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Temperament moderates developmental changes in vigilance to emotional faces in infants: Evidence from an eye-tracking study

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Abstract

Affect-biased attention reflects the prioritization of attention to stimuli that individuals deem to be motivationally and/or affectively salient. Normative affect-biased attention is early-emerging, providing an experience-expectant function for socioemotional development. Evidence is limited regarding how reactive and regulatory aspects of temperament may shape maturational changes in affect-biased attention that operate at the earliest stages of information processing. This study implemented a novel eye-tracking paradigm designed to capture attention vigilance in infants. We assessed temperamental negative affect (NA) and attention control (AC) using laboratory observations and parent-reports, respectively. Among infants (N = 161 in the final analysis) aged 4 to 24 months (*Mean* = 12.05, *SD* = 5.46; 86 males), there was a significant age effect on fixation latency to emotional versus neutral faces only in infants characterized with high NA and high AC. Specifically, in infants with these temperament traits, older infants showed shorter latency (i.e., greater vigilance) toward neutral faces, which are potentially novel and unfamiliar to infants. The age effect on vigilance toward emotional faces was not significant. The findings support the argument that the development of affect-biased attention is associated with multiple temperament processes that potentially interact over time.

KEYWORDS

attention bias, eye-tracking, infancy, temperament

1 | INTRODUCTION

Visual attention plays a fundamental role in shaping learning, self-regulation, and socioemotional behavior (Morales, Fu, & Pérez-Edgar, 2016; Posner & Rothbart, 2007). Attention is a multicomponent processing system, comprised of three networks: alerting, orienting, and executive attention (Petersen & Posner, 2012). Alerting and orienting are stimulus-driven, and their functions are in place during infancy (Corbetta & Shulman, 2002; Rothbart, Sheese, Rueda, & Posner, 2011). Executive attention functions to voluntarily control attention allocation, emerging in its simplest forms in the first and second year of life (Rothbart et al., 2011). Alerting, orienting, and executive attention operate interactively to support affect-biased attention (Petersen & Posner, 2012). Affect-biased attention, in turn, is characterized by attentional prioritization of specific aspects of the environment based on a stimulus' relative affective and motivational salience to the individual (Todd, Cunningham, Anderson, & Thompson, 2012). Affect-biased attention can manifest across multiple components of attention, including initial attention vigilance, supported by the alerting and orienting networks (Petersen

& Posner, 2012), as well as difficulty in disengaging from emotional stimuli, driven by a decreased influence of the executive attention system (Eysenck, Derakshan, Santos, & Calvo, 2007).

Normative affect-biased attention emerges between 5 and 7 months of age. It can manifest as increased vigilance, evident both prior to stimulus presentation and in the early stages of information processing (Morales et al., 2016). For example, studies have shown that 8- to 14-month-old infants exhibit faster detection of threatening versus nonthreatening stimuli, with faster looks to snakes versus flowers, and to angry faces versus happy faces when presented side-by-side (LoBue & DeLoache, 2010). When a single face is displayed in the periphery of the visual field, 6- and 12-month-olds are faster to orient to the location of fearful faces than to the happy faces (Nakagawa & Sukigara, 2019). At 7 months of age, infants show enhanced vigilance at the neural level to fearful relative to nonfearful faces presented supraliminally (500 and 1,000 ms; Leppänen, Moulson, Vogel-Farley, & Nelson, 2007; Peltola, Leppänen, Mäki, & Hietanen, 2013) and subliminally (50 and 100 ms; Jessen & Grossmann, 2015). Affect-biased attention is also evident in later attentional components (Morales et al., 2016), as research using both looking time and eye-tracking measures have demonstrated a bias in *disengaging* from fearful faces. For example, 7-month-old infants dwell longer on fearful faces than happy faces (Leppänen, Cataldo, Enlow, & Nelson, 2018; Peltola, Yrttiaho, & Leppänen, 2018), and they are slower to look away from fearful versus happy or neutral faces when a neutral stimulus is presented to the left or right of the face (Peltola et al., 2013; Peltola, Leppänen, Palokangas, & Hietanen, 2008; Peltola, Leppänen, Vogel-Farley, Hietanen, & Nelson, 2009).

Importantly, the early developmental preparedness for emotional processing might not be specific to fearful or threatening facial expressions (Leppänen, 2011; Leppänen & Nelson, 2009). In fact, there is also evidence for a positivity bias (Grossmann, Striano, & Friederici, 2007; LaBarbera, Izard, Vietze, & Parisi, 1976; Wilcox & Clayton, 1968) or a general bias toward both positive and threatening emotional faces (Burris, Barry-Anwar, & Rivera, 2017). For example, Burris et al. (2017) reported that infants and children between the ages of 9 and 48 months displayed an attention bias toward both angry and happy faces, relative to neutral faces.

Although these patterns of affect-biased attention are normative and experience-expectant, it is possible that experience-dependent tuning and refinement toward more idiosyncratic and entrenched attention bias patterns develop over the course of the first few years of life (Leppänen, 2011; Leppänen & Nelson, 2009; Morales et al., 2016). For example, individual patterns of affect-biased attention are evident for children exposed to early stressful environments (e.g., Pine et al., 2005) or maternal anxiety (e.g., Mogg, Wilson, Hayward, Cunning, & Bradley, 2012). Furthermore, experiences with one's environment may gradually shape affect-biased attention (Leppänen & Nelson, 2009), generating age-related differences in affect-biased attention patterns across infancy. However, the number of studies examining this issue in infants is still limited, and the results are mixed. In addition, it is not clear if multiple components of attention, including vigilance and disengagement, that reflect affect-biased attention show similar developmental patterns (Fu & Pérez-Edgar, 2019).

For example, a recent eye-tracking study using an infant version of the dot-probe paradigm reported that dwell time to angry faces increases with age in a sample of 4- to 24-month infants. The effect of age was not significant for happy faces (Pérez-Edgar et al., 2017). Furthermore, a related study found an age-related increase in probe fixation latency after infants fixated face pairs containing an emotional face, but not after trials with nonsocial threats (e.g., snakes) (LoBue, Buss, Taber-Thomas, & Pérez-Edgar, 2017). However, other cross-sectional eye-tracking studies with infants have not found significant age effects for affect-biased attention (Burris et al., 2017, 9- to 48-month-olds; Morales et al., 2017, 4- to 24-month-olds).

One explanation for the mixed findings is that constitutional factors, such as temperament, may moderate maturational changes associated with affect-biased attention patterns (Field & Lester, 2010; Morales et al., 2016). Temperament reflects biologically based individual differences in reactivity and self-regulation in emotional, motor, and attentional processes (Rothbart & Derryberry, 1981). Negative affect (NA) represents a reactive emotional dimension of temperament, characterizing the tendency to experience fear, anger, distress, and sadness (Rothbart & Derryberry, 1981). Self-regulation is reflected in the dimension of effortful control, which encompasses attention control (AC). Subserved by the executive attention network, AC reflects the ability to shift, focus, and sustain attention in order to support current goals (Rueda, 2012). In early infancy, the orienting network supports the earliest form of AC (Harman, Rothbart, & Posner, 1997). The more voluntary form of AC starts to develop toward the end of first year of life and can modulate NA (Rothbart et al., 2011).

Importantly, NA is associated with individual differences in attention orienting (Posner & Rothbart, 2009). For example, at 4- and 6-months of age, infants with greater NA show longer disengagement latency from a central attractor stimulus to a peripheral distractor (McConnell & Bryson., 2005). Higher NA is related to greater difficulty in disengaging from fearful faces in infants between 9- and 12-months of age (Conejero & Rueda., 2018; Nakagawa & Sukigara, 2012). The effect of NA may change with maturation (e.g., Nakagawa & Sukigara, 2012) and NA moderates age-related differences in threat bias in 4- to 24-month-olds. That is, the relation between dwell time to angry faces and subsequent face disengagement is dependent on levels of NA only for younger infants (Pérez-Edgar et al., 2017). While LoBue and Pérez-Edgar (2014) found that high NA is linked to facilitated threat detection in childhood, we lack evidence supporting NA-related individual differences in threat vigilance during infancy. Furthermore, it is possible that NA might be associated with a general form of affect-biased attention in infants, rather than a specific threat bias (Vallorani et al., under review). For example, while one study reported that higher temperamental fearfulness is linked to greater neural activation toward fearful versus happy faces in 7-month-olds (de Haan, Belsky, Reid, Volein, & Johnson, 2004), another study found that higher NA is related to greater activation to happy but not fearful faces in 3- to 13-month-olds (Martinos, Matheson, & de Haan, 2012).

The regulatory dimension of temperament may also influence age-related changes in affect-biased attention. At 12 months, high parent-reported temperamental regulation was associated with faster latency to fixate a peripheral target in the overlap task (Nakagawa & Sukigara, 2013), as well as a peripheral fearful face in a modified Posner cueing task (Nakagawa & Sukigara, 2019). However, when assessed at 18 and 24 months, high temperamental regulation (i.e., effortful control) was related to slower disengagement in the sample. One possibility is that the orienting network dominates the earliest form of AC in early infancy. Hence, high AC means better attention shifting. As the executive attention network becomes more integrated and efficient after the first year of life, better AC is marked by greater attention engagement and focusing (Martinos et al., 2012; Nakagawa & Sukigara, 2013). However, as both studies measured the broader regulatory temperament factor, we do not know how age, temperamental NA and AC jointly influence affect-biased attention. In addition, given the focus on disengagement, it is not clear if similar patterns will be evident for initial vigilance.

Currently, there are competing models examining how temperamental NA and AC may influence the development of affect-biased attention (Henderson, Pine, & Fox, 2015; Henderson & Wilson, 2017). The top-down model (Derryberry & Rothbart, 1997) proposes that greater AC facilitates disengagement from arousing stimuli, thus downregulating NA and reducing its effect on maladaptive attention bias toward these stimuli in a top-down, goal-directed manner (Derryberry & Reed, 2002; Rothbart et al., 2011). As an example, only children (9–18 years old) with high NA and low effortful control, but not those with both high NA and AC displayed attention bias to threat (Lonigan & Vasey, 2008). Similarly, 9- to 13-year-olds scoring high on temperamental fearfulness and low AC had greater threat-related attention bias than children with low fear and low AC (Susa, Benga, Pitica, & Miclea, 2014). Evidence for the role of AC in moderating the impact of NA on affect-biased attention in infants is limited. Emerging supporting evidence shows that increased NA is associated with difficulty disengaging from fearful faces in an overlap task only in 9- to 12-month-olds with poor AC performance (Conejero & Rueda, 2018). The effect of NA was not significant for infants with average to high AC.

Competing with this formulation is the model proposing that NA and AC interact to sustain patterns of temperamental reactivity and regulation over time (Rothbart & Bates, 2007). For example, 9-month-old infants with lower sustained attention, a proxy of AC, display stable behavioral inhibition, a temperament type characterized with high negative reactivity, over the course of early childhood (Pérez-Edgar et al., 2010). The risk potentiation model (Henderson et al., 2015; Henderson & Wilson, 2017) proposes that high NA potentiates the engagement of AC as an attempt to regulate NA. The two temperament dimensions may form a positive feedback loop, where NA and its impact on affect-biased attention are elevated rather than downregulated over time. While findings in children (Fu, Taber-Thomas, & Pérez-Edgar, 2017; White, McDermott, Degnan, Henderson, & Fox, 2011) and young adults (Jarcho et al., 2013, 2014) support this model, limited research speaks to how NA and AC may interact to shape the development of affect-biased attention during infancy.

This study aimed to investigate the interactive effect of age and temperament on attention vigilance in infants with a relatively wide age range (4- to 24-months). We implemented an eye-tracking task designed to capture early attention vigilance. The task recruited the alerting network that functions to maintain arousal and readiness, supporting rapid detection of a peripheral stimulus. The orienting network underlies attention shifts from the central fixation to the periphery (Petersen & Posner, 2012). Vigilance is indexed by latency of initial fixation to a face that appears in one of the four corners of the screen (Armstrong & Olatunji, 2012). Faster face detection speed indicates heightened vigilance supported by the alerting and orienting networks (Corbetta & Shulman, 2002).

Vigilance toward salient social stimuli may influence sustained attention and attention disengagement patterns evident at later stages of information processing (Frank, Amso, & Johnson, 2014), and shape fear-related learning and behaviors over time (Leppänen & Nelson, 2012; LoBue, 2013). Moreover, the cognitive motivation model supports the argument that clinical anxiety is characterized by initial attention allocation to threat (Mogg & Bradley, 1998). Eye-tracking studies using initial fixation latency to assess vigilance indicate that while facilitated threat detection is normative (LoBue, Matthews, Harvey, & Stark, 2014), hypervigilance to threat relative to nonthreat is associated with pediatric anxiety (Shechner et al., 2013). Hence, this study serves to enhance our understanding of the potential interaction between normative maturation and individual temperament profiles to influence the emergence of potentially maladaptive affect-biased attention patterns.

First, we examined the effect of age on vigilance. We hypothesized that vigilance to threatening faces would increase with age. Next, we investigated the impact of age, temperamental NA, and temperamental AC on vigilance. If the top-down model is supported (Derryberry & Rothbart, 1997), we should find that the relation between increased age and increased threat vigilance will be strongest for infants with high NA and low AC. If the risk potentiation model is supported (Henderson et al., 2015; Henderson & Wilson, 2017), we should find that the relation between increased age and increased threat vigilance will be strongest for infants with high NA and high AC.

2 | METHOD

2.1 | Participants

Infants (N = 259; 144 males; M_{age} = 11.28 months; SD_{age} = 5.74, $Range_{age}$ = 4.00–24.90 months) were drawn from a larger study that implemented multiple eye-tracking and behavioral paradigms to examine the relation between early temperament and attention. Participants were recruited by contacting parents identified in a university-sponsored database of families interested in research or through community advertisements and outreach.

Seven parents did not provide demographic data. Participants were predominantly White (92.7%), reflecting the surrounding rural community. Parents of the remaining 7.3% participants reported their infants as Asian American, Hispanic, African American, or Native American. In all but four families, English was the primary language spoken at home, although 22 infants were also exposed to a second language. All participants had adequate birth weight (M_{weight} = 7.64 lbs, SD_{weight} = 1.13, Range $_{weight}$ = 5.25), had no major birth complications, and were meeting motor milestones (e.g., rolling over, crawling, and walking) within normal developmental windows. Age of milestones was not correlated with eye-tracking measures in the study, p's > 0.08. Eleven infants (5 males) were born more than three weeks before their due date (21–52 days). We calculated the number of days between the due date and the date of birth to index the deviation from due date. The University Institutional Review Board approved all procedures. Parents provided written consent and were compensated for their participation.

2.2 | Measures

2.2.1 | Infant attentional control (AC)

Parental ratings were collected on the day of the laboratory visit, or not more than two weeks before the date of the first visit. Parents reported on their infants' temperament using one of the two standardized, developmentally appropriate questionnaires, based on infant age.

Infant behavior questionnaire-revised (IBQ-R)

The IBQ-R (Gartstein & Rothbart, 2003) is a 191-item instrument asking parents to rate the frequency of infants' specific behaviors in common situations during the past one or two weeks on a 7-point scale with an eighth "Does not apply" option if parents have not observed their infants in the situation described. AC was measured using the "Duration of Orienting" scale, assessing infants' ability to pay attention and/or engage with a single object for extended periods of time (e.g., "How often during the last week did the baby look at pictures in books and/or magazines for 5 min or longer at a time?"). Reports were collected from 146 parents of 4- to 12-month-old infants (82 males; M_{age} = 7.22 months; SD_{age} = 2.45). The scale scores were computed by averaging ratings on all items making up the scale, omitting any item with a "Does not apply" response (M = 3.71, SD = 1.05, Cronbach's α=0.78).

Toddler behavior assessment questionnaire (TBAQ)

Parents of 12- to 24-month-old infants (N = 104; 56 males; M_{age} = 16.96 months; SD_{age} = 4.06) reported their infants' temperament using the TBAQ (Goldsmith, 1996), a 120-item instrument assessing the frequency of infants' various behaviors as they occurred in the past month. Modeled after the IBQ-R, the TBAQ asks parents to rate on a 7-point scale with an eighth "Does not apply" option. This study used the "Appropriate Attentional Allocation" scale that assesses infants' ability to maintain and control attention (e.g., "How often was your child easily able to stop activities when asked to do so?"). Scale scores were derived by taking the mean of all items for the scale, omitting any item with a "Does not apply" response (M = 3.78, SD = 0.82, Cronbach's α = 0.87).

Questionnaire AC composite

Infants assessed by the IBQ-R and TBAQ did not differ in sex, birth weight, the deviation from due date, or other demographic measures (p's > 0.32), except for the presence or absence of age-related motor milestones. In order to conduct data analyses with the full sample, we created a single AC composite by standardizing and then merging the scale scores derived from the IBQ-R and TBAQ, respectively (overall sample: N = 250, M_{AC}=0.00, SD_{AC} = 1.00).

2.2.2 | Infant negative affect (NA)

To minimize the shared variance between the temperamental AC and NA measures, NA was assessed using two standardized, developmentally appropriate and laboratory-based observational protocols. Individual differences in NA are evident from 4 months of age and can be captured by measuring reactivity to novel visual and auditory stimuli (Calkins, Fox, & Marshall, 1996; Fox, Henderson, Rubin, Calkins, & Schmidt, 2001; Kagan & Snidman, 1991). With the expansion of locomotor abilities and emotional expressivity, the Laboratory Temperament Assessment Battery (Goldsmith & Rothbart, 1999) was administered to assess temperamental fear, joy, and anger/frustration in infants older than 8 months of age (Kagan & Snidman, 1991).

NA in 4- to 8-month-olds

We presented infants (N = 98; 54 males; M_{age} = 5.87 months; SD_{age} = 1.10) with two blocks of stimulus as they sat in an infant car seat in a quiet and alert state. Each block of stimuli consisted of a set of auditory presentations followed by a set of visual presentations. The order of the two auditory and visual presentations was counterbalanced across participants. One set of auditory stimuli contained nonsense syllables (ma, ga, pa). Each syllable was presented in three consecutive 10-s trials, with 5-s inter-trial intervals (ITIs). One set of visual stimuli consisted of mobiles differing in the number of hanging stuffed jungle animals (one, three, then five). Each mobile was displayed for 20 s (ITIs were approximately 10 s) above the infant's face at an unreachable distance. The other set of auditory stimuli consisted of eight sentences, each lasting about 6 s in duration with 2-s ITIs. The sentences were presented in four pairs. Each sentence pair was spoken by a single voice, two voices, three voices and four voices simultaneously. As a result, the pairs differed in sound volume and sensory complexity. The other set of visual stimuli followed the same procedure as the previous set, except that the elements on the mobiles were stuffed bears. All sessions were videotaped, allowing for behavioral coding of infant reactivity.

Coding was based on previously described procedures (Calkins et al., 1996; Fox et al., 2001; Kagan & Snidman, 1991). This study specifically focuses on NA, which was comprised of the total duration of fussing and crying. The NA score was computed by taking the sum of prorated fussing and crying scores ($M_{NA4\text{-}8mo}$ = 15.11, $SD_{NA4\text{-}8mo}$ = 20.36). Interrater reliability was calculated on ~ 20% of the data with 91.8% agreement and κ = 0.57.

NA in 8- to 24-month-olds

The Laboratory Temperament Assessment Battery (Goldsmith & Rothbart, 1999) was administered for infants between 8- and 24-month of age (*N* = 155; 86 males; M_{age} = 14.63 months; SD_{age} = 4.72). The order of the six episodes was the same across participants. The procedure began with infants seated in an infant car seat in a neutral and alert state. Episodes were terminated if the infant became overly distressed.

Two episodes, *Unpredictable Mechanical Toy* and *Stranger Approach*, were designed to elicit the emotion of fear. In *Unpredictable Mechanical Toy*, 8- to 15-month-old infants were presented with a mechanical dog that moved toward the infant three times with 10-s pauses in between movements. The dog barked after the final approach. For 15- to 24-month-old infants, a large plush spider approached the infant and then retreated twice with 10-s pauses in between movements. Both paradigms ended with the experimenter entering the room and inviting the child to play with the object. For the *Stranger Approach* episode, a male research assistant entered the room, walked toward the infant slowly, pausing for 15 s at the predesignated stopping point.

Puppet and *Peek-a-boo* were designed to elicit the emotion of joy. During the *Puppet* episode, the experimenter presented a puppet show and encouraged in the infant to interact with the two puppets. For *Peek-a-boo*, the experimenter sat behind a curtain screen, and intermittently revealed his or her face for 2 s and said “peek-a-boo”. The game continued for six trials.

Container and *Gentle Arm Restraint* were used to assess the emotion of anger/frustration. In *Container*, the infant was given an attractive toy to play. The experimenter then took the toy away and placed it in a glass container for 30 s. The trial was repeated two more times. The infant was allowed to play with the toy in between trials. In the *Gentle Arm Restraint*, the infant was allowed to play with an attractive toy. The parent then held down the infant's forearms so she/he cannot reach the toy. The procedure was conducted twice for 30 s each with a brief break in between.

Of particular interest in this study was temperamental NA coding (Buss & Goldsmith, 2000), obtained by summing the total intensity of facial anger, facial sadness, bodily sadness, distress vocalization, and struggle across all six episodes ($M_{NA8\text{-}24mo}$ = 59.9, $SD_{NA8\text{-}24mo}$ = 30.34). Interrater reliability was assessed in ~20% of the data with 90.3% agreement and κ = 0.92.

Laboratory observational NA composite

Infants assessed by the two laboratory assessment batteries did not differ in sex, birth weight, the deviation from due date, or other demographic variables, *p's* > 0.31, except for the presence or absence of age-related motor milestones. In order to conduct data analyses with the full sample, we created the NA composite by standardizing the NA scores for 4- to 8-month-olds and 8- to 24-month-olds respectively, and then combining the standardized scores into a single NA measure (overall sample: *N* = 253, M_{NA} = 0.00, SD_{NA} = 1.00). There were two outliers for the NA composite score (>*M* + 3*SDs*). The outliers were Winsorized by reassigning the scores to the threshold for the maximum value (i.e., *M* + 3*SDs*).

2.2.3 | Attention vigilance

Eye-tracking data were collected during the Visual Detection paradigm (Figure 1) to assess initial vigilance and attention to faces. The task consisted of 45 trials. Each trial begins with a central attention getter, which was presented until the participant fixated for at least 100ms. The fixation stimulus was then followed by a face presented in one of the four corners of the computer screen. The face stimuli were taken from the NimStim face stimulus set (Tottenham et al., 2009). Ten actors (5 male) provided neutral,

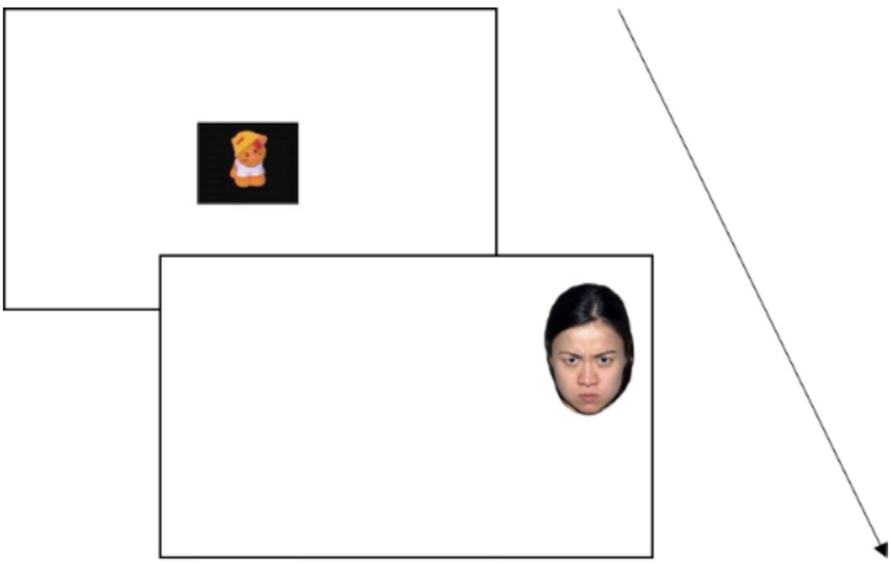

FIGURE 1 Schematic of the Visual Detection paradigm. *Note*: In each trial, a central attention getter is presented till the participant fixated for at least 100 ms. The fixation stimulus is removed and then followed by a face presented in one of the four corners of the computer screen. Each trial advanced after 100 ms fixation on the target face or after 4,000 ms if no fixation was detected. Every 7 trials, a blank white screen was presented for 4,000 ms

angry, and happy facial expressions. Each category of facial expression was presented for 15 trials. No face stimulus appeared in the same location consecutively. Location of the emotion faces was counterbalanced across the four corners of the screen. The face pictures were each 5.08 × 3.68 cm. Trial initiation was triggered by infant fixation rather than predetermined presentation timing (Oakes, 2012). Each trial advanced after 100 ms fixation on the target face or after 4,000 ms if no fixation was detected. To minimize habituation, a blank white screen was presented for 4,000 ms after every seven trials. The order of face stimulus was randomized across participants. Task presentation was controlled by Experimenter Center (SensoMotoric Instruments).

2.3 | Eye-tracking data acquisition and processing

The eye-tracking data were acquired using a RED-m Eye Tracking System (SensoMotoric Instruments) and an integrated 22-inch (1,920 × 1,080 at 60Hz) presentation monitor. During the task, infants sat on either an adjustable highchair or their caregiver's lap at a 60 cm viewing distance from the eye-tracker monitor. The eye-tracker has cameras embedded that detect and record the reflection of an infrared light source on the cornea relative to the pupil from both eyes. The eye-tracking system has a 60-Hz sampling rate and an average accuracy of 0.5 to 1°, equivalent to 0.5 to 1 cm area on the screen with the 60 cm viewing distance. Once the experimenter made sure the infant's eye gaze was on the center of the screen, testing began with a 5-point calibration and four-point validation procedure during which an audiovisual animation was presented at the center and four corners of the screen. Data collection continued until all 45 trials had been presented, or the infant had stopped attending to the presentation.

The raw x-y position coordinates of fixations, defined as gaze maintained for at least 80 ms within a 100-pixel maximum dispersion, were exported with BeGaze (SensoMotoric Instruments). An area of interest (AOI) encircling and including the entire location of the face stimulus was created using BeGaze. Data processing was restricted to gaze data within the specified face AOI. Latency to fixate to the face AOI in each trial were extracted and calculated with in-house Python (Python Software Foundation, https://www.python.org/) and MATLAB (The MathWorks, Inc.) scripts. Further data processing and analyses were conducted using R (R Development Core Team, 2008).

To reduce potential artifacts resulting from low-quality eye-tracking data, we implemented a multistep exclusion procedure during eye-tracking data collection and processing. First, we did not administer the eye-tracking task if infants were distressed or deemed unable to attend to the task. Of the 259 participants, 230 attempted the task. Second, data from 18 infants who completed a pilot version of the task were excluded. Third, we excluded participants who were not able to complete at least half the task (i.e., less than 22 trials; $N = 32$). Finally, of the 180 infants who completed the current task, data from one infant were lost due to technical issues, leaving a sample of 179 participants who provided usable eye-tracking for further data processing.

We then examined the quality of the collected data post visit. Good initial calibration is crucial for obtaining reliable and robust eye-tracking data (Morgante, Zolfaghari, & Johnson, 2012). To this end, we first assessed the participants' calibration quality based on the average deviation degrees of the infant's eye gaze location relative to the location of the five calibration points. Seventeen infants were deemed to have unsatisfactory calibration, as their gaze locations deviated from the locations of the calibration points more than 4° along either the X- or Y-axis direction. This then left eye-tracking data from 162 participants for further processing.

The dependent variable (DV) of interest is the latency of the first fixation to the face AOI. The DV captures attention vigilance to faces evident in the earliest stages of information processing (Armstrong & Olatunji, 2012). To reduce the possibility that the infant was not attending to the task at the onset of the trial, we excluded fixations with latency greater than 3 standard deviations above the mean (across all infants and all fixations; 3.36% of the total number of available fixations were excluded). One infant's latency of initial fixations was above the cut-off, and thus was excluded from data analyses.

Of the 161 participants who provided valid eye-tracking data, 10 infants had missing parent-reports of AC, or observational NA measures, or both. Hence, there were a total of 151 participants who provided valid eye-tracking data and completed the between-subjects assessments.

2.4 | Statistical analyses

Preliminary analyses suggested that participants who provided valid eye-tracking data and temperament measures ($N = 151$) were older than infants who did not ($N = 108$), $M_{\text{included}} = 12.05$ months, $SD_{\text{included}} = 5.46$; $M_{\text{excluded}} = 10.21$ months, $SD_{\text{excluded}} = 5.97$; $t(257) = 2.58$, $p = .01$, $d = 0.32$. However, they did not differ in sex, the deviation from due date, temperamental NA or AC, $p's > 0.09$ (Table 1). Among the included participants, older infants fixated to the face in more trials than younger infants, $r = 0.23$, $p = .006$ (Table 2). Hence, we controlled for the number of trials with face fixations in data analyses. There was no sex-linked difference in the number of trials containing face fixations ($p = .94$) or initial face fixation latency ($p = .47$). The deviation from due date was not correlated with the number of trials with face fixations ($p = .90$) or fixation latency ($p = .72$). Hence, we did not control for sex and the deviation from due date in model testing in favor of parsimony.

The distribution of latency to initial face fixations was positively skewed (skew = 3.11, kurtosis = 12.17). We transformed the latency data using the Box-Cox method to normalize the distribution (Box & Cox, 1964; Osborne, 2010). To ease data presentation, the Box-Cox-transformed values were multiplied by 1,000. The transformed variable had a more adequate distribution ($M = 997.43$, $SD = 0.82$, skew = 0.36, kurtosis = −0.33) and was used for the analyses, tables, and figures.

First, to investigate the effect of Age, we fit a linear mixed-effects model that tested the main effects of Age and Emotionality of

TABLE 1 Means (standard deviations) for key study variables, presented separately for participants who came to visit (overall), who were included in the final model (model 2), and who were excluded from the final data analysis

	Overall (*N* = 259)	Included (*N* = 151)	Excluded (*N* = 108)
Age (months)	11.28 (5.74)	12.05 (5.46)	**10.21 (5.97)***
Sex (male/female)	144/115	86/65	58/50
N born preterm	11	6	5
Negative affect	−0.007 (0.97)	−0.06 (1.00)	0.06 (0.93)
Attentional control	0.00 (1.00)	−0.09 (0.96)	0.13 (1.04)
N trials with face fixations		27.15 (12.4)	
N Trials with angry face fixations		9.15 (4.38)	
N Trials with happy face fixations		9.03 (4.48)	
N Trials with neutral face fixations		8.97 (4.11)	
Untransformed eye-tracking data			
Latency (milliseconds) of initial face fixations		462.38 (101.31)	
Latency (milliseconds) of initial angry face fixations		458.97 (125.25)	
Latency (milliseconds) of initial happy face fixations		460.83 (134.97)	
Latency (milliseconds) of initial neutral face fixations		463.21 (131.48)	
Transformed eye-tracking data			
Latency of initial face fixations		997.510 (0.40)	
Latency of initial angry face fixations		997.480 (0.46)	
Latency of initial happy face fixations		997.528 (0.48)	
Latency of initial neutral face fixations		997.510 (0.47)	

Note: Data analyses used Box-Cox transformed eye-tracking data. The linear mixed-effects models employed trial-by-trial analyses, rather than means across trials.
**p* = .01 for included versus excluded participants.

the face (angry, happy, neutral) on the latency of initial face fixations. The effect of interest was the interaction of Age and Emotionality. To test whether the difference in latency of initial fixations across emotion is differentially influenced by age as well as temperament, we fit a second mixed-effects model that assessed the effects of three between-person variables—Age, temperamental NA and AC, and the within-person variable—Emotionality, on latency to initial face fixation. The effect of interest was the four-way interaction of Age × Emotionality × NA × AC. The number of initial face fixations was entered as a covariate in both models. To prepare data for analysis, between-person variables—number of face fixations, Age, NA and AC, were grand-mean-centered. Emotionality was dummy coded, such that "neutral" was treated as the baseline condition.

We used linear mixed-effects models as they take into account both between- and within-person variance. A baseline model including only the intercept indicated that 82.59% of the variation in initial fixation latency was explained by within-person factors, supporting the importance of using the current modeling method. In contrast to generalized linear models for repeated-measures data which use listwise deletion, multilevel modeling allowed us to test the effects of the predictors using all available eye-tracking data points across all included infants.

3 | RESULTS

3.1 | Descriptive statistics

Means and correlations for the core variables included in the model are presented in Tables 1 and 2. It should be noted that not all infants fixated on the face presented in each trial (M = 27.15, SD = 12.4, median = 29 trials with at least one face fixation), and not all infants provided valid fixation data on all face types (Table 1). One infant did not have any valid fixations on angry or happy faces, and another infant did not have any valid fixations on neutral faces.

3.2 | Preliminary analysis

The first linear mixed-effects model found a nonsignificant Age-by-Emotionality (angry, happy, neutral) interaction effect, $p = .31$. The second model revealed that the effect of interest, Age × Emotionality × NA × AC, was significant, $F(2,276) = 5.60$, $p = .004$, $\eta_p^2 = 0.04$. To probe the 4-way interaction (Figure 2), each continuous moderating variable was recentered at low (−1 SD) and high (+1 SD) levels (Aiken & West, 1991). The Age-by-Emotionality effect was significant only for infants with high NA and high AC, $F(2,276)=6.36$, $p=.002$, $\eta_p^2 = 0.04$. We then examined the

TABLE 2 Correlations of key study variables ($N = 151$)

	1	2	3	4	5	6	7	8	9
1. Age (months)									
2. Sex (male/female)	−0.01								
3. Negative affect	−0.09	0.09							
4. Attentional control	0.10	0.02	0.01						
5. *N* trials with angry face fixations	0.20*	−0.01	−0.05	−0.10					
6. *N* trials with happy face fixations	0.26**	−0.05	−0.09	−0.08	0.88***				
7. *N* trials with neutral face fixations	0.18*	0.03	−0.07	−0.05	0.87***	0.87***			
8. Latency to initial angry face fixations (transformed)	−0.15	0.04	−0.04	0.01	−0.37***	−0.35***	−0.38***		
9. Latency to initial happy face fixations (transformed)	−0.15	0.09	0.08	0.08	−0.38***	−0.38***	−0.33***	0.50***	
10. Latency to initial neutral face fixations (transformed)	−0.16	0.15	0.14	0.02	−0.32***	−0.35***	−0.34***	0.54***	0.66***

Note: The linear mixed-effects models employed trial-by-trial analyses, rather than means across trials. In addition, for Latency we used the Box-Cox transformed values to counteract the skewness.
*$p < .05$,
**$p < .01$,
***$p < .001$.

main effect of Age on latency to initial face fixation for each Emotionality. To do so, we reran the model twice with age mean-centered, and NA and AC centered at high levels. Each time, angry and happy was set as the baseline condition, respectively. Among infants with high NA and high AC, initial fixation latency to neutral faces significantly decreased as age increased, $b = -0.03$, $t(142) = -3.12$, $p = .002$. However, the main effect of Age was not significant for angry, $p = .87$, or happy faces, $p = .62$. Using a data-driven approach to reduce the complexity of interaction testing and aid interpretation, we recoded Emotionality as emotional versus neutral faces for formal analyses.

Given the lack of differentiation of Age effect on angry and happy faces, we then collapsed these trials in order to directly examine emotional versus neutral faces in a single comparison, aiding interpretability and visualization.

3.2.1 | Model 1: The impact of age and emotionality on latency of initial face fixation

After controlling for the number of trials with face fixations, $F(1,158) = 25.45$, $p < .001$, $\eta_p^2 = 0.14$, there were no significant effects of Age, $p = .12$, Emotionality (emotional vs. neutral), $p = .95$, or Age-by-Emotionality interaction effect, $p = .16$ (see Table 3 for full parameter estimates).

3.2.2 | Model 2: The impact of age, emotionality, and temperamental NA and AC on latency of initial face fixation

After controlling for the number of trials with face fixations, no main effects were significant, *p's* > 0.10. The only significant interaction effect was the Age × Emotionality × NA × AC effect, $F(1,141) = 6.96$, $p = .009$, $\eta_p^2 = 0.05$, (Table 3).

First, NA was recentered to determine the level at which the Age × Emotionality × AC effect was significant. This three-way interaction effect was significant at high levels of NA, $F(1,141) = 8.93$, $p = .003$, $\eta_p^2 = 0.06$, but not at low levels of NA, $p = .68$.

Second, with data centered at high levels of NA, we probed the Age-by-Emotionality interaction effect at high and low levels of AC. At high levels of NA and AC, there was a significant interaction effect of Age and Emotionality, $F(1,141) = 13.12$, $p < .001$, $\eta_p^2 = 0.09$. That is, increased age was related to greater differentiation of fixation latency to emotional versus neutral faces, $b = 0.02$, $t(141) = 3.61$, $p < .001$. However, the Age-by-Emotionality interaction effect was not significant at high levels of NA and low levels of AC, $p = .64$.

Focusing on the significant Age-by-Emotionality interaction effect on the latency of initial face fixations in infants with high NA and high AC (Figure 2), we examined the effect of Age on the latency of initial face fixation on emotional and neutral faces. Initial fixation latency of neutral faces significantly decreased as age increased, $b = -0.03$, $t(142) = -3.11$, $p = .002$, $\eta_p^2 = 0.06$. However, the effect of Age was not significant for Emotional faces, $p = .78$.

Together, the results suggest that an age-related change in differential vigilance toward emotional versus neutral faces was only present for infants characterized with high NA and high AC.

4 | DISCUSSION

This study adopted a novel eye-tracking paradigm to examine the effects of age and temperament on attention vigilance in 4- to 24-month-olds. We tested whether there is an age-related change in vigilance toward emotional versus neutral faces. Furthermore, we investigated whether temperamental NA and AC moderate

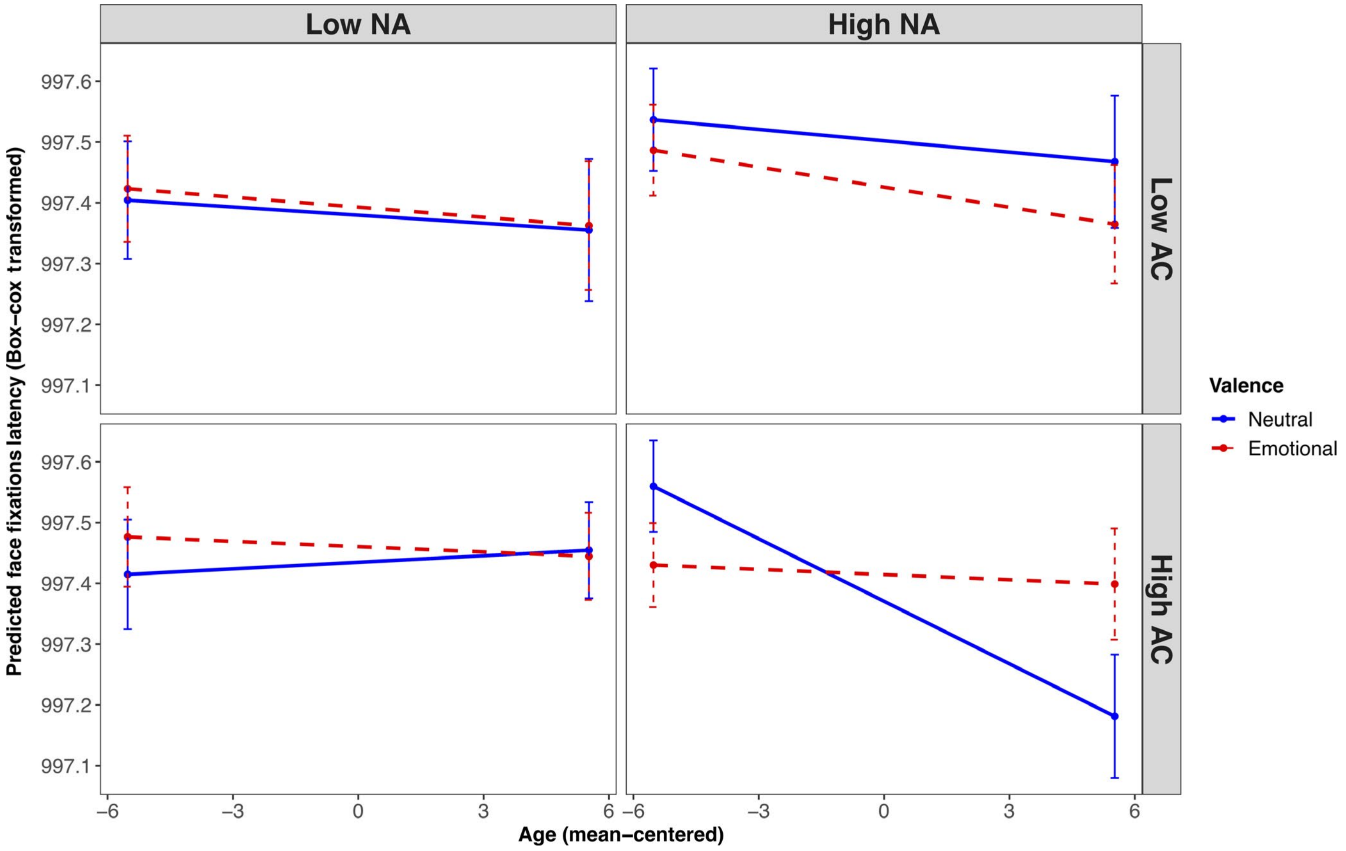

FIGURE 2 The interaction effect of Age, Emotionality, temperamental Negative Affect (NA) and Attention Control (AC) on latency of initial face fixations (Box-Cox transformed). *Note*: $^*p$ = .002; Error bar = ±1 SE

age-related changes in vigilance toward emotional versus neutral faces.

We found that age by itself did not influence the latency to fixate to the emotional versus neutral faces. Instead, we found that age-related changes in differential latency to fixate to emotional versus neutral faces were only significant for infants with high NA and high AC. Older infants with this temperamental profile showed better discrimination of emotional versus neutral facial expressions. Specifically, these infants exhibited greater vigilance toward neutral faces. There was no age effect for vigilance toward emotional faces.

Importantly, we did not find stand-alone age-related changes in vigilance toward emotional versus neutral faces. It is possible that general (main effect) maturational changes are only evident in later components of affect-biased attention, such as disengagement, but not in the early component examined in this study. For example, in an eye-tracking dot-probe study with a partially overlapping sample of 4- to 24-month-olds, older infants were slower to disengage from the face and fixate to the probe, and the age effect was only significant for angry, but not happy, faces (LoBue et al., 2017). However, age effects are not consistently found in attention disengagement (e.g., Morales et al., 2017) or general affect-biased attention indices (Burris et al., 2017; Vallorani et al., under review), underscoring the necessity to examine developmental changes in affect-biased attention patterns in the context of individual differences related to socioemotional functioning. Indeed, we found that temperamental NA and AC jointly moderated age-related changes in attention vigilance. That is, only for infants with both high NA and high AC, increased age is associated with larger differences in fixation latency to emotional versus neutral faces.

To interpret the findings, the first question focuses on what might be the underlying process that contributes to the differential fixation latency to emotional versus neutral faces in older infants with high NA and high AC. We speculate that the finding may reflect the possibility that infants' ability to discriminate facial expressions presented in the periphery of the visual field improves with age. Before 5 months of age, attention orienting is driven by stimulus salience rather than socioemotional relevance (i.e., faces; Frank et al., 2014; Frank, Vul, & Johnson, 22009; Kwon, Setoodehnia, Baek, Luck, & Oakes, 2016). A shift takes place at 6 to 7 months, such that infants display greater preference in looking at faces in the visual field (Frank et al., 2014, 2009; Kwon et al., 2016), and show facilitated detection of affectively salient faces, such as angry (e.g., LoBue & DeLoache, 2010) and happy (e.g., Grossmann et al., 2007) faces. Adopting a modified Posner cueing paradigm that presents individual face stimuli in the periphery, Nakagawa and Sukigara (2019) found that 6- and 12-month-old infants are faster to look toward the location of fearful than happy faces. Moreover, vigilance toward fearful faces is positively correlated with parent-reported attention orienting ability. Thus, the age-related improvement in peripheral emotion discrimination that we found in infants with high NA and

TABLE 3 Results of linear mixed-effects models examining the effects of age, face emotionality, and temperament on latency of initial face fixations

Predictor	*B*	*t*	*p*	η_p^2
Model 1				
N trials with face fixations	−0.01	−5.04	<.001	0.14
Age	−0.01	−1.57	.12	0.02
Emotionality	−0.001	−0.07	.95	<0.001
Age × Emotionality	0.003	1.4	.16	0.01
Model 2				
N trials with face fixations	−0.01	−4.89	<.001	0.14
Age	−0.01	−1.58	.12	0.02
Emotionality	0.002	0.06	.95	<0.001
NA	0.02	0.43	.67	0.001
AC	−0.02	−0.55	.58	0.002
Age × Emotionality	0.005	0.99	.32	0.01
Emotionality × NA	−0.02	−0.71	.48	0.004
Emotionality × AC	0.03	1.27	.21	0.01
Age × NA	−0.01	−1.53	.13	0.02
Age × AC	−0.01	−0.75	.45	0.004
NA × AC	−0.05	−1.68	.1	0.02
Age × Emotionality × NA	0.01	1.69	.09	0.02
Age × Emotionality × AC	0.01	1.56	.12	0.02
Emotionality × NA × AC	0.03	1.31	.19	0.01
Age × NA × AC	−0.01	−1.79	.07	0.02
Age × Emotionality × NA × AC	0.01	2.63	.009	0.05

Abbreviations: AC, attention control; NA, negative affect.

high AC can be attributed to increased experience with faces across the first year (Leppänen & Nelson, 2009) and enhanced efficiency of the orienting network (Harman et al., 1997). While not directly tested in this study, evidence suggests that by 12 to 18 months, infants are likely able to extract meaning from facial expressions and use this meaning to guide locomotion (e.g., Campos, Kermoian, & Zumbahlen, 1992; Tamis-LeMonda et al., 2008).

Here, we cannot make a strong inference that infants indeed discriminated facial expressions in the periphery. Moreover, it is also possible that any discrimination present was driven by lower-level perceptual differences (e.g., differences in eyes) associated with different expressions (Leppänen, Hietanen & Koskinen, 2008). However, our findings are consistent with evidence indicating that there are age-related improvements in discrimination between emotional expressions presented in foveal or peripheral fields. The possibility that older infants may be able to glean deeper socioemotional information from faces helps explain the age-related increase in vigilance toward neutral versus emotional faces in infants with high NA and high AC—a point we will elaborate below.

The second question asks why age was associated with heightened vigilance toward neutral, rather than emotional faces in infants with high NA and high AC. We lack evidence regarding how age and the reactive and regulatory aspects of temperament moderate attention vigilance in infancy. However, existing studies have indicated that (a) attention bias to emotional faces, mostly threatening expressions, emerges around the second half of the first year (e.g., facilitated angry face detection: LoBue & DeLoache, 2010), and (b) temperamental NA and AC jointly influence attention bias to threatening faces (e.g., Conejero & Rueda, 2018). Hence, the lack of threat vigilance across all participants and the absence of age-by-temperament moderation effect on threat vigilance in this study are difficult to reconcile with the existing literature. Interpretations of the current findings would thus need to be taken with caution.

By 1 year of age, infants are capable of using emotional faces as social signals to guide their behavior (Campos et al., 1992; Tamis-LeMonda et al., 2008), and such social referencing ability might be more well-practiced in older infants with high AC. While infants are infrequently exposed to threatening or neutral faces in normative rearing environments (Belsky, Gilstrap, & Rovine, 1984; Sugden, 2012), neutral faces are more ambiguous than threatening faces in terms of signaling intentions and/or information about the environment (e.g., potential dangers). Hence, over the course of development, emotional faces may become less ambiguous, but neutral faces may remain ambiguous. Our findings suggest that temperamental NA and AC moderate age-related increases in attention vigilance toward neutral faces. Specifically, it is possible that vigilance toward the potentially ambiguous social signal in high NA infants is enhanced with age, accompanied by the emergence of higher levels of AC, a regulatory function supporting orienting.

Future longitudinal studies are needed to investigate whether vigilance toward neutral faces in infants with high NA and high AC is normative, as described above, or a risk factor for anxiety problems. According to the risk potentiation model (Henderson et al., 2015; Henderson & Wilson, 2017), high NA potentiates the engagement of AC as a compensatory mechanism in at-risk individuals over the course of development. High NA and high AC may gradually calcify affect-biased attention (Henderson et al., 2015; Henderson & Wilson, 2017). In addition, the cognitive-motivational model (Mogg & Bradley, 1998) suggests that anxiety is associated with a lowered threshold for perceiving threat. While we cannot determine if these infants perceived neutral faces as novel and potentially threatening or ambiguous, evidence supports an increased risk for anxiety in children displaying attention bias toward neutral stimuli (Heuvel, Henrichs, Donkers, & Bergh, 2017; Kelly, Maratos, Lipka, & Croker, 2016). Studies examining the longitudinal relation between infants' affect-biased attention patterns and socioemotional adjustment would enable us to draw informed inferences of when and under what circumstances early hypervigilance to neutral faces is normative or maladaptive.

A number of strategies can be used to test the robustness of the current findings and further our understanding of how age and temperament interact to influence attention vigilance. First, researchers can adopt a person-centered approach to identify profiles of attention vigilance based on eye-tracking indices from multiple tasks. For example, latent profile analyses (LPA) can reveal whether there are subgroups of infants displaying different patterns of attention across tasks. In an LPA incorporating dwell time and latency measures from all three eye-tracking tasks in our larger study, Vallorani et al. (under review) characterized the probability of displaying a heightened pattern of affect-biased attention. They found that infants' NA was associated with the relation between age and the probability of exhibiting affect-biased attention only in the context of being exposed to high maternal anxiety. The visual search paradigm (LoBue, 2014) provides another useful task for capturing vigilance.

Second, future research can implement multimodal assessments of attention vigilance that combine ERP with eye-tracking measures. For example, the current findings would be supported if infants with high NA and high AC also show age-related increases in amplitude for the Nc or face processing components such as N290 and P400 (Leppänen et al., 2007), in addition to the attention patterns revealed by eye-tracking. Moreover, the multimodal recording could inform the relation between infants' overt orienting patterns and covert attention processes. For example, researchers could investigate whether larger ERP amplitudes in response to neutral faces are driven by overt attention preference toward specific features of the expressions, or a bias toward neutral faces more generally (e.g., Vanderwert et al., 2015).

Third, this study assessed NA based on infant behaviors in the laboratory (Buss & Goldsmith, 2000; Fox et al., 2001), whereas AC was assessed based on parental report (Gartstein & Rothbart, 2003; Goldsmith, 1996). Using both parental report and laboratory assessments can provide a more comprehensive and stable assessment of temperament and minimize reporter bias (Shiner et al., 2012). Other studies have measured AC in the laboratory using experimental paradigms that tap into goal-directed gaze shifting (e.g., Conejero & Rueda, 2018), or observational paradigms that examine gaze behavior when exposed to stimuli that are designed to elicit NA (e.g., Brooker et al., 2011; Crockenberg & Leerkes, 2006). Future investigations are needed to examine whether our findings can be replicated when temperamental NA and AC are assessed based on behaviors in both home and laboratory environments.

5 | CONCLUSIONS

This study implemented a novel eye-tracking paradigm to study attention vigilance in infants aged between 4 and 24 months. Specifically, we examined the role of temperamental NA and AC in moderating age-related changes in fixation latency toward emotional versus neutral faces. We found no significant age-related changes in vigilance across the full sample. Rather, we found that older infants with high NA and high AC displayed shorter latency to attend to neutral faces. The findings are inconsistent with the existing literature, which suggests that infants show attention bias toward threatening faces, and the threat bias may be moderated by reactive and regulatory aspects of temperament. A possible interpretation of our findings is that older infants are more experienced with using emotional faces to guide actions. However, neutral faces remain relatively ambiguous social signals. Hence, as AC function matures over time, older infants with high NA and high AC show greater vigilance to neutral faces that might be more ambiguous for these infants and thus require greater processing. Future replications of the current findings are necessary in studies that use multiple tasks and multiple levels of analyses for temperament and affect-biased attention. Furthermore, longitudinal assessments are important to understanding the interactive relation between early temperament, affect-biased attention, and socioemotional functioning.

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon request.

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