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The interaction between infant negative emotionality and cognition predicts ADHD-related behaviors in toddlerhood

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ABSTRACT

Attention-deficit/hyperactivity disorder (ADHD) is a highly prevalent disorder commonly identified in childhood. Affective and cognitive characteristics that are identifiable as early as infancy could be signals of risk for developing ADHD. Specifically, the interplay between emotionality and cognition may be important in predicting early symptoms of ADHD. This study examined the independent and interactive effects of infant negative emotionality and cognition on the development of inattention and hyperactivity/impulsivity in toddlerhood among infants at high and low familial likelihood for ADHD. Participants were 64 infants (M = 8.7, SD = 1.8) at high (n = 32) and low (n = 32) familial likelihood for ADHD, defined as at least one parent with ADHD or two parents without ADHD, respectively. Negative emotionality and cognition in infancy were assessed using the Infant Behavior Questionnaire and the Bayley's Scales of Infant and Toddler Development, and ADHD symptoms were assessed at toddler follow-up (M= 20.0, SD= 3.2) using the Child Behavior Checklist. Accounting for the quality of parent-child interaction, infants' negative emotionality (β = .033, p = .938) and cognition (β = .006, p = .884) did not independently predict toddlers' ADHD-related behaviors, but their interaction did (β = .110, p = .019). For infants with higher levels of cognition (>95th percentile), higher negative emotionality predicted more ADHD-related behaviorss. For infants with lower levels of cognition (<11th percentile), higher negative emotionality predicted fewer ADHD-related behaviors. There may be two affective-cognitive pathways to inattention and hyperactivity/impulsivity in toddlerhood. The combination of higher levels of negative emotionality and cognition may result in greater frustration when goals are blocked, resulting in the expression of dysregulated behaviors (i.e., ADHD symptoms). Alternatively, low levels of negative emotionality and cognition combined may lead to dysregulation that is primarily cognitive in nature (such as the inattention symptoms of ADHD). Investigating affective and cognitive processes simultaneously may be important for increasing understanding of the early signals of ADHD risk.

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1. Introduction

Attention-deficit/hyperactivity disorder (ADHD) is a highly prevalent neurodevelopmental disorder (Polanczyk et al., 2014; Willcutt, 2012). Children with ADHD followed to adulthood have been found to have lifelong impairments in educational, occupational, and interpersonal domains even when symptoms desist (Barkley, 2014; Molina et al., 2009; Wehmeier et al., 2010). These ADHD-related impairments are estimated to amount to hundreds of billions of dollars in economic costs annually, worldwide (Faraone et al., 2021). Children with ADHD are most often identified for evaluation and/or treatment at school-age (Visser et al., 2014). Yet, even before school entry, symptoms of ADHD have been found to impact social and preacademic skill development (Campbell, 1994; McGoey et al., 2002).

Although defined by symptoms of inattention, hyperactivity, and impulsivity, it has been suggested that ADHD is more accurately described as a disruption in the development of behavioral inhibition that impairs self-regulation, the ability to stop/control one's behavior and simultaneously engage in another behavior (Posner & Rothbart, 2000), and the ability to employ executive functioning skills necessary for future-oriented tasks (Barkley, 1997). Individuals with ADHD have been found to have impairments in both cognitive and affective processes involved in regulation. Extensive research has examined various aspects of cognition among individuals with ADHD. A meta-analysis by Pievsky and McGrath, 2018 found moderate impairment in multiple neurocognitive domains including reaction time variability, response inhibition, working memory, planning, and organization. There has also been increasing recognition of difficulties in emotion dysregulation amongst individuals with ADHD (see meta-analyses by Graziano & Garcia, 2016 and Beheshti et al., 2020). Growing literature on ADHD and emotion regulation has suggested the need for additional criteria or presentations of ADHD that address impairment in affective regulation (e.g., Karalunas et al., 2019).

Importantly, affective characteristics that are identifiable as early as infancy could be signals of risk for developing ADHD (Nigg et al., 2004). Negative emotionality is a temperament dimension characterized by increased negative affect that has been frequently examined in infancy and toddlerhood in relation to later ADHD (Rothbart & Bates, 2006). A meta-analysis found a weakly positive association between infants' and toddlers' negative emotionality and childhood ADHD symptoms, this weak association found may be a reflection of the mixed results in the literature (Bilgin et al., 2020; Gurevitz, Geva, Varon, & Leitner, 2014; Joseph et al., 2022). These mixed findings suggest the need to examine other characteristics (e.g., cognition) that may strengthen the association between negative emotionality and ADHD symptoms.

Although there is robust literature for school-aged children with ADHD documenting their lower or more variable levels of performance on numerous measures of cognition in relation to children without ADHD (e.g., reaction time variability, working memory; Kofler et al., 2013; Ramos, Hamdan, & Machado, 2020), minimal research has examined early developing cognitive skills in *infancy* as predictors of later ADHD symptoms (Arnett et al., 2013; Shephard et al., 2021). Research with preschool children found that children at the borderline or moderate range of the Bayley Mental Developmental Index (MDI) at age 3 were more likely to meet criteria for an ADHD diagnosis at age 5 (Baker et al., 2010). Examining early predictors of ADHD, Arnett and colleagues (2013) found, in a typically developing sample, that cognitive deficits as early as 15-months were predictive of significant ADHD symptoms when children were in 3rd grade. Furthermore, results also demonstrated that almost half of the variance in ADHD was left unexplained, accounting for cognitive performance, suggesting that other factors (e.g., temperament) are necessary to capture early identification of ADHD. Given the mixed results of the extant literature examining the relation between infant emotionality and childhood ADHD, it is possible that the interplay between emotionality and cognition may be important in predicting early symptoms of ADHD.

Literature supports the interaction between cognitive and affective regulation processes in explaining social-emotional development in children and adults (Okon-Singer et al., 2018). Specifically, amongst preschool aged children, emotion regulation is most favorable at average levels of inhibitory control (Carlson & Wang, 2007). However, despite the extensive research on both emotion and cognitive processes in children with ADHD, there is limited research on the interaction between these constructs (e.g., Sjöwall et al., 2015). One study found interactive profiles of cognitive and affective regulation associated with ADHD in a sample of preschoolers, such that children with ADHD were more likely to demonstrate poorer emotion regulation and executive functioning (Ros and Graziano, 2020). However, specifically examining the interaction between affective and cognitive regulation for their independent and interactive effects as early risk factors of ADHD in infancy have not been examined. Understanding these interactive associations in infancy could inform etiologic models and help inform early screening to improve early access to intervention.

Self-regulatory capacity begins to develop in infancy with external support provided through interaction with parents. Early parenting has been found to be important for the development of both affective and cognitive aspects of regulation, and a predictor of childhood ADHD. Positive parent-child relationships, defined by a secure, stable, and responsive environment have been associated with stronger child emotion regulation (Morris et al., 2017). On the other hand, parent-child relationships with greater negative (i.e., harsh, controlling, or angry) parenting behaviors are associated with emotion dysregulation (Morris et al., 2007). Similarly, positive parenting quality throughout toddlerhood (i.e., 14- 36 months) has been associated with better cognitive performance on the Bayley's Scales of Infant and Toddler Development (Lugo-Gil & Tamis-LeMonda, 2008). Furthermore, in a sample of low-income families, high levels of harsh, rejecting parenting and low levels of parental warmth in the first 2 years of life were associated with more ADHD symptoms at age 5-7 (Joseph et al., 2021). As such, parent-child interactions are an important, and potentially modifiable, factor that can influence the developmental trajectory of self-regulation and risk for expression of ADHD symptoms in childhood.

Using a cohort of infants at high and low familial likelihood for ADHD prospectively followed to toddlerhood, this study aimed to examine the independent and interactive effects of infant negative emotionality and cognition on the development of ADHD-related behaviors in toddlerhood while controlling for the quality of parent-infant interactions. We hypothesized that greater negative emotionality and lower cognitive performance in infancy would each independently predict greater ADHD-related behaviors in toddlerhood. We also hypothesized that the interaction between negative emotionality and cognition would predict ADHD-related

behaviors in toddlerhood such that higher levels of negative emotionality would only predict greater ADHD-related behaviors in toddlerhood at relatively lower levels of cognition.

2. Methods

2.1. Participants

Participants were families with infants at high and low familial likelihood for ADHD recruited from Southwestern Pennsylvanian for participation in the Pittsburgh ADHD Risk in Infancy Study (PARIS). Of the 73 enrolled infants, 64 (88%) (M= 8.7, SD= 1.8) and their biological parent pairs completed the toddlerhood follow-up assessment and had complete data for inclusion in the current study. High familial likelihood infants had at least one parent who met the Fifth Edition of the Diagnostic and Statistical Manual of Mental Disorders (DSM-5) criteria for childhood ADHD with persistence into adulthood (*n= 32*) and low familial likelihood infants had two parents without ADHD (n= 32*)*. Of the families with ADHD, 8 included a mother with ADHD, 21 included a father with ADHD, and 3 included two parents with ADHD. Both male and female infants were enrolled, and high- and low-familial likelihood offspring were group-matched on infant sex, race, and ethnicity. Families were excluded if the infant was born before 38 weeks of gestation, had a low birth weight (< 5lbs 8 oz), or was exposed to perinatal substances as determined by both mother and father report. Toddler follow-up occurred between 18 and 30 months of age (M= 20.0, SD= 3.2). Participant characteristics are shown in Table 1.

2.2. Procedures

All parents participated in a research visit to determine ADHD status and co-morbid psychiatric disorders. Assessments were conducted by a masters or doctoral-level clinician, research-trained to evaluate symptoms and impairment of ADHD across the life-span. Parents also completed questionnaires remotely using Qualtrics (Provo, UT) regarding demographics and their infant's temperament and toddler's behavior. Infants completed a neurodevelopmental examination with behavioral specialists blinded to family history of ADHD. Informed consent was obtained prior to study participation. All families were compensated for their time and the study protocol was approved by the University of Pittsburgh Institutional Review Board.

2.3. Measures

2.3.1. Parent ADHD

The Conners' Adult ADHD Diagnostic Interview (CAADID; Epstein et al., 2001) is a semi-structured interview to examine presence of ADHD in childhood and adulthood. Parents were identified as having ADHD (*yes, no*) if they met DSM-5 criteria for any presentation, 6+ symptoms in childhood and 5+ symptoms in adulthood with impairment across the lifespan.

2.3.2. Parenting

The Parent-Child Dysfunctional Interaction subscale of the Parenting Stress Index-Short Form (PSI-4-SF; Abidin, 2012) contains 12

Table 1
Participant demographics.

Familial likelihood for ADHD		High (N= 32)	Low (N= 32)
		M (SD)	***M (SD)***
Child Age at Time 1 (months)		8.9 (2.0)	8.4 (1.5)
Child Age at Time 2 (months)		19.7 (2.9)	20.3 (3.5)
		N (%)	***N (%)***
Child Race			
	Asian	1 (3.1)	2 (6.3)
	Black or African American	2 (6.3)	3 (9.4)
	White or European American	26 (81.3)	23 (71.9)
	More than One Race	3 (9.4)	4 (12.5)
Child Ethnicity			
	Hispanic or Latinx	3 (9.4)	3 (9.4)
	Not Hispanic or Latinx	29 (90.6)	29 (90.6)
Highest Parent Education			
	High School or GED	1 (3.1)	1 (3.1)
	Technical/Secretarial School	1 (3.1)	0 (0.0)
	Partial College (>1 year)	2 (6.3)	2 (6.3)
	Associate or 2-Year Degree	3 (9.4)	4 (12.5)
	College or University Graduate	10 (31.3)	7 (21.9)
	Graduate or Professional Training	15 (46.9)	18 (56.3)
Parent Relationship Status			
	Single, Never Married	7 (21.9)	2 (6.3)
	Married	25 (78.1)	30 (93.8)

Note: High familial likelihood indicates at least one parent has an ADHD diagnosis

items and assesses stress related to poor-quality interactions between the parent and their child, feelings of rejection from the child, or improper bonding with the child. Parents rate each item on a scale from 1 (*Strongly Disagree*) to 5 (*Strongly Agree*). The PSI contains 2 additional domains of parent stress: Parent Distress and Difficult Child. Scores were combined by averaging both parents' scores, and the Cronbach's alpha for the Parent-Child Dysfunctional Interaction scale in our sample was 0.87.

2.3.3. Infant temperament

The Infant Behavior Questionnaire – Revised Very Short Form (IBQ-R-VS; Putnam et al., 2014) is a 37-item questionnaire used to assess infant temperament. Parents rated how often their child exhibited a particular behavior in the past week on a 7-point scale (1=Never, 7=Always). The IBQ-R-VS includes a negative affect subscale that combines sadness, distress to limitations, and fear. The Cronbach's alpha in our sample was 0.78 for negative affect.

2.3.4. Infant cognition

The Bayley Scales of Infant and Toddler Development III (BSID; Bayley, 2006) is a clinician-administered developmental assessment, administered in our sample by masters-level neurodevelopmental specialists. The BSID produces age-normed composite scores (index M=100, SD=15) for cognitive, language, and motor skills for children between the ages of 1 and 42 months of age. The Cognitive Index contains items measuring domains such as habituation, concept formation, object permanence, and sensorimotor development. The Bayley's Cognitive Index has been found to be predictive of later IQ in other samples at elevated likelihood for neurodevelopmental disorders (Bode et al., 2014; Månsson et al., 2021).

2.3.5. Toddler ADHD-related behaviors

The Child Behavior Checklist for Ages 1½-5 (CBCL; Achenbach & Rescorla, 2001) is a questionnaire used to assess problem behaviors in preschool-aged children. Parents rated their child on 99 problem behaviors using a 3-point scale (0=*Not True (as far as you know)*, 2=*Very True or Often True*). Parents' scores were combined using the highest per item score to obtain a 6-item scale of ADHD problems, with scores of 11 or higher being in the clinical range, and a score of 10 considered to be borderline clinical range. The Cronbach's alpha for ADHD problems in our sample was 0.81.

2.4. Analytic approach

SPSS v. 27 was used to conduct multiple linear regression. Negative emotionality and cognition were mean-centered prior to analysis. Main effects were tested by regressing toddlers' ADHD-related behaviors measured continuously on infants' negative emotionality and cognition (predictors), as well as infant's family history of ADHD, sex, age, parent education, and parent-child interaction (covariates). Interactive effects were tested by entering as a predictor the cross-product of negative emotionality and cognition. The PROCESS macro was used to probe the interaction using the Johnson-Neyman technique for finding regions of significance (Hayes, 2018; Johnson & Neyman, 1936). The Johnson-Neyman technique is an alternative to the ANCOVA approach to probe slopes, which allows for testing of the simple-slopes at percentile values of the moderator (Montoya, 2019).

3. Results

3.1. Zero-order correlations and group comparisons

Zero-order correlations amongst the covariates, predictors, and ADHD-related behaviors are shown in Table 2. Although none were significant at $p < .05$, Infants with greater parent-child relationship difficulties were marginally more likely to have lower cognition scores. Infants with least one parent with ADHD (high familial likelihood) were marginally more likely to have greater negative affectivity, see Table 3.

3.2. Regression analyses

See Table 4 for full results of regression analyses. Participants who were younger at the infant assessment showed greater ADHD-related behaviors at the toddler assessment, but no other covariates significantly predicted ADHD-related behaviors. We found no main effects of infants' negative emotionality or cognition on toddler's ADHD-related behaviors. However, there was a significant interaction between negative emotionality and cognition. The Johnson-Neyman regions of significance analysis showed that negative

Table 2
Intercorrelations.

		1	2	3	4
1	Parent-Child Dysfunctional Interaction	–			
2	Infant Negative Affect	.035	–		
3	Infant Cognitive Development	-.243^{+}	-.118	–	
4	Toddler ADHD-Related Behaviors	.034	.005	.089	–

Note: $^{+}p < .09$

Table 3
Descriptive statistics and comparison between infants at high and low familial likelihood for ADHD.

	Mean	SD	Range	High familial likelihood *M (SD)*	Low familial likelihood *M (SD)*	*p*
IBQ: Negative Affect Subscale	*4.2*	*0.8*	*2.7 – 6.2*	*4.4 (0.7)*	*4.0 (0.8)*	*.085*$^{+}$
BSID: Cognitive Composite Score	*110.8*	*9.3*	*90 – 125*	*109.5 (10.1)*	*112.0 (8.3)*	*.273*
BSID: Cognitive Scaled Score	*12.1*	*1.9*	*8 – 15*	*11.9 (2.0)*	*12.4 (1.7)*	*.254*
CBCL: Toddler ADHD Problems Scale	*6.2*	*2.6*	*0 – 12*	*6.3 (2.6)*	*6.0 (2.7)*	*.606*
Parent-Child Dysfunctional Interaction	*17.7*	*6.0*	*12 – 51*	*18.3 (4.8)*	*17.1 (7.0)*	*.419*
	N	%		High-Risk*N (%)*	Low-Risk*N (%)*	*p*
CBCL: Toddler ADHD Problems Scale, Borderline or Clinical Range	*7*	*10.9*		*5 (15.6)*	*2 (6.3)*	*.230*

Note: $^{+}$p <.09, IBQ: Infant Behavior Questionnaire, BSID: Bayley Scales of Infant and Toddler Development III, CBCL: Child Behavior Checklist for Ages 1½-5

Table 4
Regression models predicting toddler ADHD-related behaviors.

	Model 1		Model 2	
	B	SE	B	SE
Intercept	8.374	5.922	9.406**	2.299
Parent ADHD	.509	.690	.767	.671
Infant Sex	.104	.695	.146	.668
Infant Age	-.406*	.201	-.464*	.194
Parent-Child Interaction	.066	.059	-.016	.057
Infant Negative Affect	.033	.420	-.012	.404
Infant Cognition	.006	.040	-.010	.039
Negative Affect X Cognition			.110*	.046

Note: *p <.05; **p <.01, One tailed test

emotionality positively predicted ADHD-related behaviors when cognition was at or above the 95th percentile (values ≥ 12.7; *n*= 3). However, at levels at or below the 11th percentile of cognition (values ≤ 10.9; *n*= 7), negative emotionality was inversely related to ADHD-related behaviors. Negative emotionality was not associated with ADHD-related behaviors when cognition was between the 10th and 95th percentiles. See Fig. 1 for a visual display of the interaction.

4. Discussion

The current study examined the independent and interactive effects of negative emotionality and cognition in infancy on later development of ADHD-related behaviors in toddlerhood. This study adds to the growing literature examining infant negative

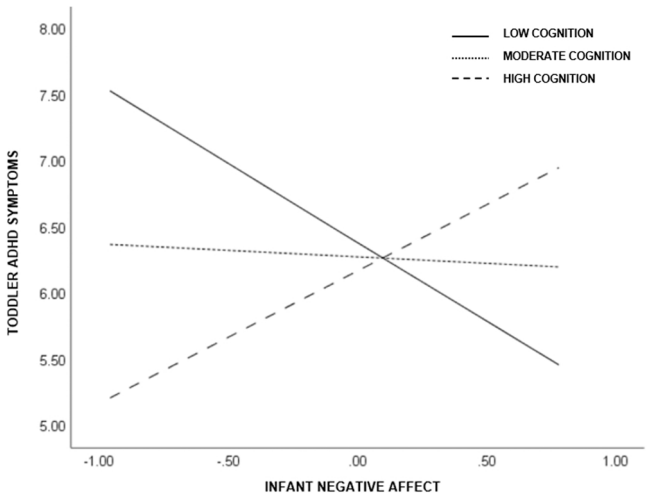

Fig. 1. Interaction between negative emotionality and cognition.

emotionality as a predictor of later psychopathology (Kostyrka-Allchorne et al., 2020). Importantly, this is one of the first studies to examine infant global cognition and is the first to examine the interactive effects of negative emotionality and cognitive processes in infancy in relation to later ADHD-related behaviors.

The literature on infant negative emotionality on childhood ADHD is mixed, with some research supporting and others not finding a direct effect of early negative emotionality on later ADHD symptoms/diagnosis (e.g., Einziger et al., 2018; Meeuwsen et al., 2019; Miller et al., 2018; Williams & Sciberras, 2016). Results of the current study found no direct effect of infant negative emotionality on toddler ADHD-related behaviors. This is in line with some of the previous null findings but may also be explained by the brief measure of infant temperament. Negative emotionality was comprised of the sadness, distress to limitations, and fear scales in infancy which may benefit from further exploration in future studies. Given the mixed findings, together with the current findings, there is a need to examine other factors that may modify the relation between early temperament and later ADHD-related behaviors.

Independently, infant cognition also did not directly predict toddler ADHD-related behaviors. Although research in older children suggests a correlation between factors of cognition (e.g., executive functioning) and ADHD (e.g., Pievsky and McGrath, 2018), prior work has not examined the effect of cognition as early as infancy on ADHD symptoms. An important difference between our study and previous studies of cognition and ADHD in older children is that, due to the developmental stage, infants' cognition is unable to be assessed with as high of a level of specificity relative to older children. Specifically, the cognitive subscale of the BSID represents global cognitive ability as opposed to specific executive functions (e.g., sustained attention, working memory) implicated in ADHD (Månsson et al., 2021). Only three studies have examined BSID in toddlerhood in relation to later ADHD symptoms, including two with children born prematurely, and all found a significant negative association between BSID cognitive score and ADHD symptoms (Arnett et al., 2013; Gould et al., 2019; Johnson et al., 2016). Our null finding suggest that in infancy, a more refined characterization of cognitive ability may be necessary to identify early developing cognition that maps onto later skills of executive functioning.

Although we failed to find main effect prediction of ADHD-related behaviors from negative emotionality and cognition, their interaction was statistically significant. Negative emotionality was associated with ADHD-related behaviors when infant cognition was at the extremes, either high or low cognitive performance. Interestingly, higher negative emotionality predicted more ADHD-related behaviors when cognition was high and lower negative emotionality predicted more ADHD-related behaviors when cognition was low. Thus, our findings suggest a potentially critical need to consider these variables jointly when studying their role in ADHD symptom development.

Regarding infants with high levels of cognition, they may be more explorative and seek independence in activities often limited at this age. Thus, coupled with a greater tendency to experience negative emotions, we speculate that high cognition infants may more often feel frustrated when their goals are blocked. This could lead to the heightened expression of dysregulated behaviors that include or mimic ADHD-symptoms (e.g., impulsivity). Concerning infants with low levels of cognition and low negative emotionality, our finding of higher ADHD symptoms may suggest a distinct ADHD-related pathway. Given the overall lower level of dysregulation in this group, at least emotionally, these infants may have elevated risk for the inattention (and not the impulsive) dimensions of ADHD. This pathway could also represent a precursor to sluggish cognitive tempo, a collection of symptoms characterized by confusion, day-dreaming, and slowed thinking or behavior, associated with some cases of ADHD predominately inattentive presentation (Becker & Barkley, 2018). These findings are consistent with research conducted with older children, in which differential ADHD symptom profiles have been found based on deficits in executive function vs. emotion regulation. For example, executive dysfunction has been shown to be associated with inattention, and emotion dysregulation has been associated with hyperactivity (Martel et al., 2008), supporting the possibility of multiple affective-cognitive pathways to the development of ADHD symptoms. Neuroimaging research identifying different patterns of brain development for children with ADHD and high vs low IQ as compared to typically developing peers also supports this possibility (De Zeeuw et al., 2012).

Findings from the current study have clinical implications. If replicated within larger and more representative samples, these results could help providers identify early risk factors to help inform the potential for the development of ADHD. Importantly, our findings of heightened ADHD-risk among infants with differing combinations of negative emotionality and cognition could lend greater specificity in the identification of those at risk for the development of ADHD. The presence of established early risk factors for ADHD could also help providers initiate early intervention services to help improve the cascade of negative outcomes associated with ADHD. Continued research on the interactions of emotion and cognition in predicting ADHD could also aide refinement of etiologic models for this enduring childhood disorder.

Strengths of this study include prospective data collection from infancy through toddlerhood, objectively measured infant cognition assessed by research-trained master's level clinicians, and use of a cohort at elevated familial likelihood for ADHD, with parent ADHD well-characterized in childhood and adulthood. Additionally, the temperament and cognition findings adjust for the potential contribution of early parent-child interactions. An important limitation of this study is that ADHD-related behaviors were measured in toddlerhood when some inattention, hyperactivity, and impulsivity is considered normative and before diagnosis of ADHD can be determined. Future work should follow children to school-age to assess the predictive value of the interaction of affective and cognitive regulation on childhood ADHD diagnostically. Additionally, infant temperament and toddler ADHD symptoms were measured using parent reports which may have resulted in some shared variance; future research should include more observational assessments of temperament or ADHD-related behaviors and/or teacher reports. These preliminary findings should be replicated in a larger and more diverse sample to fully understand its implications.

5. Conclusions

There may be two affective-cognitive pathways to ADHD-related behaviors in toddlerhood. The combinations of higher levels of

negative emotionality and cognition or low levels of negative emotionality and cognition in infancy each predicted ADHD-related behaviors in toddlerhood. This interaction suggestions that investigating both affective and cognitive processes will be important in better understanding early risk signals of ADHD.

CRediT authorship contribution statement

Heather Joseph: Conceptualization; Writing – original draft; Project administration; Funding acquisition; **Nicole Lorenzo:** Conceptualization; Formal analysis; Visualization; Writing – original draft; **Frances Wang:** Conceptualization; Writing – original draft; **Michelle Wilson:** Investigation; Visualization; Writing – original draft; **Brooke Molina:** Writing – review & editing; Supervision

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