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Special Issue Article

Early development of negative and positive affect: Implications for ADHD symptomatology across three birth cohorts

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Abstract

High levels of early emotionality (of either negative or positive valence) are hypothesized to be important precursors to early psychopathology, with attention-deficit/hyperactivity disorder (ADHD) a prime early target. The positive and negative affect domains are prime examples of Research Domain Criteria (RDoC) concepts that may enrich a multilevel mechanistic map of psychopathology risk. Utilizing both variable-centered and person-centered approaches, the current study examined whether levels and trajectories of infant negative and positive emotionality, considered either in isolation or together, predicted children's ADHD symptoms at 4 to 8 years of age. In variable-centered analyses, higher levels of infant negative affect (at as early as 3 months of age) were associated with childhood ADHD symptoms. Findings for positive affect failed to reach statistical threshold. Results from person-centered trajectory analyses suggest that additional information is gained by simultaneously considering the trajectories of positive and negative emotionality. Specifically, only when exhibiting moderate, stable or low levels of positive affect did negative affect and its trajectory relate to child ADHD symptoms. These findings add to a growing literature that suggests that infant negative emotionality is a promising early life marker of future ADHD risk and suggest secondarily that moderation by positive affectivity warrants more consideration.

Keywords: ADHD symptomatology, infant temperament, negative affect, positive affect, trajectory analysis

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Individual differences in emotionality (also called reactivity in a reactivity-regulation temperament model) emerge very early in development, can be reliably assessed in infants as young as three months of age, and are hypothesized to be transdiagnostic markers of risk for psychopathology (Cicchetti, Ackerman, & Izard, 1995; Frick, 2004; Gartstein & Rothbart, 2003; Nigg, 2006; Nigg, Goldsmith, & Sachek, 2004; Rothbart & Posner, 2006; Rothbart & Sheese, 2007; Rothbart, Posner, & Hershey, 1995; Stifter & Dollar, 2016; Whittle, Allen, Lubman, & Yücel, 2006). Bottom-up processes such as emotional reactivity, and top-down processes such as effortful control, promote the development of self-regulation in a dynamic manner with bidirectional influences during early development. The emergence of effective self-regulation is a process that may have an expectable range of emotionality with which to contend. When emotional reactivity is very strong, it may disrupt the consolidation of effortful control and associated self-regulation functions (Nigg, 2006; Nigg, Karalunas, et al., 2020; Rothbart et al., 1995).

Effortful control and related self-regulatory processes are crucial to adjustment, and weak effortful control is a hallmark feature of attention-deficit/hyperactivity disorder (ADHD) (where it is characterized as inattention, impulsivity, or later in development, as poor executive functioning). Further, although emotional

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reactivity is not part of the diagnostic criteria for ADHD, it is a widely recognized clinical feature that appears to be part of the syndrome (and, historically, has been recognized as such) (Nigg, Sibley, Thapar, & Karalunas, 2020; Shaw, Stringaris, Nigg, & Leibenluft, 2014). Thus, extremes of reactivity in early infancy are a hypothesized candidate to predict subsequent ADHD and related problems (Frick & Morris, 2004; Kostyrka-Allchorne, Wass, & Sonuga-Barke, 2020; Nigg, 2006; Nigg et al., 2004; Rothbart, 2011; Rothbart et al., 1995). To test that hypothesis, however, requires prospective studies from infancy into the early school age years when ADHD is typically first identified. Such studies have been few and thus the present study seeks to move toward filling that gap.

The above-described literature provides ample support for the inclusion of negative and positive valence systems as exemplar domains in the Research Domain Criteria (RDoC) framework (Cuthbert & Insel, 2013; Kozak & Cuthbert, 2016). Thus, an RDoC-based approach to studying ADHD can profit from consideration of the early emergence of temperamental reactivity in both positive and negative valence domains (Nigg, Sibley, et al., 2020). Although an association between infant emotionality and internalizing and externalizing symptomatology has been frequently hypothesized (Cicchetti et al., 1995; Frick & Morris, 2004; Rothbart & Posner, 2006; Stifter & Dollar, 2016) and has received some initial empirical support (e.g., Edwards & Hans, 2015; Morales et al., 2021), its association specifically with emerging ADHD symptomatology in children has been very little studied in prospective cohorts.

The core hypothesis guiding the present study is derived from those findings in addition to studies of ADHD in childhood. Children with ADHD were recalled by caregivers in one study to have displayed high levels of negative affect early in life (Gurevitz, Geva, Varon, & Leitner, 2014). Studies of children with family history of ADHD suggest that at-risk infants as young as 6 to 7 months old display more distress to limitation (a measure of anger/frustration) as well as fewer regulatory behaviors during a task intended to elicit fear or sadness (Auerbach, Atzaba-Poria, Berger, & Landau, 2004; Sullivan et al., 2015). As noted, prospective data relating infant temperament and child ADHD symptoms are limited. However, Willoughby, Gottfredson, Stifter, and Investigators (2017) utilized latent profile analysis (LPA) to summarize temperament data collected between 6 and 36 months of age. These authors report that infants who displayed increased fear and anger exhibited more ADHD symptoms when they were in the first grade.

Research examining the association between infant positive affect and ADHD is much more limited, with only two studies to our knowledge that have addressed this question. Frick, Forslund, and Brocki (2019) found that maternal report of higher positive affect in 10-month-old infants predicted more ADHD symptoms at 36 months of age (Frick et al., 2019). Miller and colleagues (Miller, Degnan, Hane, Fox, & Chronis-Tuscano, 2019) found that parent-rated positive emotionality at 4 months of age predicted more ADHD symptoms at 9 years – but only in girls who experienced less sensitive parenting. Interestingly, neither of these studies found a direct effect of negative emotionality on child ADHD symptoms, highlighting heterogeneity in existing study results. Consideration of relative levels, or balance between infant positive and negative affect, may help to reduce such conflicting findings, and has significant potential to lead to more comprehensive characterization of early emotion-related phenotypes that confer risk for development of ADHD symptoms.

Although individual rankings in temperament scores tend to exhibit stability over time (Pedlow, Sanson, Prior, & Oberklaid, 1993), within-individual development of temperament follows a characteristic course in the first year of life (Lemery, Goldsmith, Klinnert, & Mrazek, 1999; Stifter & Dollar, 2016). Previous research suggests that both negative (Braungart-Rieker, Hill-Soderlund, & Karrass, 2010; Gartstein et al., 2010; Gartstein, Hancock, & Iverson, 2018) and positive affect (Bridgett, Laake, Gartstein, & Dorn, 2013; Gartstein et al., 2018; Sallquist et al., 2010) normatively increase across the first year of the child's life. However, positive and negative valence domains are not unitary; rather, for many purposes a more granular, trait-level analysis (e.g., fear, anger/frustration) may be helpful for capturing psychopathology risk (Stifter & Dollar, 2016). Individual dimensions of affectivity, which have been shown to differentiate early infancy (Sroufe, 1997), show unique patterns of change across the first year of life (Gartstein & Hancock, 2019) that are presumed to be related to differential maturation of their underlying neural mechanisms (Thomas et al., 2019; Whittle et al., 2006).

Although individual differences in the development of negative and positive affect over the first year of life have been noted and have been related to other symptoms of psychopathology (e.g., internalizing and externalizing symptoms in toddlerhood (Giesbrecht, Letourneau, Dewey, & the APrON Study Team, 2020), they have not yet been applied to the study of ADHD. Consideration of these trajectories may be important. While prior studies have looked at a single early time point in infancy in relation to later ADHD symptoms, little work has been done to explore how early trajectory variation may set the stage for later ADHD symptomatology. In addition, little attention has been paid to trajectories of positive and negative emotionality in the context of one another, particularly as they may be related to ADHD symptoms.

These gaps in our knowledge lead to the following two research questions: (a) Does considering both the level and trajectory of infant emotionality provide unique information about ADHD symptomatology, or is a static assessment early in infancy sufficient for signaling risk? One possibility is that the answer varies by valence domain. (b) Does considering the developmental course of negative and positive affect together provide additional information about ADHD symptomatology than can be gained by examining the trajectory of either positive or negative emotion traits in isolation?

We consider here both variable-centered and person-centered statistical approaches. Variable-centered approaches report information about average levels of change over time, which can be used to predict factors such as emerging ADHD symptomatology. However, variable-centered approaches can obscure important individual differences in developmental course that can be more readily identified using a person-centered statistical approach (Magnusson, 2003). Person-centered approaches have the advantage of allowing for the identification of subgroups of individuals who differ in their initial level and pattern of change over time. These models can also consider multiple trajectories in a single model to examine heterogeneity in both. The resultant subgroups can then be compared to one another on ADHD symptoms. Looking at both variable- and person-centered perspectives in the same study provides the most comprehensive characterization of the development of negative and positive affect in relation to ADHD risk. Following previous reports, we included measures of infant sadness, fear, and distress to limitation (dimensions of negative affect) as well as smiling/laughter and high-intensity pleasure (dimensions of positive affect) to provide a more fine-grained perspective on the early development of infant emotionality.

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An ongoing and important issue for the field of developmental psychopathology surrounds the issue of replication (Amir & Sharon, 1990; Francis, 2012; Shrout & Rodgers, 2018). Our primary analyses relied on pooled data from participants recruited from Oregon and California (primary analysis). We attempted to replicate the key results in a large Finnish population cohort (replication analysis).

Primary Analysis: Method

Participants

The participants in the primary analysis were 191 children that were pooled from two prospective studies of offspring of women recruited in the first or second trimester of pregnancy whose offspring were followed at regular intervals until 4–8 years of age. The first cohort came from a sample in Oregon ($n = 57$) (Gustafsson et al., 2020). Exclusion criteria included high-risk or medically complicated pregnancy, extreme life circumstances (specifically, homelessness), active substance use (i.e., alcohol, tobacco, marijuana, opioids), and being less than 18 years old. In order to maximize the variation in infant temperamental reactivity and regulation in early life in this sample, an effort was made to over-select women with a family or personal history of ADHD or elevated symptoms of ADHD, as defined by the mother or father carrying a current or childhood diagnosis of ADHD or by the mother scoring ≥80th percentile on the Barkley Adult ADHD Rating Scale-IV (BAARS-IV) Quick Screen (Barkley, 2011) at enrollment. All procedures were approved by the Institutional Review Board at Oregon Health & Science University. Participants who at the time of these analyses had completed at least one infant temperament assessment ($n = 57$) were included in this analysis. A subsample of these children ($n = 33$) were assessed for ADHD symptoms at 6 years of age. The second cohort was recruited in California ($n = 134$) (Graham et al., 2018). Exclusionary criteria for infants were birth before 34 weeks' gestation, and evidence of a congenital, genetic or neurologic disorder. Participants who at the time of these analyses had completed at least one infant temperament assessment were included. A subsample of these children ($n = 79$) were assessed for ADHD symptoms at 4 to 8 years of age. All procedures were approved by the Institutional Review Board at the University of California, Irvine.

Measures

Infant temperament

Infant negative and positive affect were assessed using the revised Infant Behavior Questionnaire (IBQ-R) (Gartstein & Rothbart, 2003) which was administered in the Oregon study at 3, 6, and 12 months of age and in the California sample at 3, 6, 9, and 12 months of age. The current analyses utilized the *fear*, *distress to limitation*, and *sadness* subscales as measures of negative affect. We used the *smiling/laughing* and *high-intensity pleasure* subscales as measures of positive affect. These dimensions were selected based on previous literature implicating them in the emergence of ADHD symptomatology.

Child ADHD dimension

When children were approximately 6 years old (*mean age* = 6.12 years, $SD = .13$; range = 5.97–6.35) for the Oregon sample and between 4 and 8 years old for the California sample (*mean age* = 6.92 years, $SD = 1.07$; range = 4.73–8.56), mothers completed the Strengths and Difficulties Questionnaire (SDQ; $n = 33$ Oregon sample, $n = 79$ California sample) (Goodman, 2001). The hyperactivity/inattention subscale (hereafter, SDQ hyperactivity) was used in the current analyses as a proxy for level of ADHD dimensional symptomatology. Twenty-four percent of the Oregon sample had SDQ hyperactivity at or above the clinical cut point (8 or above) (Silva, Osório, & Loureiro, 2015), as compared to 8% of the California sample, $\chi^2 = 4.34$, $p = .04$.

Covariates

Mothers reported on their current depressive symptoms using the Center for Epidemiological Studies Depression Scale (CES-D) (Radloff, 1977). CES-D scores were collected at the time of the 6- and 12-month assessments in the Oregon sample and at 3-, 6-, and 12-month assessments in the California sample. These scores were averaged to capture maternal depressive symptoms across the child's first year of life and were controlled for in analyses predicting SDQ hyperactivity as a way to account for possible effects of maternal mood on reports of infant temperament. Child age at the time of the ADHD assessment (in years) and child sex (0 = *female*, 1 = *male*) were also included as covariates, given potential sex differences in ADHD symptom severity (Arnett, Pennington, Willcutt, DeFries, & Olson, 2015).

Analytic strategy

Combining the cohorts

The decision to combine the Oregon and California samples was made to increase sample size and statistical power, and to capture a wider range of symptoms and ADHD risk. Unsurprisingly, the cohorts differed on the child SDQ hyperactivity (Oregon *mean* = 4.34, $SD = 3.20$, California *mean* = 3.08, $SD = 2.61$; $t = 2.10$, $p = .04$) and on IBQ high-intensity pleasure at 3 months; sadness at 6 months, and fear and smiling at 6 and 12 months (all $p < .05$). However, the correlations among the IBQ-R subscales, and between the IBQ-R subscales and child SDQ hyperactivity scores, were grossly similar across the two cohorts. Though these comparisons support the decision to combine the datasets, the data collection site was controlled for in all analyses predicting child SDQ hyperactivity scores to account for potential variability in findings attributable to site.

Research question 1: Relating baseline and change in emotionality to ADHD symptoms

The average trajectories of each dimension of negative and positive affect were modeled using latent curve modeling (LCM) (Bollen & Curran, 2006), a variable-centered statistical technique. Unconditional models were first estimated to establish the functional form of each trajectory; each IBQ-R subscale (i.e., distress to limitation, fear, sadness; smiling/laughter, high-intensity pleasure) was considered in its own model due to prior evidence that these dimensions may have distinct neural underpinnings and implications for subsequent mental health risk (Nigg, 2006; Thomas et al., 2019; Whittle et al., 2006). Both linear and quadratic effects were tested. Models were estimated using Mplus 8.5 (Muthén & Muthén, 1998-2017) with the robust maximum likelihood estimator. Full information maximum likelihood (Allison, 2003) was used to handle missing data. Model fit was evaluated using the comparative fit index (CFI), Tucker–Lewis index (TLI), and the root mean square error of approximation (RMSEA). CFI and TLI values above .90 and RMSEA values

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below .08 indicate adequate model fit (Browne & Cudeck, 1993; Hu & Bentler, 1999). To test associations between each IBQ dimension and child SDQ hyperactivity scores, a series of conditional LCMs were estimated (one for each dimension of affect), where the SDQ hyperactivity score was regressed on the intercept and slope of the IBQ scale, as well as on child sex, age at the SDQ assessment, data collection site, and maternal depressive symptoms during infancy.

To test whether there were subgroups of individuals who differed in their initial levels of and/or their slope of each IBQ dimension, we used latent class growth analysis (LCGA) (Jung & Wickrama, 2008), a person-centered statistical technique. Again, separate LCGAs were estimated for each IBQ dimension. To determine the best class-solution, Bayesian information criteria (BIC) values and the results of Vuong–Lo–Mendell–Rubin likelihood ratio tests (VLMR LRT) for the k-class versus $k-1$ class model were examined. The best class solution is generally one that has a lower BIC value, paired with a significant VLMR LRT, and where all resulting classes contain at least 5% of the sample (Asparouhov & Muthén, 2012; Jung & Wickrama, 2008). One- through five-class unconditional LCGA models were fit to the data. After the best-class solution was selected, the resulting classes were compared to one another on their average child SDQ hyperactivity scores using Mplus. Dummy coded variables that contrasted the various classes were created and the SDQ hyperactivity score was regressed on these dummy coded variables in a series of multiple regressions that also controlled for child sex, age, maternal depressive symptoms, and data collection site. This approach was selected over comparing these classes using an analysis of covariance (ANCOVA), despite their conceptual similarity, because it allowed us to account for missing data and therefore yielded model results that more closely parallel the LCM results.

Research question 2: Evaluating joint contribution of components of positive and negative affect and their trajectories

The second research question was also tested using LCGA. Six LCGAs were estimated. In each model, two trajectories were considered, one for a single dimension of negative affect (distress to limitation, fear, *or* sadness) and one for a single dimension of positive affect (smiling/laughter *or* high-intensity pleasure); the six models corresponded to the six combinations of these variables (e.g., fear and smiling/laughter; sadness and high-intensity pleasure). Resultant classes were compared to one another on child SDQ hyperactivity (controlling for child sex, age, maternal depressive symptoms, and data collection site), as above.

Primary analysis: Results

Sample description

Sample demographics and average SDQ scores appear in Table 1. Mean levels of IBQ-R scores at each assessment time point appear in Table 2.

Research question 1: Trajectories of infant negative or positive affect

LCMs (variable-centered analyses)

The parameters and results from the LCMs that examined the trajectory of the individual subscales of infant affect are described in detail in Online Supplement A and are depicted in Figure 1. On average, each dimension of affect increased significantly across the first year of the child's life, though the shape of the trajectory varied across individual dimensions of affect. Specifically, a linear model appeared to characterize distress to limitation and sadness trajectories best, while a model that included both a linear and a quadratic slope term best characterized fear, smiling/laughter, and high-intensity pleasure. In the case of the nonlinear trajectories, there was an increase in each construct over time, but this rate of change appeared to slow toward the end of the first year of life.

The intercept (B = 1.44, $p = .01$) but not slope ($p = .87$) of sadness predicted greater SDQ hyperactivity scores, controlling for child sex, age, maternal depressive symptoms, and data collection site. Neither the intercept nor the slope of the other dimensions of affect were associated with SDQ hyperactivity scores ($ps > .28$).

LCGAs (person-centered analyses)

Results from the LCGAs that considered one dimension of affect at a time suggest that for some, but not all, dimensions of affect

Table 1. Sample demographics

Variable	Oregon Mean (*SD*)	California Mean (*SD*)	Finland Mean (*SD*)
Maternal age	31.13 (4.81)	27.72	31.10 (4.20)
Child sex (% female)	39%	45%	55%
Child age at SDQ assessment	6.12 (0.12)	6.92 (1.07)	4.21 (.20)
Maternal race (% White)	80%	78%	99.90%
SDQ hyperactivity score	4.65 (3.14)	2.99 (2.61)	3.22 (2.33)

Note: SDQ = Strengths and Difficulties Questionnaire.

Table 2. Mean Infant Behavior Questionnaire (IBQ-R) scores for the US and Finnish samples

	US cohort (primary analysis)				Finnish cohort (replication analysis)	
	3M	6M	9M	12M	6M	12M
Distress to limitation						
Mean	3.49	3.70	3.98	4.19	3.35	3.83
SD	.90	.91	.95	.90	1.01	.98
Fear						
Mean	2.26	2.80	3.14	3.28	2.51	2.97
SD	.87	1.06	1.10	1.04	1.16	1.20
Sadness						
Mean	3.27	3.60	3.56	3.63	3.43	3.61
SD	1.01	1.00	1.01	.99	1.10	1.04
Smiling/Laughter						
Mean	4.72	5.23	5.47	5.34	4.32	4.82
SD	1.18	1.08	1.01	.80	1.19	.96
High-intensity pleasure						
Mean	5.40	6.09	6.33	6.20	5.99	6.28
SD	1.04	.66	.64	.64	.84	.66

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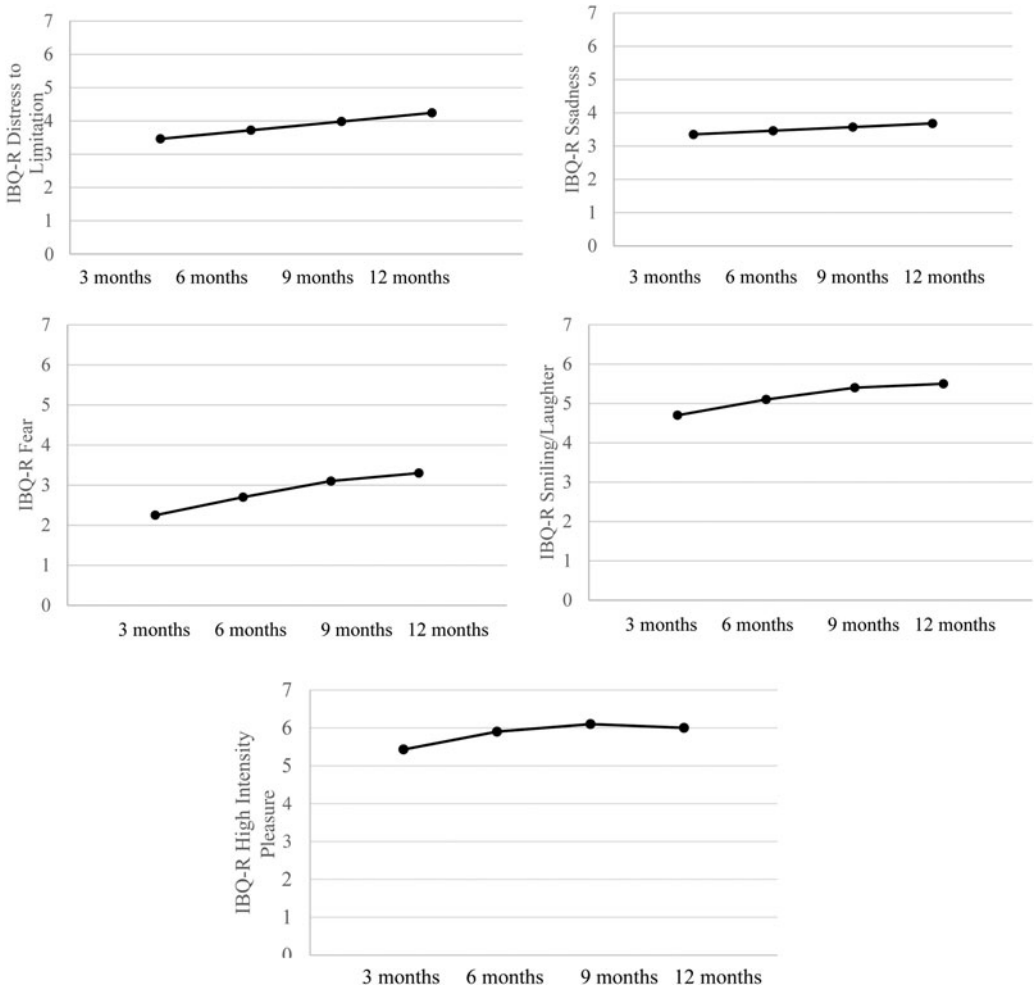

Figure 1. Primary analysis, research question 1: Visual depiction of the model-implied average trajectories from the latent curve models.
Note: IBQ-R = revised Infant Behavior Questionnaire.

there were meaningful subgroups of infants who differed from one another in their overall level and slopes. Detailed description of the results of these models appear in Online Supplement A and LCGA model fit statistics appear in Supplemental Table S1. Specifically, fear was best characterized by three classes ("low, stable," "low increasing," and "high, stable"), sadness by two classes ("high, stable" and "lower, increasing") and smiling/laughter by three classes ("low, stable," "moderate, increasing," and "high, increasing"). These results are depicted in Figure 2. The models that considered distress to limitations and high-intensity pleasure did not yield meaningful subgroups.

The presence of these subgroups suggests that there is meaningful variability in individual level and trajectory of these dimensions of infant emotionality. However, these classes did not differ in terms of their average SDQ hyperactivity scores (*p*s > .35; means are presented by class in Supplemental Table S3), suggesting that the rate of change in a single dimension of affect does not provide meaningful additional information about emergent ADHD risk.

Research question 2: LCGAs that considered both positive and negative affect

LCGAs (person-centered analyses)

The LCGAs that considered different combinations of positive and negative affect trajectories also suggested that there were meaningful subgroups in some, but not all models. The LCGA that considered distress to limitation with smiling/laughter and the LCGA that included sadness with smiling/laughter both yielded four-class solutions, whereas the LCGA that included fear with smiling/laughter and the LCGA with sadness and high-intensity pleasure yielded 2-Class solutions. The distress to limitation with high-intensity pleasure and fear with high-intensity pleasure models did not produce meaningful subgroups. See Online Supplement B for full details related to these analyses, Supplemental Table S2 for fit statistics and Supplemental Figures S2–S4 for a depiction of the resultant classes. Mean SDQ hyperactivity scores for each class are presented in Table 3.

Subgroup differences in SDQ hyperactivity scores

Interesting differences in SDQ hyperactivity scores emerged between the classes capturing different combinations of distress to limitation and smiling/laughter, which yielded a four-class solution (see Figure 3): Class 1 (41%; $n = 78$) "moderate, increasing distress/high, increasing smiling"; Class 2 (17%; $n = 33$) "high, increasing distress/moderate, stable smiling"; Class 3 (12%; $n = 23$) "low, increasing distress/high, increasing smiling"; and Class 4 (30%; $n = 57$) "moderate, increasing distress/moderate, stable smiling"). Specifically, Class 4 ("moderate, increasing distress/moderate, stable smiling") had significantly lower SDQ hyperactivity

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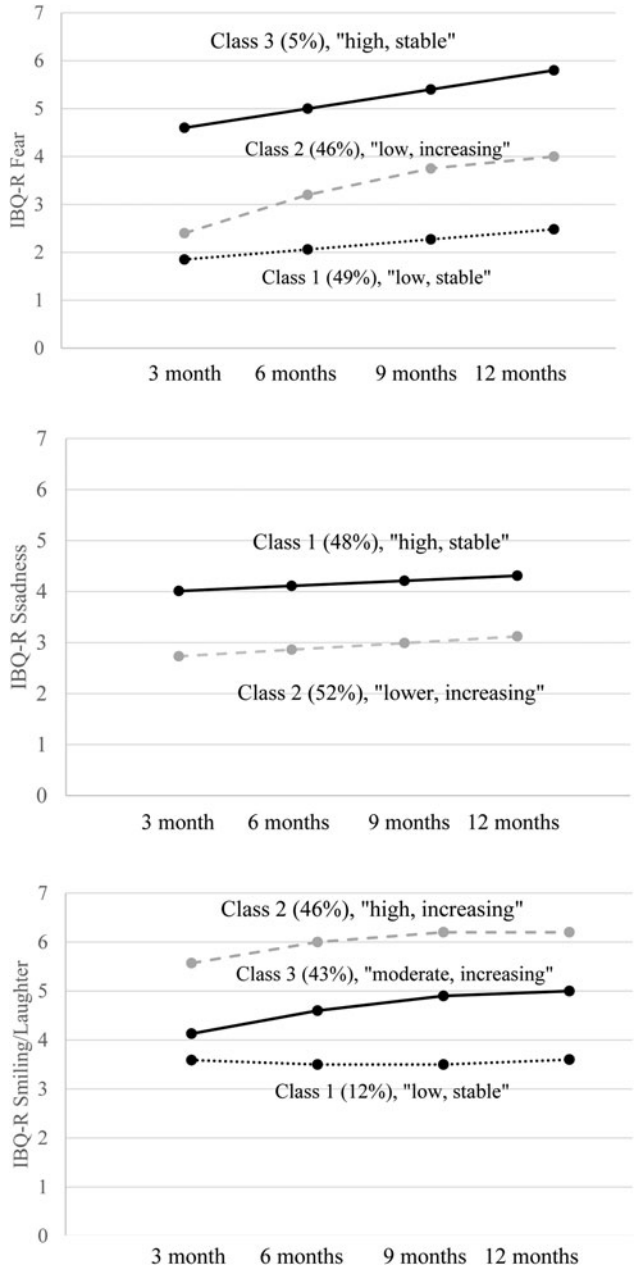

Figure 2. Primary analysis, research question 1: Depiction of results of latent class growth analyses that considered a single dimension of affect.
Note: IBQ-R = revised Infant Behavior Questionnaire.

scores than Class 2 (17%) ("high, increasing distress/moderate, stable smiling") (B = −1.67, p = .027), controlling for age, sex, site, and maternal depressive symptoms. None of the other classes differed from one another in terms of ADHD symptoms, ps > .28.

Summary of primary analysis

Results from our primary analyses suggest that the individual dimensions of negative and positive emotionality show different patterns of change over the first year of life, a finding that supports our decision to consider these dimensions individually. This conclusion is based on observed differences in the intercept and/or slope of these dimensions, differences in the shape of the trajectories (linear vs. quadratic), as well as differences in the subgroups produced using LCGA. The intercept (3-month assessment), but not slope, of sadness predicted greater SDQ hyperactivity scores in middle childhood, suggesting rate of change in a single dimension of affect does not provide meaningful additional information about emergent ADHD risk in this sample. If replicated, this result may suggest that even a single assessment of emotionality, obtained during the first months of life, may be helpful for identifying at-risk children.

Results also suggest that there were subgroups of individuals who differed in their intercept and/or slope of both negative and positive emotionality. Of note, there were four classes of infants who differed in terms of their distress to limitation and smiling/laughter. Two of these groups (one whose distress to limitation was higher than their smiling/laughter, and the other who exhibited moderate, increasing distress and moderate smiling/laughter) differed on their average SDQ hyperactivity scores, suggesting that additional information is gained by considering both positive and negative affect in the same model.

Based on these results, and in an effort to address issues of nonreplicability in psychological research, we aimed to test similar research questions using data from a replication sample. Specifically, we looked to see if both level and trajectory of individual dimensions of affect were associated with emerging ADHD symptoms. To most comprehensively characterize associations between early affect and child ADHD symptomatology, the decision was made to examine both overall level and change in each dimension of affect as they may relate to child symptomatology rather than focusing only on the sadness–ADHD association observed in the primary analyses (i.e., analyses were conducted "blind" to the results of the primary analysis). To replicate our second set of findings, we also examined whether there were subgroups of individuals who showed different patterns of distress to limitation and smiling/laughter, and if so, whether they differed on SDQ hyperactivity scores.

Replication Analysis: Method

Participants

The replication sample is part of a longitudinal FinnBrain Birth Cohort Study that researches environmental and genetic influences on child brain and behavioral development (Karlsson et al., 2018). Pregnant women were recruited to the study after their participation in an ultrasound at gestational week 12. The inclusion criteria were a verified pregnancy and knowledge of Finnish and/or Swedish, the official languages in Finland. The parents gave their own consent and consented on behalf of their child. All procedures were approved by the Ethics Committee of the Hospital District of Southwest Finland. Participants included in the current study (n = 1,032) were selected based on the available assessment of infant temperament at both 6 and 12 months and child ADHD symptom assessment at 5 years of age. Children with known congenital central nervous system or major health conditions diagnosed in infancy were excluded.

Measures

Infant temperament was assessed using the IBQ-R at 6 and 12 months of child age. ADHD symptoms were assessed using the SDQ hyperactivity subscale at 5 years (mean age = 5.21 years, SD = .20, range = 4.69–6.01 years). Child sex and age at the SDQ assessment as well as maternal depressive symptoms were

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Table 3. Primary analysis, research question 2: Raw attention-deficit/hyperactivity disorder (ADHD) symptom means presented by subgroup for latent class growth analysis that considered both positive and negative affect

	Distress to limitation & smiling/laughter		Fear & smiling/laughter		Sadness & smiling/ laughter		Sadness & high-intensity pleasure	
	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*
Class 1	3.24	2.32	3.27	2.89	3.05	2.68	3.85	3.31
Class 2	4.84	3.61	3.54	2.81	3.7	2.79	3.14	2.49
Class 3	3.56	2.94	–	–	3.03	2.52	–	–
Class 4	2.66	2.54	–	–	5.08	3.75	–	–

Note: SDQ = Strengths and Difficulties Questionnaire.

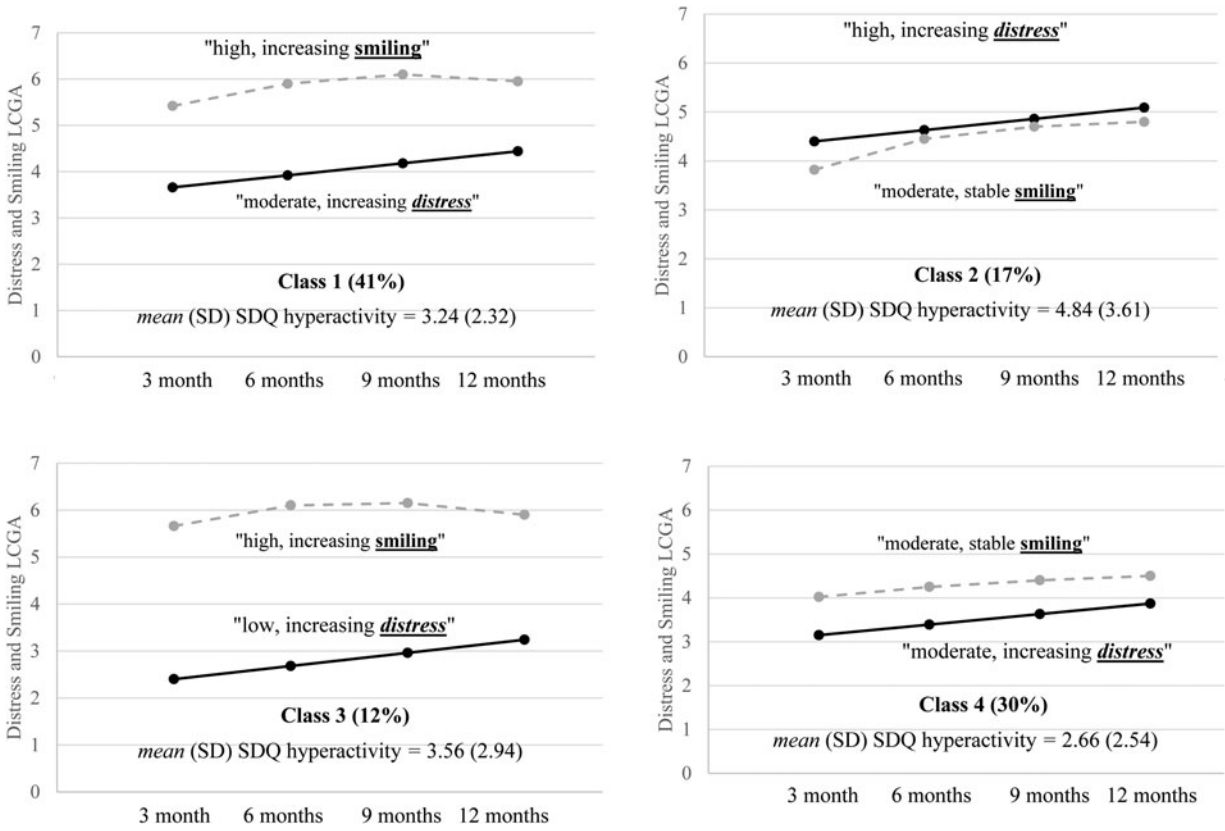

Figure 3. Primary analysis, research question 2: Depiction of results of latent class growth analysis considering both distress to limitation and smiling/laughter (four-class solution). *Note:* LCGA = latent class growth analysis. SDQ hyperactivity = Strengths and Difficulties Questionnaire, hyperactivity/inattention subscale. *SD* = standard deviation. Distress = distress to limitation subscale of the revised Infant Behavior Questionnaire (IBQ-R) (Gartstein & Rothbart, 2003) smiling = smiling/laughter subscale of the IBQ-R. Means and *SD*s presented here are raw means (unadjusted for covariates).

considered as covariates. Maternal depressive symptoms at 6 and 12 months were assessed using the Edinburgh Postnatal Depression Scale (EPDS) (Cox, Holden and Sagovsky, 1987) at 6 and 12 months. Scores on the EPDS were averaged, as was done for the primary analyses. Infant gestational age at birth (weeks) was also included as a covariate, given known variation in this cohort (33–42 gestational weeks).

Analytic strategy

Because the study used for the replication analyses did not collect at least three assessments of temperament in the first year of life (which is required to model trajectories), LCM could not be conducted. Instead, change scores that capture the change in that dimension from 6 to 12 months were calculated for each construct. Both the baseline measure of each trait at 6 months and the change score (controlling for the baseline of each trait) were then entered into a general linear model predicting SDQ hyperactivity scores. Child sex, age at the SDQ assessment, maternal depressive symptoms, and gestational age at delivery were included as covariates in these models. Each dimension of affect (distress to limitation, fear, sadness, smiling/laughter, and high-intensity pleasure) was considered in a separate model, with multiple comparisons corrected using Bonferroni adjustment. To impute the missing data in the covariates (mainly age at SDQ assessment), Markov

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chain Monte Carlo (MCMC) multiple imputation with 10 datasets was used, with virtually no change in the results when compared to nonimputed data.

To replicate the results addressing research question 2 in the primary analysis, and specifically the finding that considering both distress to limitation and smiling/laughter trajectories in the same model may help in the prediction of child ADHD symptoms, a latent class analysis (LCA) (Lanza & Cooper, 2016) including distress to limitation and smiling/laughter at 6- and 12-month time points was conducted. The models were estimated using Mplus 8.1 (Muthén & Muthén, 1998–2017) using the robust maximum likelihood estimator. The latent class analysis classes were examined based on the same indices as in the primary analysis (BIC and VLMR LRT). Finally, child SDQ hyperactivity scores at 5 years were regressed on dummy coded variables that captured the various contrasts between the classes, controlling for the same factors as the models described above. The class sizes and means are reported from the unconditional models, although the classes remained highly similar in the models with predictors.

Replication Analysis: Results

Sample description

Sample characteristics are displayed in Table 1. Mean levels of IBQ-R scores at each assessment time point appear in Table 2. Fifty-nine (5.7%) children in the sample scored at or above 8 on the SDQ hyperactivity. As was observed in the primary analyses, children on averaged increased in each dimension of negative and positive emotionality between 6 and 12 months of age ($ps < .001$).

Research question 1: Relating baseline and change in emotionality to ADHD symptoms

Regression models (variable-centered analysis)

Results from the regression models that related baseline and change in emotionality to SDQ hyperactivity scores at age 5 years are displayed in Table 4. There was a significant positive association between distress to limitation and sadness at 6 months and SDQ hyperactivity scores at 5 years, even after controlling for child sex, age, maternal depressive symptoms, and gestational age at birth. Infant smiling/laughter at 6 months was negatively associated with ADHD symptoms. However, when the change scores were examined, only the increase in distress to limitation from 6 to 12 months positively predicted SDQ hyperactivity scores when controlled for the baseline and the covariates ($p = .009$). In this model, the 6-month score was also associated with child SDQ hyperactivity scores ($p < .001$) which suggests that both level and change are important here.

Research question 2: LPAs that considered both distress to limitation and smiling/laughter

LPAs (person-centered analyses)

Fit statistics associated with the LPAs are presented in Table 5. The LPA suggested a four-class solution (see Figure 4 for a depiction of these classes). In Class 1 (29%; $n = 295$), "moderate, increasing distress/moderate, stable smiling," distress to limitation at 6 months was moderate (intercept = 4.09) and increased to 12 months (intercept = 4.52) and smiling was moderate (intercept = 4.67) and only slightly increased to 12 months (intercept = 5.13). In Class 2 (17%; $n = 173$) "moderate, increasing distress/low, increasing smiling," where distress to limitation was moderate (intercept = 3.68) and increased to 12 months (intercept = 4.28), and 6-month smiling/laughter was low (intercept = 2.92) and increased to 12 months (intercept = 3.68). In Class 3 (35%; $n = 365$) "low, increasing distress/moderate, increasing smiling," distress to limitation at 6 months was low (intercept = 2.88) and increased to 12 months (intercept = 3.35), and smiling/laughter was moderate (intercept at 6 months = 4.01) and increased to 12 months (intercept = 4.59). Finally, in Class 4 (19%; $n = 199$) "low, increasing distress/high, stable smiling" distress to limitation at 6 months was low (intercept = 2.72) and increased to 12 months (intercept = 3.22), and the smiling/laughter was high at 6 months (intercept = 5.67) and remained stable (intercept at 12 months = 5.82).

Similar to the primary analysis, the class that showed higher distress than smiling (Class 2) had significantly higher SDQ hyperactivity scores than Class 4 (B = .18, $p = .022$). Class 1 also had significantly higher SDQ hyperactivity scores than Class 4 (B = .21, $p = .002$). The other class comparisons were not significant ($ps > .06$).

Summary of replication analysis

Consistent with previous research and the results of the primary analyses, the replication analysis found that, on average (variable-centered analysis), there was a significant increase in all dimensions of affect over the first year of life. Similar to the primary analysis, the replication analysis found that early negative emotionality was predictive of emerging ADHD symptomatology. However, the specific dimensions of negative affect were different (distress to limitation vs. sadness), and in the replication study, both the baseline (6 months) and the change (from 6 to 12 months) in negative affect were related to greater ADHD symptoms at 5 years. Though the results of the primary analysis were not replicated in this case, these results are broadly consistent with the primary analysis conclusion that early life measures of negative emotionality may be helpful for identifying at-risk children.

Results from the (person-centered) LPAs more closely replicated the findings of the primary analysis and confirm the utility of considering both positive and negative emotionality in the same model. Several parallels between these results and those of the primary analysis were observed. First, both sets of analyses resulted in a four-class solution, and the resultant classes captured different combinations of positive and negative affect. In both sets of models, two classes exhibited stable or relatively stable positive affect, whereas the other two classes showed growth in smiling/laughter. As was true for the results of the primary analysis, child distress to limitations increased in each class, but initial levels varied across classes. In addition, in both sets of analyses, there was one class that showed a unique pattern of higher levels of distress than smiling/laughter. Most importantly, both the primary and replication analyses found that these groups differed from one another on their average SDQ hyperactivity scores, suggesting that important information is gained by considering both positive and negative affect in the same model.

Discussion

Dysregulation of both positive and negative emotionality has been hypothesized to be a route to ADHD and other disorders (Nigg,

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Table 4. Replication analysis: The general linear model for the baseline of infant emotional reactivity at 6-months and the change of emotional reactivity from 6 to 12 months of age and Strengths and Difficulties Questionnaire (SDQ) hyperactivity/inattention symptoms at 60 months (n = 1,039)

	Model 1		Model 2 (adjusted)[a]		
	B (*SE*)	*p*	B(*SE*)	*p*	$n^2_{partial}$
Step 1: Baseline					
Distress	.31 (.07)	<.001	.22 (.07)	.003	.01
Fear	−.10 (.06)	.114	−.06 (.06)	.308	
Sadness	.25 (.07)	.001	.16 (.07)	.017	.01
Smiling/laughter	−.16 (.06)	.008	−.12 (.06)	.042	.01
High-intensity pleasure	−.09 (.09)	.332	−.07 (.09)	.400	
Step 2: Change					
$Distress_{baseline}$	.44 (.08)	<.001	.34 (.08)	<.001	.02
$Distress_{change}$	.26 (.08)	.002	.22 (.08)	.009	.01
$Fear_{baseline}$	−.12 (.07)	.096	−.08 (.07)	.279	
$Fear_{change}$	−.04 (.07)	.519	−.03 (.07)	.667	
$Sadness_{baseline}$	.25 (.08)	<.001	.18 (.08)	.026	.01
$Sadness_{change}$	.06 (.08)	.445	.03 (.08)	.677	
$Smiling_{baseline}$	−.15 (.08)	.052	−.10 (.08)	.182	
$Smiling_{change}$	−.01 (.10)	.893	.03 (.09)	.733	
High-intensity $pleasure_{baseline}$	−.19 (.12)	.105	−.21 (.12)	.073	.004
High-intensity $pleasure_{change}$	−.23 (.12)	.062	−.21 (.12)	.075	.004

Note: [a]adjusted for child sex, gestational age, maternal Edinburgh Postnatal Depression Scale (EPDS) (averaged from 6- and 12-month time points) and child age at the ADHD symptom assessment. Higher change scores reflect more positive change in the temperament trait in question.

Table 5. Replication analysis: Fit statistics for the latent class analysis including distress to limitations and smiling/laughter at 6 and 12 months

	BIC	VLMR LRT
1-Class	111896.77	–
2-Class	11611.907	<.0001
3-Class	11506.021	.0156
4-Class	**11435.918**	**.0176**
5-Class	11425.714	.0629

Note: BIC = Bayesian information criterion, VLMR LRT = Vuong–Lo–Mendell–Rubin likelihood ratio test for the *k* versus *k*−1 class solution. The bolded values describe the class solution best supported by the fit statistics.

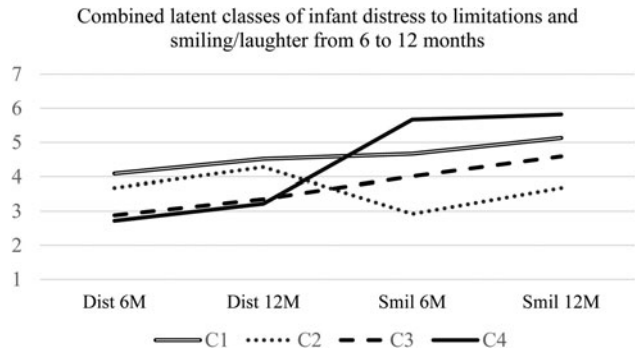

Figure 4. Replication analysis: Depiction of results of latent profile analysis considering both distress to limitation and smiling/laughter at 6 and 12 months of Age. Note: C1 (29%) = "moderate, increasing distress/moderate, stable smiling," C2 (17%) = "moderate, increasing distress/low, increasing smiling," C3 (35%) = "low, increasing distress/moderate, increasing smiling," and C4 (19%) = "low, increasing distress/high, stable smiling."

2006; Nigg et al., 2004; Nigg, Karalunas, et al., 2020). The present study partially supports that hypothesis and provides relatively novel information by prospectively examining these associations from infancy to early childhood and by confirming results in an international sample. Utilizing both variable-centered and person-centered approaches to analyzing longitudinal infant temperament data, the goal of the current study was to examine whether trajectories of infant negative and positive temperament traits (which evaluate emotionality), considered either in isolation or together, were associated with children's ADHD symptoms in middle childhood as estimated by the SDQ hyperactivity scale. Two important findings emerged that provided partial support for our hypotheses.

Our first research question centered on whether the level and/or trajectory of infant emotionality provided unique information about risk for ADHD symptomatology. Results from variable-centered analyses suggest that overall level of negative emotionality, but not rate of change across the first year, signaled risk for ADHD. Specifically, infant sadness at 3 months of age predicted SDQ hyperactivity scores at 4 to 8 years of age, but the rate of change (in this and the other dimensions of emotionality) was not related to ADHD symptoms when each dimension was considered in a trajectory model by itself. Contrary to our hypothesis, infant positive emotionality was not associated with ADHD symptoms in our primary analyses and was negatively associated with ADHD

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symptoms in our replication cohort. Aside from the possibility that the primary sample was too small to detect positive emotion effects, it is also possible that the meaning of positive emotions in infancy is somewhat different than later in life, or that low positive affect signals later behavior problems. However, given lack of replication these surmises require further evaluation.

The person-centered analysis that considered each dimension of emotionality separately also was consistent with the notion that overall level of emotionality was more predictive of ADHD symptoms than trajectories were. We make this statement based on the fact that the individual subgroups, many of whom differed in terms of slope, did not differ from one another on SDQ hyperactivity scores. This finding did not replicate (in the Finnish cohort both baseline and the change in distress to limitation was related to greater ADHD symptoms at 5 years of age). Perhaps lower power was a factor in the US sample. While these two samples converged on the idea that early negative affect may be an important marker of risk, caution is needed in interpreting these results, particularly in light of the nonreplication. Additional caution is needed in interpreting the lack of slope findings in our primary analyses, due to this study's observation that there was limited variability in individual trajectories of child temperament in this sample (as indicated by a nonsignificant slope variance in some models), which may have limited our ability to detect such effects.

Our second research question centered on whether considering the developmental course of negative and positive affect together provided additional information about ADHD symptomatology than was gained by examining the trajectory of either positive or negative emotion traits in isolation. Across several person-centered trajectory models (which considered different combinations of the various dimensions of emotionality) we found that there were subgroups of individuals who differed from one another in the intercept and/or slope of both positive and negative affect. Of note, in the case of the model that considered both distress to limitation and smiling/laughter, we were able to identify subgroups who differed significantly from one another on their ADHD symptoms. In the original sample, the "high, increasing distress/moderate, stable smiling" class exhibited significantly more ADHD symptoms than the "moderate, increasing distress/moderate, stable smiling" groups; the two classes characterized by high, increasing smiling (and varying levels of distress) had average ADHD scores that were between the means for these two classes. In the replication sample, the classes with "moderate, increasing distress/moderate, stable smiling" and "moderate, increasing distress/low, increasing smiling" exhibited greater ADHD symptoms than the group with "moderate, increasing distress/high, stable smiling." This pattern suggests that, only when exhibiting moderate, stable or low levels of positive affect (vs. high, increasing levels), does negative affect and its trajectory appear to be related to child ADHD symptoms. Further, the pattern of having higher distress than smiling also appears to predispose children to ADHD symptoms. Though the most marked difference between the classes in our analyses appears to be the infant's distress to limitation, these ADHD differences only emerged in the models that considered both positive and negative affect (and are only apparent under conditions of moderate, stable smiling *or* higher distress than smiling). Thus, these findings support the hypothesis that considering both positive and negative affect is important for determining ADHD risk. These results do not provide direct support for our hypothesis that high levels of positive affect signal risk for ADHD.

Replication is a prevailing issue in developmental psychopathology where replications of findings are rarely attempted or reported. To address this, we utilized data from a large cohort of children living in Finland to replicate a portion of the findings (replication analysis). The sample core measures (the IBQ-R for infant temperament and the SDQ for ADHD symptoms) were used across studies, though the timing and frequency of the measurement of temperament (6 and 12 months) and ADHD (5 years) in this study were slightly different than in the primary analysis. Through parallel, but not identical, analytic models we found evidence of some consistency of results, which provides us with greater confidence in our study conclusions. However, full replication was not possible due to the different timing of data collection (and specifically, the inability to model trajectories) in the study used in the replication analysis, which may explain some of the differences in the consequent findings. In addition, there are cultural factors that may play a role in explaining the slight differences across cohorts, which were recruited from different countries. First, there are differences in the age of school entry between the Finland and the United States; 5-year-olds in Finnish society do not yet attend formal school, whereas 6-year-old children in the United States typically do. The school setting typically places higher pressure on child's attention and inhibitory control and thus may amplify the ADHD symptoms reflected in caregiver reports. Differences such as these must be taken into account in the interpretation of the findings. Second, some differences in the levels of emotionality were observed between the US and Finnish cohorts (though of note, the change over time appears similar). These differences may reflect cultural factors and expectations and could contribute to a partially differential pattern observed in the consequent analyses.

This study has a number of strengths. Despite great interest in the developmental origins of ADHD and related disorders, this is the first study to examine trajectories of infant temperament in relation to ADHD symptoms and the first to show that the combination of negative and positive emotionality may be helpful for understanding heterogeneity in ADHD symptoms. This is also the first study to report a prospective association between 3-month temperament and child ADHD symptoms, which is earlier in development than previous studies have reported. This is a nontrivial contribution of this study, as it suggests that, if this finding is replicated, that ADHD risk may be able to be identified and intervened upon earlier than previously described. Further, this study used both person-centered and variable-centered approaches to understanding developmental trends in temperament. Though variable-centered trajectory has gained in popularity in this research area, this is only the second paper to our knowledge to look at subgroups of trajectories or latent classes of temperament, and the first to test for subgroups in the individual dimensions of affectivity. Our study is also the first to examine such trajectories as they related to child functioning years later. Another strength of this study was our use of a replication sample which, despite some differences in data collection and analysis, broadly validated our study's conclusions.

Despite these strengths, this study had several limitations. We relied on parent report of both temperament and ADHD symptoms. Though parent report is commonly used in clinical settings, and we controlled for maternal depressive symptoms in analyses to help alleviate concerns of a common reporter bias, future research should replicate these findings using observer ratings of temperament and/or data provided by other reporters. This study focused on infant temperament during the first year of

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life (a developmental period with particular relevance, given the substantial development of emotionality during this time period and previously described association with later ADHD); however, different insights may be gained if later assessments of temperament (including assessments of later-emerging dimensions of temperament, such as effortful control) were also considered. Future research should also consider a number of possible moderators, including child sex and early caregiving behaviors, as well as the moderating and/or mediating role of executive functioning/effortful control in transmitting the influence of temperament on later ADHD risk. In the current analyses, we controlled for maternal depression as a way to minimize possible bias in parental reports of temperament; however, maternal depressive symptoms have also been shown to contribute to infant temperament and its development (Gartstein et al., 2010), so its inclusion here may have weakened meaningful associations. Although all of the LCGA classes produced in our primary analyses met recommended criteria for the percentage of participants in each class (i.e., at least 5%), some classes included a small number of participants due to the modest sample size of our primary cohort.

Summary and Conclusion

Results from this study add to a growing literature that suggests that it may be possible to detect ADHD risk early in life and that infant emotionality is one important marker of such risk. This study reports the earliest prediction of ADHD symptoms from temperament measures to date (3-month sadness), highlights the importance of considering individual differences in overall level of emotionality in infancy, and provides evidence that considering both infant positive and negative affect together can yield important information about later risk for ADHD symptomatology. Results were broadly confirmed using a large replication sample, validating the conclusions of this study. However, additional research investigating potential mediators and moderators of the associations described herein is needed.

Supplementary Material. The supplementary material for this article can be found at https://doi.org/10.1017/S0954579421001012

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Conflicts of Interest. None.

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