$, CFI=.95, RMSEA=.03, SRMR=.06; Figure 3b). The effect of BM negative emotionality on earlier vocabulary remained

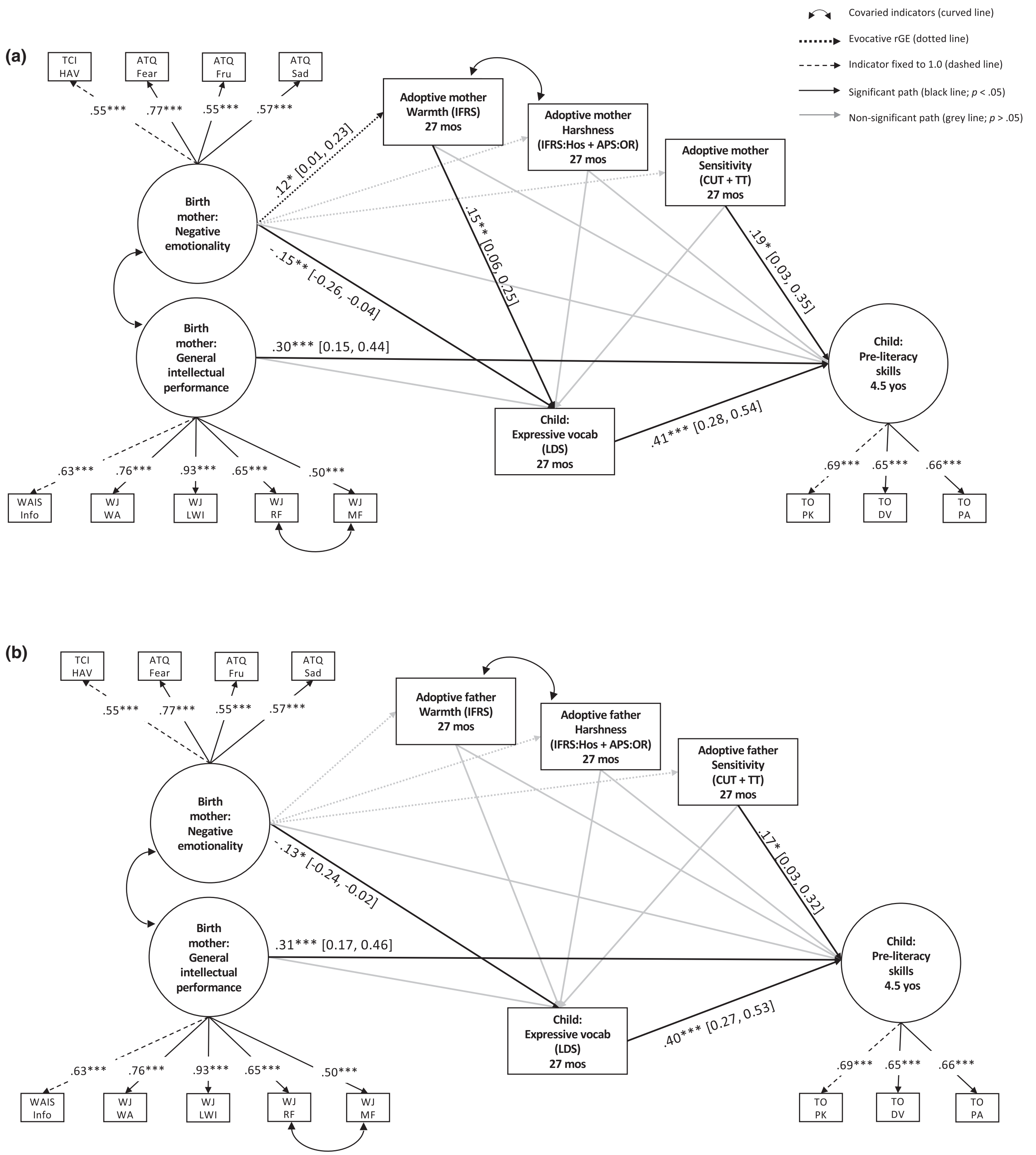

FIGURE 3 Birth mother negative emotionality and general intellectual performance, with (a) adoptive mother parenting, and (b) adoptive father parenting, predicting child language skills. Indirect pathway from birth mother negative emotionality to child pre-literacy skills (4.5 years), via child expressive vocabulary (27 months): $\beta = -.09$ [−.15, −.02]. Indirect pathway from adoptive mother warmth to child literacy skills (4.5 years), via child expressive vocabulary (27 months): $\beta = .03$ [.01, .05]. $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$. Standardized estimates; 95% CIs in brackets. ATQ, Adult Temperament Questionnaire; CUT, clean-up task; DV, definitional vocabulary; Fru, frustration; HAV, harm avoidance; Hos, Hostility subscale; IFRS, Iowa Family Rating Scales; LDS, Language Development Survey; LW, letter–word identification; MF, maths fluency; mos, months old; PA, phonological awareness; PK, print knowledge; Pos, positive affect; PS:OR, parenting scale: over-reactivity subscale; RF, reading fluency; Sad, sadness subscale; TCI, Temperament Character Inventory; temp., temperament; TO, Test of Preschool Early Literacy; TT, teaching task; WA, word-attack; WAIS, Weschler Adult Intelligence Scale; WJ, Woodcock–Johnson Achievement Tests III; yos, years old.

consistent with the maternal model. There was no effect of paternal warmth (27 months: $\beta = .04$, $p = .470$; 4.5 years: $\beta = -.07$, $p = .423$). There was an effect of paternal sensitivity on child pre-literacy; those exposed to more sensitive paternal parenting at 27 months had higher scores at age 4.5 ($\beta = .17$, $p = .022$).

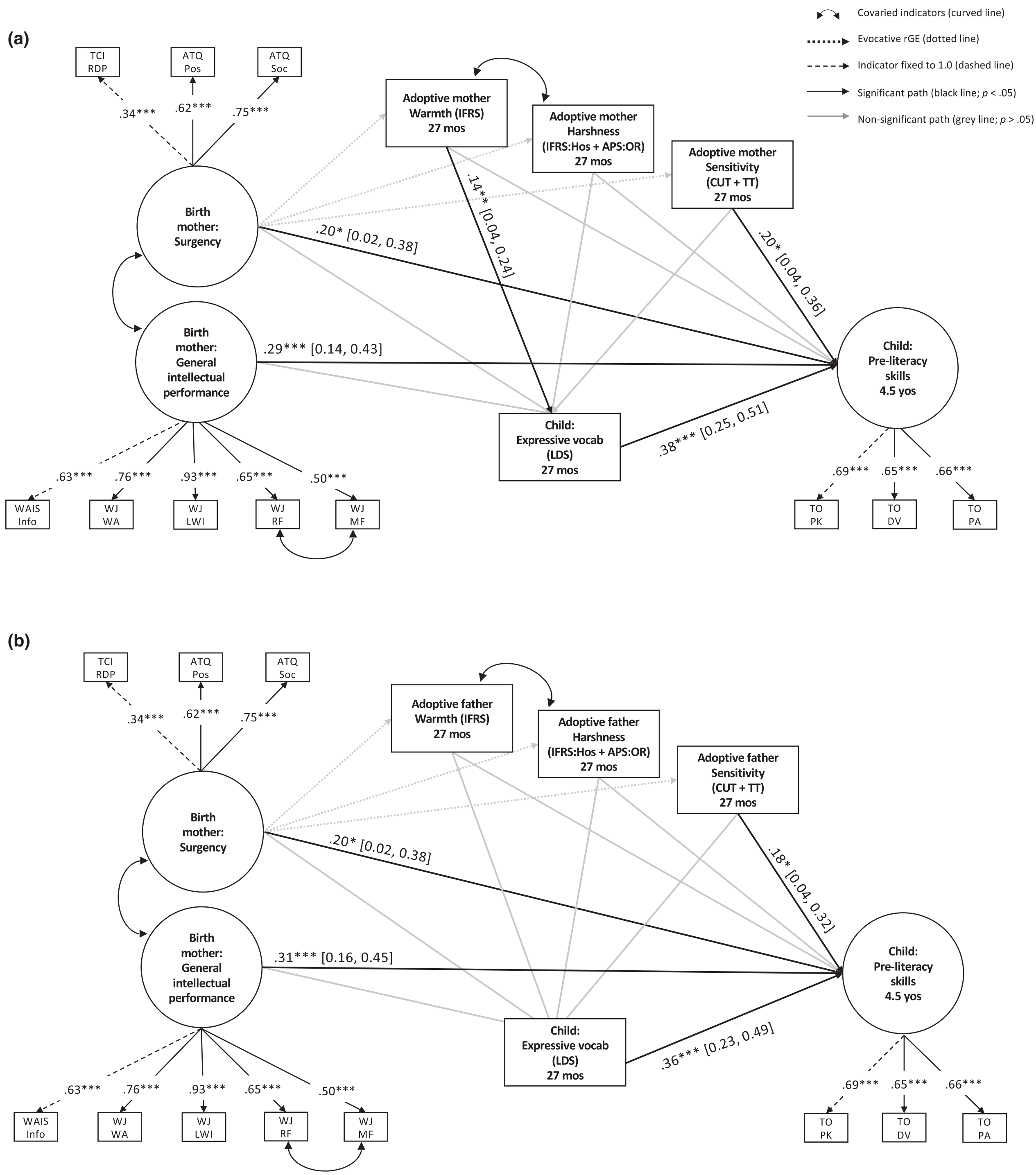

FIGURE 4 Birth mother surgency and general intellectual performance, with (a) adoptive mother parenting, and (b) adoptive father parenting, predicting child language skills. *$p<.05$, **$p<.01$, ***$p<.001$. Standardized estimates; 95% CIs in brackets. ATQ, Adult Temperament Questionnaire; CUT, clean-up task; DV, definitional vocabulary; Fru, frustration; HAV, harm avoidance; Hos, hostility subscale; IFRS, Iowa Family Rating Scales; LDS, language development survey; LW, Letter–Word Identification; MF, maths fluency; mos, months-old; PA, phonological awareness; PK, print knowledge; Pos, positive affect; PS:OR, parenting scale: over-reactivity subscale; RF, reading fluency; Sad, sadness subscale; TCI, Temperament Character Inventory; temp., temperament; TO, Test of Preschool Early Literacy; TT, teaching task; WA, Word-Attack; WAIS, Weschler Adult Intelligence Scale; WJ, Woodcock–Johnson Achievement Tests III; yos, years old.

Evocative rGE and interactions between BM negative emotionality and parenting

Higher BM negative emotionality predicted higher self-reported maternal warmth ($\beta=.12$, $p=.041$), indicating evidence for evocative *r*GE, although the indirect *r*GE effect from BM negative emotionality to pre-literacy at 4.5 years, via maternal warmth, was not significant ($\beta=.01$, $p=.129$). There was no evidence of evocative *r*GE for paternal warmth ($\beta = -.08$, $p = .166$). No significant interactions were found between BM temperament and either adoptive parent.

Semi-independent analyses using BF data

Model fit for BF analyses was good (AM model: $\chi^2(5) = 1.67$, $p = .892$, CFI = 1.00, RMSEA = .00, SRMR = .01, Figure S1a; AF model: $\chi^2(5) = 2.87$, $p = .721$, CFI = 1.00, RMSEA = .00, SRMR = .01, Figure S1b). The path coefficient for the effect of BF negative emotionality on vocabulary at 27 months was similar to BM data in both adoptive parent models ($\beta = -.09$), albeit not significant ($p = .115$). Adoptive parenting effects were highly consistent with the BM models, and there were no evocative effects or interactions. However, there were two differences with BM models: higher BF negative emotionality predicted lower pre-literacy skills at 4.5 years (with parenting, $\beta = -.27$, $p < .001$; without, $\beta = -.26$, $p < .001$). There was also a positive effect of BF general intellectual performance on vocabulary at 27 months ($\beta = .17$, $p = .002$; considered in Austerberry, Fearon, et al., 2022, but not evaluated, due to non-convergence). The indirect effect on pre-literary skills at age 4.5, via vocabulary at 27 months, was significant ($\beta = .02$, $p = .021$). See Supporting Information for Figures.

Surgency

Main analyses using BM data

AM model

The final model contained BM surgency and maternal parenting as predictor variables, and child language skills as the dependent variable (fit: $\chi^2(107) = 144.59$, $p = .009$, CFI = .96, RMSEA = .03, SRMR = .05; Figure 4a). There was an effect of BM surgency on language at 4.5 years only when parenting variables were added (with parenting, $\beta = .20$, $p = .033$; without, $\beta = .18$, $p = .059$); higher genetic propensity for surgency predicted higher pre-literacy at age 4.5 years. There was no effect on earlier child vocabulary at 27 months ($\beta = .11$, $p = .080$). Effects of maternal parenting were highly consistent with the negative emotionality models, with self-reported warmth predicting child vocabulary at 27 months ($\beta = .14$, $p = .005$) and sensitivity predicting child pre-literacy at 4.5 years ($\beta = .20$, $p = .012$).

AF model

The final model contained BM surgency, paternal parenting, and child language skills (fit: $\chi^2(107) = 160.29$, $p = .001$, CFI = .95, RMSEA = .03, SRMR = .05; Figure 4b). BM effects were highly consistent: there was an effect of BM surgency on child pre-literacy skills at 4.5 years ($\beta = .20$, $p = .031$), and no effect on expressive vocabulary at 27 months ($\beta = .11$, $p = .095$). The effects of paternal parenting variables were highly consistent with those in the negative emotionality model: children exposed to more sensitive paternal parenting at 27 months had higher pre-literacy skills at 4.5 years ($\beta = .18$, $p = .014$), and no other effects were found. There was also no evidence of evocative *r*GE.

Evocative rGE and interactions between BM surgency and parenting

There was no evocative effect of BM surgency on parenting. There was a significant interaction between BM surgency and maternal parenting when predicting child pre-literacy at 4.5 years ($\beta = -.27$, $p = .004$). Probing the interaction using a simple slopes approach identified that the positive effect of BM surgency on child pre-literacy at 4.5 years was significant when maternal warmth was low (Figure 5). Thus, when exposed to less warm maternal environments at 27 months, the effect of higher genetic propensity for surgency was protective for child pre-literacy skills at 4.5 years. There was no significant interaction between BM surgency and maternal parenting when predicting earlier vocabulary at 27 months ($\beta = .12$, $p = .058$), and no interactions between BM surgency and paternal variables.

Semi-independent analyses on BF data

Model fit was good (AM model: $\chi^2(23) = 16.97$, $p = .811$, CFI = 1.00, RMSEA = .00, SRMR = .02, Figure S2a; AF model: $\chi^2(5) = 3.24$, $p = .663$, CFI = 1.00, RMSEA = .00, SRMR = .01, Figure S2b). The positive effect of BF surgency on pre-literacy at 4.5 years was consistent with the BM models (with parenting, $\beta = .41$, $p < .001$; without, $\beta = .40$, $p < .001$); unlike the BM models, there was also a positive effect on vocabulary at 27 months (with parenting, $\beta = .13$, $p = .011$; without, $\beta = .13$, $p = .014$).

There was no evidence for rGE between BF surgency and parenting. There was an interaction between BF surgency and paternal, but not maternal, parenting when predicting pre-literacy at 4.5 years ($\beta = -.17$, $p = .007$; Figure S3), similar to the interaction found in BM data. Probing the interaction identified the effect of BF surgency on child language ability was most pronounced when paternal warmth was lower: when exposed to less warm paternal environments at 27 months, the effect of BF surgency was protective for pre-literacy at 4.5 years. There were no other interactions. See Supporting Information for Figures.

Post-hoc sensitivity analyses

There were no suppression effects when testing adoptive parenting variables separately. There was no evidence of evocative *r*GE between birth parent general

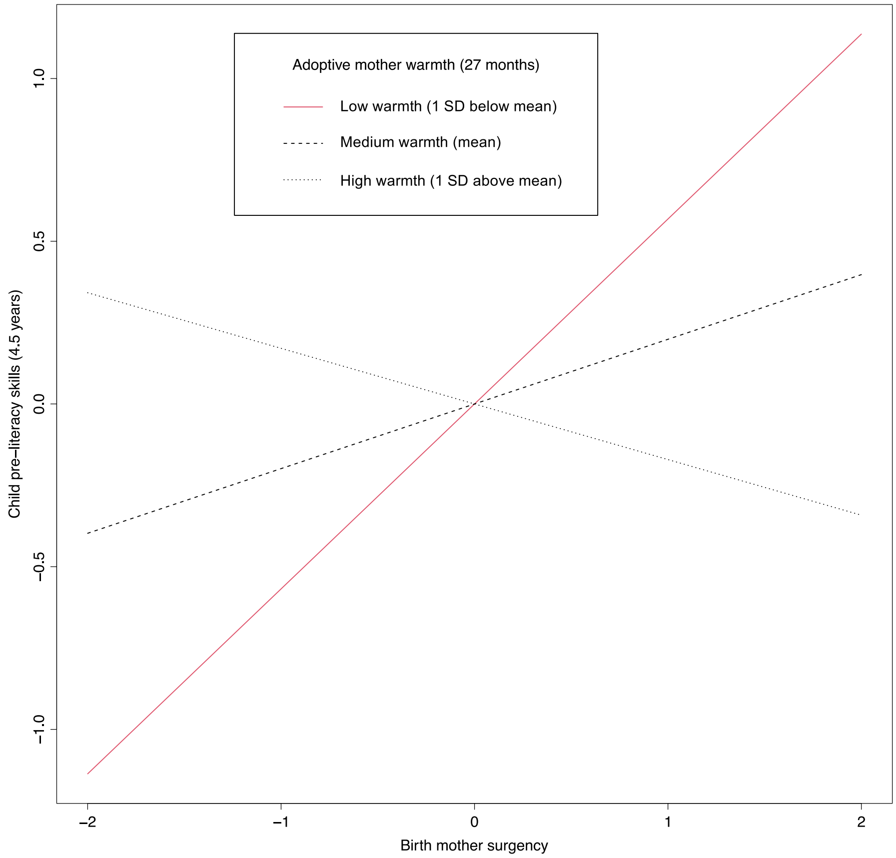

FIGURE 5 Simple slopes interaction plot showing interaction between adoptive mother warmth at 27 months and birth mother surgency on child pre-literacy at 4.5 years. Red line = significant regression slope, black line = non-significant regression slope.

intellectual performance and parenting variables. There were significant longer-term indirect effects of BM negative emotionality and parenting behavior on child academic achievement at age 7 years via earlier child language, but not for BM surgency. Results were consistent when testing only Cohort I data, when using factor score extraction on BM data, and with removal of harsh parenting. For full analyses, see Supporting Information.

DISCUSSION

Consistent with our hypotheses, latent genetic propensity for negative emotionality predicted less proficient vocabulary at 27 months, and latent genetic propensity for surgency predicted greater pre-literacy at 4.5 years when parenting was considered. We also demonstrated the effects of parenting behaviors on early language. Our inferences on these parenting effects are stronger than those possible in conventional parent–child designs (Reuben et al., 2016). We not only controlled for genetic effects on children's language and negative emotionality and surgency indexed by birth parent scores but, more importantly, also ruled out the effects of genes common to rearing parents and their offspring. With these research design strengths, we also identified that greater adoptive maternal warmth positively predicted vocabulary at 27 months and that both greater adoptive maternal and paternal sensitivity positively predicted pre-literacy at 4.5 years. While the genetic propensity for temperament and parenting were both directly related to children's emerging language skills, we also found evidence of evocative *r*GE. Higher genetic propensity for negative emotionality elicited more warmth in AMs, but not in fathers. Finally, genetic propensity for surgency exerted a beneficial effect on child pre-literacy at 4.5 years when adoptive parents demonstrated less warmth at 27 months, the magnitude of the effect ($\beta = -.27$) being almost equal to that of birth parent intellectual performance alone ($\beta = .31$), showing evidence for gene–environment interaction.

The effect of genetic propensity for temperament on emergent language skills

Our genetic effects were supported by convergent evidence from the BF analyses, which showed very similar path coefficients to BM data (see Supporting Information for further discussion of BF analyses). In our main models on BM data, we confirmed that higher genetic propensity for negative emotionality was directly associated with lower vocabulary at 27 months (Cioffi et al., 2021), with indirect effects persisting to 7 years in post-hoc analyses. These results are consistent with non-genetically sensitive studies that identify associations between higher negative emotionality and less proficient language skills (Coplan et al., 1999; Salley & Dixon, 2007). They are also consistent with those that indicate negative emotionality may affect how children learn, such as by reduced focus on target objects during word learning (e.g., Hilton et al., 2019). Although there was an indirect effect of birth parent negative emotionality on pre-literacy at 4.5 years, mediated by its effect on earlier vocabulary, the lack of a direct effect may reflect changes in emotional regulation not measured here. Growth in emotional regulation skills from toddlerhood to school-entry may temper the effects of negative emotionality on language (e.g., Posner & Rothbart, 2000).

Consistent with non-genetically sensitive literature that identifies positive associations between surgency and early language (Dixon & Smith, 2000; Slomkowski et al., 1992), we confirmed our hypothesis that increased genetic propensity for surgency had beneficial effects on pre-literacy skills at 4.5 years, but only once parenting behaviors—measures of environmental effects—were added. At 27 months, the path coefficient was also positive but not significant. It is possible that children with a higher genetic propensity for surgency may have greater readiness to interact and learn from those around them, which in turn, impacts language and pre-literacy skills over time. At 27 months, where language ability is still emerging, the effects of surgency may not manifest in our measures at the cohort level, but rather, may manifest on a finer-grain scale, such as during active learning. For example, lab-based studies demonstrate that 3-year-olds higher in social responsiveness and positive affect are better at judging how reliable an informant is during word learning (Canfield et al., 2015).

The indirect effect of surgency did not persist to middle childhood in post-hoc analyses. Of note is that surgency comprises a wide range of behaviors, including high activity levels linked to externalizing behavior (e.g., Stringaris et al., 2010) that might negatively impact learning. However, surgency measures in this study indexed sociability and positive affect, but not high activity or distractibility. Gartstein et al. (2012) found that although high activity predicted externalizing behavior in 4-year-olds, sociability did not—consistent with our surgency indicators. It is, however, possible that sociability might be beneficial during early childhood when children rely on others, particularly caregivers, to scaffold language learning (Tomasello, 2003) as measured by vocabulary. However, in later childhood where vocabulary has been established, and children focus on more formal code-related language skills such as pre-literacy, sociability might instead interfere with demands to forgo the rewards of peer interaction in favor of classroom learning. Further research on temperament profiles across the timescale of language development is warranted to determine whether negative emotionality and surgency differ in pervasive effects on language skills over time.

The effect of parenting on emergent language skills

Our second set of hypotheses was partially confirmed—although harsh parenting failed to predict lower language proficiency, and adoptive parenting warmth and sensitivity showed positive effects on child language. The confirmed hypothesis of positive effects of parenting warmth and sensitivity at 27 months on early language is consistent with literature that suggests the shared environment accounts for a large amount of variance in language skills from infancy to the preschool period (Austerberry, Mateen, et al., 2022). The effect of maternal warmth on language at 27 months may reflect how vocabulary in particular—an early measure of language—is affected by the immediate environment. The association between low SES and reduced early language skills appears less evident for parent–child interactions that contain language-boosting behaviors such as conversational turns and child-directed speech (Hoff, 2006). As parents typically account for much of preschool language input, it is possible that parenting warmth affects expressive vocabulary as a general measure of how much the primary caregiver enjoys interacting with their child and engages in doing so, reflecting early proximal caregiving environment quality. Expression of parental warmth may therefore be particularly useful for promoting early vocabulary.

However, as children's language progresses to more formal skills such as pre-literacy, more targeted parenting behavior may have an effect. In our sample, parenting sensitivity predicted pre-literacy skills at 4.5 years. Parental sensitivity comprises formalized behavior around structuring children's learning environment and contingent responses (Vygotsky, 1978), and parents demonstrated this behavior during tasks with specific goals (e.g., solving puzzles). Sensitivity may thus be important for pre-literacy tasks similar to the TOPEL, which tests skills such as word blending and letter recognition that are explicitly taught.

The impact of parenting warmth and sensitivity on language found in our study is consistent with the non-genetic literature that demonstrates how the early social environment can impact both early and longer-term language outcomes (Bornstein et al., 2020). The indirect effects of warmth and sensitivity also persisted in language at 7 years in our post-hoc analyses, mediated by their positive effect on language at 27 months and 4.5 years. Our measures of warmth and sensitivity correspond with those tested in a recent meta-analysis (Madigan et al., 2019) that found significant positive effects of both on language skills between 1 and 6 years. Although our measures do not directly capture the moment-by-moment responsiveness from caregiver linguistic and social input that appears to scaffold language learning from infancy (Tamis-LeMonda et al., 2004), it is likely that warm and sensitive parenting, as measured here at 27 months when children are still acquiring language, may capture a degree of this responsiveness. In particular, verbal responsiveness appears to facilitate language learning during preschool, with increased maternal verbal descriptions, imitations, and child-directed speech between 9- and 18-months-old predicting increased vocabulary size (Weisleder & Fernald, 2013) and language milestones (Tamis-LeMonda et al., 2001) at 2 years. Increasing the frequency of labeling objects and actions via intervention at 6 months has also demonstrated gains in use of words at 1 year (Landry et al., 2006). Higher warm and sensitive parenting may thus confer or possibly overlap with increased language-facilitating behaviors from infancy. Future studies that directly examine verbal responsivity in relation to warm, sensitive parenting over time may help understand this link.

The null finding in relation to harsh parenting and language may be partially reflective of the relatively sparing use of harsh parenting in this sample. As prospective adoptive parents typically have strong economic resources to afford a domestic adoption and undergo rigorous processes to ensure a non-harmful environment before adopting, harsh parenting in EGDS is low. Negative associations between harsh parenting and child outcomes might only emerge when a fuller range of the predictor is present (Berthelon et al., 2020).

Gene–environment interplay effects on emergent language skills

Our third and fourth hypotheses concerned evocative and interaction effects, respectively, between genetic propensity for temperament and parenting. There was an evocative effect of negative emotionality, partially confirming our third hypothesis. Higher BM negative emotionality was related to higher levels of AM warmth, consistent with similar families from middle-SES backgrounds (Paulussen-Hoogeboom et al., 2007). Higher evoked, self-reported warmth toward children with higher genetic propensity for negative emotionality might also indicate greater maternal responsiveness to child distress from infancy, and thus greater support for emotional regulation, that benefits language development (Leerkes et al., 2009). These results indicate that children's genetic propensity can elicit parenting behavior patterns that affect child outcomes. Negative emotionality evoking warmer, rather than harsher, parenting also demonstrates how gene-on-environment effects might positively impact children's outcomes. Of interest is that the results suggested maternal warmth ($\beta = .15$) can counteract the effect of genetic propensity for negative emotionality ($\beta = -.15$), highlighting the importance of early parenting effects on language. It is thus also possible that for children with higher negative emotionality, interventions that encourage parenting warmth may be particularly beneficial for language development.

A prolific twin study also found evidence of *r*GE when examining self-reported parent communication at 4- to 5-years-old and concurrent language (Dale et al., 2015), suggesting heritable influences of language and the early parenting environment, but crucially, was not able to separate passive from evocative *r*GE. Although no other genetically sensitive research has examined temperament, parenting, and language, our results on warm parenting are broadly consistent with literature on evocative effects. For example, adolescents' genetic predisposition toward aggression and delinquency was found to evoke maternal criticism in a children-of-twins study (Narusyte et al., 2011). In EGDS, higher child genetic propensity for externalizing psychiatric illness was found to evoke higher negative parenting attitudes, primarily when marital problems were also present (Fearon et al., 2015). More broadly, a meta-analysis of twin and adoption studies identified that genetic influences on parenting account for 23%–40% of the variance, with evidence for evocative effects of child genes on parenting negativity and warmth (Klahr & Burt, 2014).

Of note is that we also did not find that genetic propensity for surgency elicited more warm and sensitive parenting (*r*GE), which, in turn, would be posited to positively influence language skills. However, there was an interaction between birth parent surgency and AM warmth on pre-literacy at 4.5 years. Accordingly, where adoptive environments were less warm at 27 months, the effect of genetic propensity for surgency on higher pre-literacy proficiency at 4.5 years was stronger. Where maternal warmth is high during language acquisition at 27 months, it is possible that a 'ceiling effect' means higher genetic propensity for surgency provides limited *extra* benefit toward language at 4.5 years. Conversely, where maternal warmth is lower during early language acquisition, a genetic propensity toward surgency might lead a child to seek social input elsewhere—for example, childcare, extended relatives, and siblings—that benefits pre-literacy at 4.5 years. Findings from twin studies also suggest genes can play a protective role under certain environments—Asbury et al. (2005) found increased heritability of verbal ability in 4-year-old twins when parent-reported parent–child communication was low. More broadly, other genetic studies have demonstrated a stronger influence of genetic antisocial behavior risk in adolescents exposed to less warm parenting, and the effects of physical maltreatment on 5-year-olds developing conduct disorder are stronger in those with higher genetic risk (Horwitz & Neiderhiser, 2011). In sum, our results align with other genetic literature that demonstrates genes and the environment compensate for one another across a range of child outcomes.

Study limitations

Despite the methodological strengths of the study, including its genetically sensitive and prospective longitudinal design, as well as its use of multiple informants and methods, there are several limitations. One is limited range of SES in the sample. As SES effects on language have been well documented (Hoff, 2006), it is possible that warmth and sensitivity may have different effects when there are other economic constraints and cultural differences relative to different parenting strategies. Furthermore, the indirect effect of maternal warmth and sensitivity accounts for an estimated 5% of the variance between SES and child language (Borairi et al., 2021), indicating other factors are at play (e.g., childcare quality). Furthermore, we did not have more detailed measures that may better capture the impact of parenting on language development, such as verbal responsivity (Tamis-LeMonda et al., 2001). We also did not have information on the presence of clinical language delays, so cannot state to what extent these findings would relate to atypical language development.

Another limitation is that we do not account for how child expressive vocabulary might affect caregiver behavior. There is evidence from multivariate twin analyses and polygenic score research that genetic influences underlying children's intellectual and academic development may evoke differences in parenting (Tucker-Drob & Harden, 2012). However, we did not find evidence for *r*GE via birth parent general intellectual performance, suggesting that during very early childhood, these effects may yet be manifest.

A final limitation is that the sample utilizes data and builds on literature from Western, educated, industrialized, rich, and democratic (WEIRD) populations, limiting its applicability. For example, heritability in anxiety and depression across Chinese adolescent twins appears lower than in existing WEIRD literature, with stability explained by the shared environment rather than by genes due to transitions in the Chinese school system (Zheng et al., 2016). Thus, culture-specific changes in the environment might have more pronounced impacts on trait emergence in different populations. Genetically sensitive, non-WEIRD studies that examine gene–environment interplay are thus a key direction for future research.

CONCLUSION

In sum, we found differential effects of genetic propensity for negative emotionality and surgency on children's early language ability, where birth parent negative emotionality appears to have a detrimental effect on children's early expressive vocabulary, and birth parent surgency positively affects children's early pre-literacy skills. We also found beneficial effects of maternal warmth and parenting sensitivity for language development, unconfounded by common gene effects, and evocative effects of birth parent negative emotionality on AM warmth. Taken together, these results highlight not only how children's individual, genetically influenced characteristics can affect emergent language but also highlight the importance of the early caregiving environment for language development after accounting for specific genetic influences. We also demonstrate how these sources might operate together to support emergent language skills. Specifically, we identified that the warmth of the early caregiving environment has the potential to compensate for the effects of genetic propensity for negative emotionality on early language ability. Conversely, genetic propensity for surgency may act as a protective factor for early language development in less optimal parenting environments.

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DATA AVAILABILITY STATEMENT

The data, materials, and analytic code necessary to reproduce the analyses are not publicly accessible. The analyses presented here were pre-registered on the Open Science Framework (https://osf.io/hq28s/?view_only=7caa06e044084265b58a50f18c323632; pre-registration differences: https://osf.io/gd8tw/?view_only=d9b2378ab20a439386870ec430234004).

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