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Stability of Individual Differences in Social and Nonsocial Visual Attention From Newborn to 14 Months

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ABSTRACT

Given the foundational nature of infant visual attention and potential cascading effects on later development, studies of individual variability in developmental trajectories in a normative sample are needed. We longitudinally tested newborns ($N = 77$) at 1–2 and 3–4 weeks, then again at 2, 4, 6, 8 and 14 months of age, assessing individual differences in their attention. Newborns viewed live stimuli (facial gesturing, rotating disk), one at a time, for 3 min each. Older infants viewed a 10-s side-by-side social–nonsocial video (people talking, rotating disk). We found short-term developmental stability of interindividual differences in infants' overall, social, and nonsocial attention, within the newborn period (1–4 weeks), and within the later infancy period (2–14 months). Additionally, we found that overall attention, but not social and nonsocial attention, was developmentally stable long term (newborn through 14 months). This novel finding that newborn overall attention predicts later overall attention through the first year suggests a robust individual difference. This study is a first step toward developing individual difference measures of social and nonsocial attention. Future studies need to understand why newborns vary in their attention and to identify the potential impact of this variability on later social and cognitive development.

1 | Introduction

Infant visual attention is foundational for later development (Colombo 2001; Oakes and Amso 2018; Oakes 2023). For example, early infant visual attention is associated with children's later cognitive development, motor activity, impulsivity, and behavior difficulties (Papageorgiou et al. 2015; Rose et al. 2003; Rose et al. 2012). The newborn period (i.e., first 28 days after birth), in particular, is a time of rapidly developing visual acuity, attention control, and visual cortex maturation (Graven and Browne 2008). Newborn visual attention is one of the earliest ways infants interact with their environment (Brazelton 1978). Yet, there are few longitudinal studies of infant attention beginning in the newborn period, and it is unclear whether newborn visual attention predicts later developmental trajectories of attention (Jones and Klin 2013).

In developmental psychology more broadly, researchers have traditionally taken one of two complementary approaches to studying development, either focusing on normative, group-level, average development, or focusing on interindividual differences, that is, the variability among individuals (Pérez-Edgar et al.

2020). However, studies of newborn social behavior have almost exclusively been limited to the former, aiming to characterize whether and when a given capacity typically emerges (for review, see Colombo 2001; Nascimento et al. 2023). When interindividual variability is observed in newborn behaviors, studies generally treat it as noise rather than as meaningful information (Simpson et al. 2014).

Studies of interindividual variability in newborn attention, in particular, are necessary to understand how it is foundational for development in and beyond the newborn period (Markus et al. 2000; Mundy et al. 2009; Papageorgiou et al. 2015; Salley et al. 2016). For example, at 6–10 days of age, newborns at risk for autism spectrum disorder (ASD) visually attend more to nonsocial stimuli (averted-gaze face photos and videos of random motion) while low-risk newborns visually attend more to social stimuli (direct-gaze face photos and videos of biological motion), suggesting visual preferences soon after birth may be linked to the later development of developmental disorder (Di Giorgio et al. 2016). Other studies report that, in the first four days of age, typically developing newborns' greater attention to face photos (human faces and schematic face-like configurations) was associated with nonsocial attention (to moving objects) at 1 month of age (Barten and Ronch 1971) and lower rates of childhood surgency and fewer behavioral difficulties at 7.5 years (Papageorgiou et al. 2015).

If newborn attention is associated with infants' later attention, it could be useful for designing assessments to capture whether newborns are on track for healthy development (Wakschlag et al. 2019). Yet there are few studies of interindividual differences among typically developing newborns. Such studies are needed to understand the variability in low risk, typically developing newborns' overall attention and their visual attention to social and nonsocial stimuli separately as they relate to infants' later attention development.

Interindividual variability in newborn attention has been studied in limited contexts, most commonly focusing on social attention (i.e., attention to people). Notable interindividual differences in newborn social attention have already been reported (Connellan et al. 2000; Nagy et al. 2007; Simpson et al. 2016). For example, newborns vary in their levels of eye contact (Hittelman and Dickes 1979; Leeb and Rejskind 2004). Given that most studies of infant attention focused on specific types of attention (e.g., to faces), it is unclear whether the patterns reported reflect a broader interest (more general attentiveness) versus a specific interest (in a particular category of stimuli, such as people). Therefore, to have a more complete understanding of infant attention, there is a need for studies that use a wider variety of stimuli, including both social and nonsocial stimuli.

Most studies of newborn attention have notable limitations in their measures. For example, experimenter report measures are most common, often with a Likert scale which only roughly approximates attention (Brazelton et al. 1987; Tronick and Lester 2013) and is likely less accurate than coding from video, which enables objective judgments from multiple rater's blind to hypotheses/stimuli and assessment of rater agreement. Prior studies also typically combine scores of infants' attention to social and nonsocial stimuli into one overall attention score (Fink et al. 2012; Salisbury et al. 2005) making it difficult to understand social and nonsocial attention as potentially distinct.

There are theoretical frameworks that support the distinction between social attention, nonsocial attention, and overall (combined) attention. According to the overall attention hypothesis, infants' attentiveness—attention holding (i.e., total cumulative look duration)—is a persistent interindividual difference that is consistent (stable) across contexts (stimuli/situations) and over time (Rothbart and Derryberry 1981; Sigman et al. 1997). Studies have supported this idea by showing test–retest stability of attention over a brief timespan (15 days) in 11 month old infants across different types of video stimuli (Wass and Smith 2014), and a positive correlation in infants' overall attention (to photo pairs of faces and geometric patterns) from 3.5 months to toddlerhood (2–3 years; Rose and Feldman 1987; Rose et al. 2012; White et al. 2022). These findings provide some empirical support for the overall attention hypothesis, suggesting that there may be long-term developmental stability of interindividual differences in overall attention.

On the other hand, according to the domain-specific attention hypothesis, interindividual differences in infants' attention to specific stimulus types (e.g., social attention or nonsocial attention) are theorized to reflect individual differences in infants' qualities, such as their social interest or motivation (Bradshaw et al. 2024; Maylott et al. 2021; Robledo et al. 2010). However, since most longitudinal studies of infant attention have only tested one stimulus type at a time and have been limited to older infants beyond the newborn period, the domain specific attention hypothesis has yet to be fully tested. One exception to this general pattern is a longitudinal study, which found stability with age from 12 to 43 months in high-risk-ASD infants who were grouped based on their preference for nonsocial videos (geometric shapes) or social videos presented simultaneously (Pierce et al. 2011). However, it is unclear whether interindividual differences in the *amount* of social and nonsocial attention were each consistent with age and whether patterns would be similar in typically developing infants.

Among studies of typically developing infants, there are reports of stable interindividual differences with age in social attention from 3–9 months (Frank et al. 2014; White et al. 2022); however, to our knowledge, only one study examined these interindividual differences for both social and nonsocial attention. In this study, infants tested monthly between 6–9 months of age showed stable interindividual differences in their habituation time looking to faces but not to objects (Robledo et al. 2010). The authors concluded that time looking at the face might be related to individual differences in infant sociality, potentially an underlying temperament dimension. These findings are consistent with the domain-specific hypothesis. However, this study did not examine whether infants' social and nonsocial attention are related, which the overall attention hypothesis predicts, as well as whether such stable individual differences are already present in the newborn period.

TABLE 1 | Hypotheses and predictions for short-term and long-term stability of interindividual differences in infants' overall, social, and nonsocial visual attention.

	Predictions about the short-term developmental stability of individual differences		Predictions about the long-term developmental stability of individual differences (newborn period to 14 months)
	Newborn period	2–14 months	
Overall attention hypothesis	Newborn with higher social attention will have higher nonsocial attention within each visit	Stable interindividual differences in overall attention from 2 to14 months	Newborn overall attention will predict trajectories of later (2–14 month) overall attention
	Newborn with higher overall attention in the first visit will have higher overall attention in the second visit		
Domain specific attention hypothesis	Newborn with higher social attention in the first visit will have higher social attention in the second visit	Stable interindividual differences in social attention from 2 to14 months	Newborn social attention will predict trajectories of later (2–14 month) social attention[a]
	Newborn with higher nonsocial attention in the first visit will have higher nonsocial attention in the second visit	Stable interindividual differences in nonsocial attention from 2 to14 months	Newborn nonsocial attention will predict trajectories of later (2–14 month) nonsocial attention

[a]CONSPEC-CONLERN theory, unlike the domain specific attention hypothesis, predicts that infants will *not* show long-term stability of interindividual differences to social stimuli that include faces within the newborn period.

While the overall attention hypothesis and domain-specific attention hypothesis predict stable long-term interindividual differences with age, there is another theory of early infant attention that predicts that there may not be long-term stable interindividual differences with age. The CONSPEC and CONLERN two-process theory of attention suggests that newborns' attention to faces is subcortically driven, whereas in later infancy, it is cortically driven (Johnson et al. 2015; Morton and Johnson 1991); therefore, predicting long-term stability in interindividual differences to be unlikely across these ages since different mechanisms underlie each stage. While this theory is specifically about attention to faces, it has also been hypothesized that the mechanisms underlying infants' visual preferences more generally are also changing with age (Johnson 1990), which may result in lack of long-term developmental stability of interindividual differences in infants' attention more generally, including nonsocial attention (Hood et al. 1996).

1.1 | Current Study

The current study examined interindividual differences in the age-related development of infant visual attention. Specifically, we assessed whether infants exhibit short-term developmental stability of interindividual differences in their social, nonsocial, and overall attention within the newborn period, and from 2 to 14 months. We also examined interindividual differences in visual attention (overall, social, and nonsocial), exploring whether newborn visual attention to a social partner or an object predicts trajectories of attention from 2 to 14 months (long-term developmental stability). We tested four predictions of the overall attention hypothesis and six predictions of the domain specific attention hypothesis (Table 1).

2 | Methods

2.1 | Participants: Newborns and Older Infants

Participants were healthy, full-term (≥ 37 weeks) newborns, with no known hearing or vision problems, living in Miami, including 1- to 2-week-olds (Visit 1: $N = 77$; mean age = 18 days, SD = 5, range: 7–27 days) and 3- to 4-week-olds (Visit 2: $N = 69$; mean age = 24 days, SD = 3.13, range: 16–29 days), followed longitudinally at 2-month-olds ($N = 54$; mean age = 61 days, SD = 5, range: 52–72 days), 4-month-olds ($N = 49$; mean age = 116 days, SD = 5, range: 115–137 days), 6-month-olds ($N = 54$; mean age = 186 days, SD = 6, range: 175–198 days), 8-month-olds ($N = 51$; mean age = 245 days, SD = 8, range: 215–256 days), and 14-month-olds ($N = 44$; mean age = 420 days, SD = 12, range: 397–443 days) (Table 2). The mean birth weight was 3.29 kg (SD = .42, range: 1.87–4.17 kg). The mean gestational age at birth was 39.1 weeks (SD = 1.28, range: 37–43 weeks). We tested male ($n = 41$) and female ($n = 36$) neonates of various ethnicities, 43 Hispanic/Latino, and races, 16 Black or African American, 48 White, seven multiracial (one Black and Asian; 11 Black and unknown; one White and American Indian/Alaska Native; one White and Black; one White, Black, and Asian; one White, Black, and unknown), and six not reported.

Parents reported their ages: mothers' mean age = 32 years, SD = 5, range: 20–43 years; fathers' mean age = 35 years, SD = 5, range: 23–51 years. Parents reported their highest levels of education: 6.50% of mothers and 25.60% of fathers had less than

TABLE 2 | Number of participants who completed visits at each age.

	1–2 weeks	3–4 weeks	2 months	4 months	6 months	8 months	14 months
1–2 weeks	77						
3–4 weeks	64	64					
2 months	54	46	48				
4 months	49	42	31	55			
6 months	54	47	37	44	54		
8 months	51	44	35	44	46	51	
14 months	44	38	30	39	39	42	44

Note: Sample sizes reflect the number of usable participants. Reasons for exclusion included fussiness/sleepiness (1–4 weeks), inattentiveness (2–14 months), parental interference, equipment problems (e.g., calibration), and experimenter error. Our final sample included 20 infants who completed all seven visits, 19 infants who completed six visits, 16 infants who completed five visits, four infants who completed four visits, six infants who completed three visits, seven infants who completed two visits, and five infants who completed one visit. In our sample, 71.4% of participants (55/77 infants) completed at least five visits, including at least one newborn visit, and 69% of participants (53/77 infants) completed at least the newborn visit and a later age visit (≥ 8 months).

or equivalent to a high school education, 57.14% of mothers and 52.70% of fathers had some college or a 4-year degree, and 36.36% of mothers and 21.62% of fathers had advanced degrees. In terms of household income ($), 3.9% of families reported an income of $10,000–19,999, 3.9% of families reported an income of $20,000–29,999, 9.1% of families reported an income of $30,000–39,999, 10.4% of families reported an income of $40,000–49,999, and 55.84% of families reported an income of $50,000 a year or more.

Caregivers and infants were invited into our lab for two newborn visits on separate days between 1 and 4 weeks after birth. We tested each infant twice to maximize the number of newborns in the optimal state for testing. This approach resulted in 13 infants (17%) who contributed usable data for one newborn visit, while 64 infants (83%) contributed usable data for both newborn visits. We recruited families through local events (e.g., baby expos and fairs) and local community and professional centers (e.g., classes for pregnant people). Parents reported demographics about their infants and families (age, ethnicity/race, income, and highest level of education) through online questionnaires administered through RedCap (redcap.miami.edu) and Qualtrics (qualtrics.com). The University of Miami Institutional Review Board ethics committee approved the study.

2.2 | Design of Age-Appropriate Assessments

In the current study, our goal was to create tasks that sensitively capture individual differences in attention at each age. We also wanted to keep our stimuli as naturalistic yet engaging as possible. We therefore, assessed newborns with live stimuli, to which they are more responsive (Slater et al. 2010), one at a time and presented longer durations to give them enough time to process them (Reynolds and Romano 2016), whereas we assessed 2- to 14-month-olds with video stimuli, which elicit responses similar to those elicited by live stimuli (Diener et al. 2008), presented two at a time for briefer durations to avoid boredom and accommodate their faster processing with age (Ross-Sheehy et al. 2003). Further, given that eye tracking of newborns can be less reliable than that of older infants (Wass et al. 2013; Hessels and Hooge 2019; Zeng et al. 2024), we only used eye tracking with older infants.

2.3 | Newborn Testing Materials and Procedures

2.3.1 | Stimuli: Newborn Facial Gesture and Disk Conditions

During each visit, newborns observed 3 min each of social and nonsocial stimuli one at a time, presented in a counterbalanced order (Figure 1). The social stimuli were provided by an adult experimenter performing novel facial gestures (tongue protrusion and mouth opening; approximately 80° (tall) × 50° (wide) visual angle. The dynamic social stimuli (facial expressions) are within newborns' facial repertoires (Meltzoff et al., 2018). The nonsocial stimuli included a novel rotating disk, 13.5 cm in diameter (48.5° visual angle) with high-contrast orthogonal red and black stripes. The nonsocial disk was designed to be captivating for the newborn, to ensure that the infants were attentive and interested (Simpson, Paukner, et al. 2014). All stimuli were presented at a distance of 15–20 cm from the newborn's face, which is the optimal distance for newborns to see in front of them (Dobson and Teller 1978). To maximize newborns' visual attention and interest, we presented stimuli using a "burst-pause" design in which, in each condition, newborns observed nine 20-s periods alternating between active (gesturing/rotating disk) and inactive (still-face/disk) stimuli (Meltzoff and Moore 1983).

2.3.2 | Newborn Testing Room Setup

Three cameras recorded each test session: one camera was on a tripod capturing the newborn's face from approximately 45° to the infant's left side, one hand-held capturing the infant's face from approximately 45° to the infant's right side, and one capturing a side view of both the experimenter and the newborn. To obtain high-quality video recording under low illumination levels, we used two video cameras (Sony HD Handycams with 9.2 Megapixels HDR-PJ540) that framed only the newborn's face. Two floor lamps, one positioned 45 cm in front of the newborn, and one positioned 60 cm in front and slightly to the infant's right side, were on their dimmest setting (30 watts). Two spotlights (Aramox LED Reading Light USB Clamp Desk Lamps) were positioned 25 cm behind the newborn (one slightly to the left

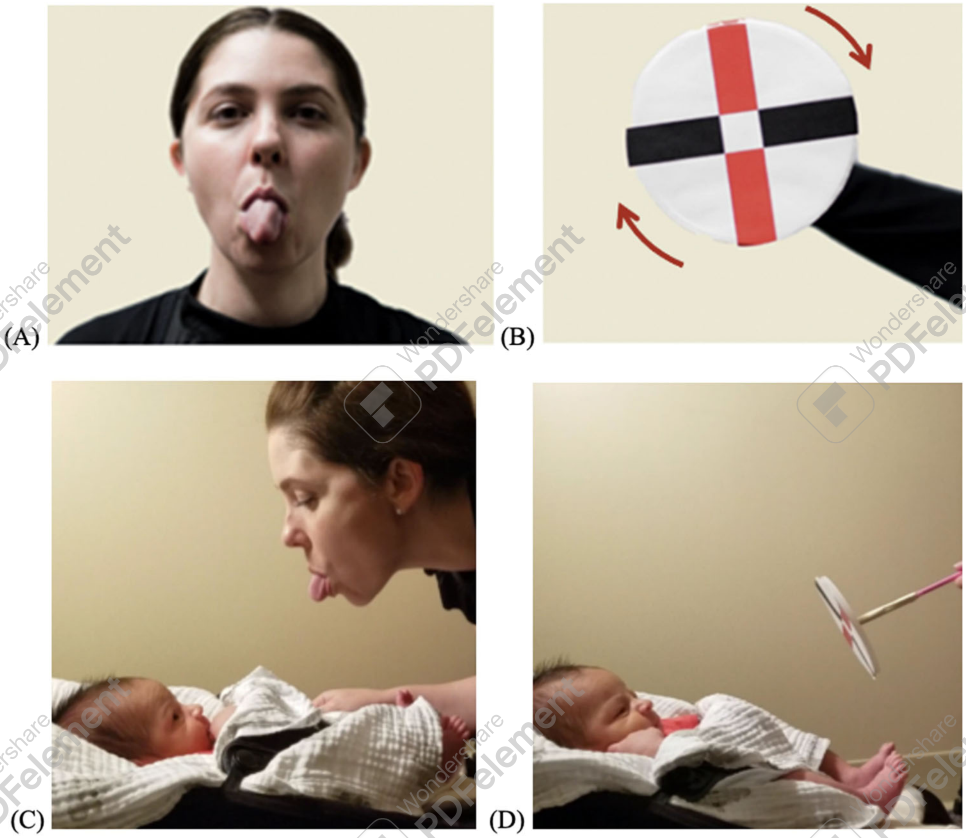

FIGURE 1 | Examples of newborn stimuli: (A) social stimulus (face with tongue protrusion/retraction), (B) nonsocial stimulus (rotating disk). Side views of the newborn experimental setup with (C) social and (D) nonsocial stimuli.

and one slightly to the right of the infant's head) to illuminate the stimuli and ensure the infant could see them (following procedures by Meltzoff and Moore 1989). These two spotlights highlighted the stimuli (adult faces and the disk) and minimized distractors. Newborns sat in a padded infant seat (BabyBjorn Bouncer Balance Soft Cotton), with an additional insert (DorDor & GorGor CuddleMe Infant Head Support with Organic Cotton 2-in-1 Reversible), inclined at an approximately 30° angle from the ground (the maximum recline setting), with a blanket under the infant and on top of the infant's torso and legs, for comfort. The seat supported the newborn in a relaxed, semi-upright position.

2.3.3 | Newborn Testing Procedure

Before the family arrived, we determined the presentation order of the stimuli (i.e., whether the social [tongue protrusion, mouth opening] or nonsocial stimuli [disk] would be presented first) using a semi-randomized list of counterbalanced orders. Once the family arrived, we obtained informed consent from caregivers. Once the newborn reached a quiet, calm, and alert state, their parents placed them into the infant seat. The experimenters avoided interaction with newborns before testing. Once ready for testing, a white washcloth (30.5 cm × 30.5 cm, displayed at a visual angle of approximately 91° × 91°) occluded the stimulus from the newborn's view before the test began. Each condition began with a 20-s "acclimatization" period of the still stimuli (no movement) to allow newborns to become familiar with the test setting, immediately followed by the first burst-pause 3-min test period with either a face or disk. After the first stimulus, if the newborn continued to be in the appropriate state for testing, we immediately followed with the next condition. If not in the right state (e.g., fussy, sleepy), infants were given a break before the next condition was attempted. If, once the test started, the infant fell asleep or became fussy, we stopped the test and tried again after a short break.

The newborns were free to look wherever and whenever they wished. For newborns who were not looking at the stimulus at all, either because their eyes were closed or averted away from the stimulus, the experimenters tried to engage the newborn once (per condition) by making soft clicking sounds and repositioning the stimulus in the infants' gaze direction but made no further attempts to direct the infants' attention after that, even if the infant looked away again. The entire visit lasted 30–120 min, depending on how long the infant needed to get into an acceptable state for testing. Families received $50 for each of the two newborn visits.

2.4 | Older Infant Materials and Testing Procedure

2.4.1 | Stimuli: Older Infant Social and Nonsocial Videos

At each of the older infant visits (2, 4, 6, 8, and 14 months), infants observed a silent 10-s video pair, with one social video and one nonsocial video simultaneously played side by side (Figure 2;

FIGURE 2 | Human infant side view of the experimental setup (A) and a screenshot of the video stimuli (B).

Video S1). On one half of the screen, a spinning white disk with orthogonal red and black stripes on a black background, rotating 180°, moving across four locations (starting in the center, then moving to the top left, then the bottom left, and ending in the top right) was presented. On the other half of the screen, infants observed the social stimulus video, which displayed two middle-aged, White men looking at each other and then back to the camera, talking, smiling, and laughing, on a colorful background. Our goal was not to equate the social and nonsocial stimuli in their low-level features, but to design them such that one was of high *social* salience (i.e., socially relevant) and one was of high *low-level* salience (e.g., higher contrast, more movement). An advantage of this method, which has been used in prior research, is that infants have to overcome their initial low-level salience bias to attend to the social stimulus, providing us with their relative attention to each, when in competition with one another (e.g., Kwon et al. 2016; Maylott et al. 2020; Pierce et al. 2011). The location of the videos was counterbalanced so the social and nonsocial were equally likely to occur on the left and right sides of the screen. Each video was 560 × 320 pixels (15.0 cm × 8.5 cm; displayed at a visual angle of 14.3° × 8.1°) and appeared on a black screen, sized 1280 × 720 pixels (28 cm × 51 cm; visual angle of 26.3° × 46.0°). A previous study reported findings from a subset of these data but only focused on group-level patterns (Maylott et al. 2020).

2.4.2 | Older Infant Eye Tracker and Testing Setup

This video was presented on a remote 58.4 cm monitor (51 cm in width × 28 cm in height; visual angle of 46.0° × 26.3°) with integrated dark pupil eye tracking technology using a Tobii TX300 eye tracker (Tobii Technology, Danderyd, Sweden) (Figure 2B). We recorded infants' eye gaze via corneal reflection (sampling rate: 300 Hz). The test room had a constant illumination of 202 lux, achieved by standard overhead lights.

2.4.3 | Older Infant Testing Procedure

We followed infant eye-tracking guidelines (Hessels et al. 2015; Oakes 2010). Infants were required to be awake, alert, and calm for the testing. Infants sat on a parent's lap 60 cm from the monitor (Figure 2A). The parent was instructed not to speak or point to the screen during testing. All people (experimenters and additional family members) were quiet and positioned outside of the infant's view to reduce distractions.

Before testing, infants were calibrated with five to nine preset locations, including each corner and the center of the screen. We repeated calibrations for missed or unreliable points until they were considered acceptable. Calibrations of at least three points for each eye were deemed acceptable. After calibration, a central cartoon attracted the infant's attention. Then, the social–nonsocial video pair played while infants were free to look on or off the screen.

Testing ended once the video ended, or the infant was too sleepy or fussy to continue. If, once the video started, the infant fell asleep or became fussy, we stopped the test and attempted another session after a short break. In total, each visit took approximately 20–30 min (excluding breaks), with the infant's testing lasting 5–10 min. Families received $50 for each of the five older infant visits.

2.5 | Measures

2.5.1 | Newborn Measure: Continuous Affect Rating and Media Annotation (CARMA) Coding of Newborn Attentiveness

We used a common method to measure newborn visual attention holding by video recording newborns and then scoring offline, frame by frame, where newborns look. Raters ($N = 5$) blind to the conditions independently scored the newborns' attention to the stimulus while watching the newborns' video recordings during testing. The rating was completed offline using a Thrustmaster T16000M FCS joystick (www.thrustmaster.com; Carentoir, France) with the CARMA software (Girard 2014) on a Dell Windows computer with a 27-inch monitor. The raters rated how confident they felt that the newborn was looking at the stimulus on a scale from 0 (*definitely not looking*) to +100 (*definitely looking*). We exported the attention ratings at 1-s intervals, which we then averaged across the 3-min test for each condition of each newborn visit. This continuous measure allowed us to capture coders' ratings of the newborns' attention, giving more information than simply having coders make a categorical/dichotomous decision if the newborn was looking or not.

We created the newborn social attention score by averaging across the tongue protrusion and mouth opening conditions during each visit. We then averaged across the two newborn visits to create a mean face look score (*newborn social attention*), a mean disk look score (*newborn nonsocial attention*), and a *newborn overall attention* score (sum of newborn social attention score and newborn nonsocial attention score). Social and nonsocial attention scores, therefore, ranged from 0 (*not looking at all*) to 100 (*looking the entire test period*), and overall attention scores ranged from 0 (*not looking at all in either condition*) to 200 (*looking the entire time in both social and nonsocial conditions*).

All raters established inter-rater reliability based on the intraclass correlation coefficient (ICC) of the absolute agreement, two-way random effects model (k = 3; Koo and Li 2016) on the 1-s attentiveness ratings on 30% of all videos. The ICC was .85 (95% CI = [0.84, 0.86]) for overall attentiveness. At least two raters independently coded all videos. Each rater coded at least 47 videos (mean: 251.4 videos, SD: 187.74). For videos coded by multiple raters, we averaged across raters for analysis. In cases where raters disagreed in the initial training set of 10% of the videos (i.e., ICCs < .80), we retrained them by discussing discrepancies while rewatching the videos and reminding them of the operational definitions. Once the raters were retrained, they (again) independently coded the videos, after which we confirmed acceptable reliability (ICCs > .80) was achieved.

As an additional validity check, we also examined correlations between raters' average ratings and experimenter-reported infant attentiveness. Experimenter-reported infant attentiveness was tracked live during the newborn assessment. Immediately after each test, the experimenters who served as the face models were asked to rate each newborn's attention to their faces during the testing session on a scale from 0 (*not at all*) to 10 (*looking the entire time*). We then confirmed a strong positive correlation between the experimenter-reported infant attentiveness rating and the independent, blind, video-based rating of infant attention (averaged across the two visits), $r\,(77) = 0.524$, $p < 0.001$.

2.5.2 | Older Infant (2–14 Months) Measures: Eye Tracking

To measure attention holding at each of the older ages, we extracted three dependent measures from Tobii Studio: nonsocial "fixation duration" (hereafter called *nonsocial attention*), social "fixation duration" (hereafter called *social attention*), and "fixation duration sum" (social + nonsocial; hereafter called *overall attention*). These measures were extracted from two areas of interest (AOIs), one around the social video and one around the nonsocial video, each measuring 632 × 578 pixels (17 cm × 15 cm; visual angle of 16.1° × 14.3°) using the I-VT fixation filter within Tobii Studio.

We included infants' data only if at least one fixation was detected on either side of the screen. This resulted in the exclusion of 12 infants (20% of the sample) at 2 months of age.

2.6 | Data Analyses

All analyses were performed in R version 4.3.1 and RStudio version 2023.12.1. We used a multilevel model-building approach in R by using the lme4 package (Bates et al. 2015; for model estimation) and lmerTest (Kuznetsova et al. 2017; for the statistical significance of fixed effects) to account for nesting in our data due to repeated measures, that is, nesting time within infants. We used full information maximum likelihood (FIML) within the HLM framework, which allowed us to use all available data and is able to account for missing data, that is, including all data points at Level 1 (individual visit) (Hox et al. 2017; Field and Wright 2011; Bryk and Raudenbush 1992). Newborn attention measures (overall, social, and nonsocial attention) and age were the predictors, and later attention measures (overall, social, and nonsocial fixation durations) were the outcomes. We recoded the ages for the outcome variable (2 months = 0; 4 months = 2; 6 months = 4; 8 months = 6; and 14 months = 12) by subtracting 2 from the age in months to make the zero intercept meaningful, that is, fixation duration when the baby was 2 months old, and to reduce the variance associated with quadratic and cubic terms in case of a nonlinear trajectory. We also mean centered the newborn measures (overall, social, and nonsocial attention) to make the intercept for each measure representative of an average infant.

3 | Results

3.1 | Preliminary Analyses

We confirmed that average developmental trajectories of attention replicated previous studies' findings of normative, average, nonlinear age-related changes (see Supporting Information Results and Discussion and Figures S1–S3).

3.2 | Overall Attention Hypothesis

3.2.1 | Overall Attention Hypothesis: Correlations

We found a statistically significant positive correlation between newborn social and nonsocial attention ($r\,(76) = 0.475$, $p < 0.001$; Figure 3). This finding indicates that newborns who looked more at one type of stimulus (e.g., social) also looked more at another type of stimulus (e.g., nonsocial), providing support for the overall attention hypothesis.

We also found that newborns had interindividual developmental stability in their overall attention between the two newborn visits (Visit 1 at Weeks 1–2 and Visit 2 at Weeks 3–4), $r\,(66) = 0.350$, $p =$ 0.004 (Figure 4), consistent with the overall attention hypothesis. These findings suggest that overall attention levels may be a stable interindividual difference across the newborn period.

3.2.2 | Overall Attention Hypothesis: Later Infant (2–14 months) Interindividual Stability ICC

Across all five ages, the ICC was 0.56 (95% CI = [0.37, 0.70]), that is, 56% of the variance in infants' overall attention was explained at the infant level, suggesting a small to moderate level of interindividual stability in overall attention across 2, 4, 6, 8, and 14 months of age (Figure S7).

3.2.3 | Overall Attention Hypothesis: Growth Curve Analysis

To examine the growth-related changes, our model examined whether age and newborn overall attention predicted older infants' overall attention from 2 to 14 months of age. A model-based intraclass correlation indicated that stability within infants

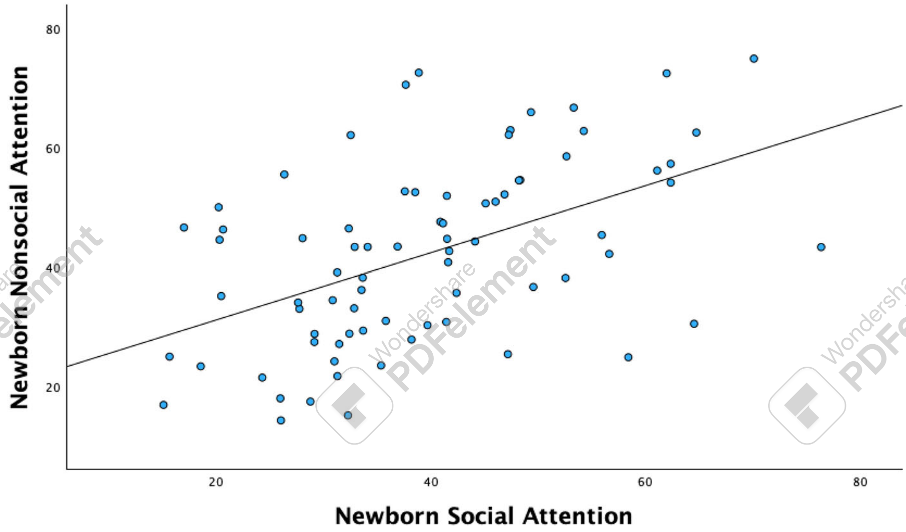

FIGURE 3 | Statistically significant positive correlation between newborn social attention and nonsocial attention. Scores for both social and nonsocial attention range from 0 to 100.

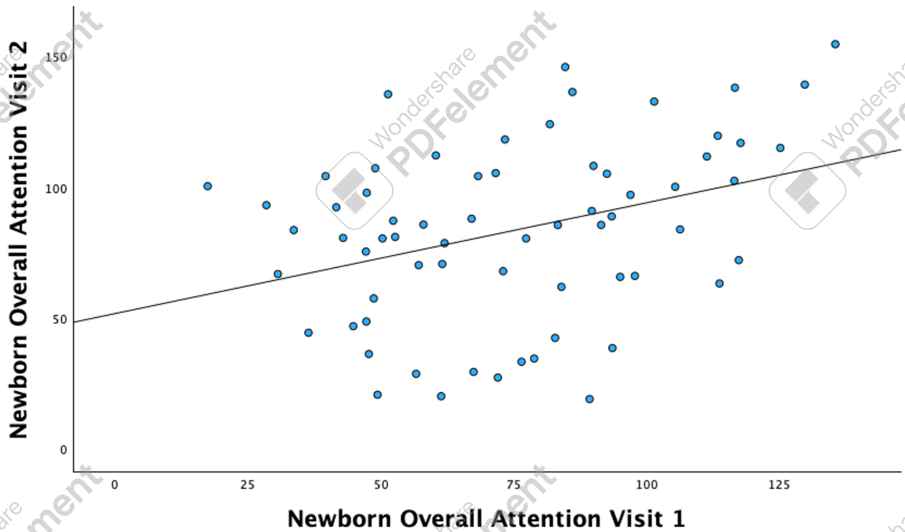

FIGURE 4 | Statistically significant positive correlation between newborn overall attention during Visit 1 and overall attention during Visit 2. Scores for overall attention ranged from 0 to 200 (newborn average attention to the faces [0–100] + disk [0–100]) as it combined social and nonsocial attention.

accounted for 22% of the variability in overall attention (i.e., fixation duration) from 2 to 14 months of age, highlighting the need for a multilevel model. After visually inspecting the plot of means (Figure S4) and conducting a likelihood ratio test comparing a model without linear effects to a model with linear effects, we included nonlinear effects of age in our final model (Table S1). The final model then examined the linear and quadratic effects of age, the impact of newborn overall attention, and the interactions between newborn overall attention and linear age, as well as newborn overall attention and the quadratic effect of age on later overall attention (Table 3).

The model revealed that infants' attention levels from 2 to 14 months followed a quadratic trajectory (b = −0.06, SE = 0.00, p < 0.001) above and beyond an increasing linear trajectory (b = 1.03, SE = 0.12, p < 0.001) (Table 3). Additionally, infants' attention from 2 to 14 months was predicted by the interaction between newborn overall attention and the quadratic age term (b = 0.001, SE = 0.00, p = 0.029), above and beyond an interaction between newborn overall attention and the linear age term (b = −0.01, SE = 0.01, p = 0.034). These findings support our prediction that newborn overall attention would be associated with overall attention (social and nonsocial) later in infancy. To further probe this effect, we conducted a simple slopes analysis to examine the interaction between age quadratic and newborn overall attention on later overall attention. At a low newborn total attention level (1 SD below the mean, i.e., 59.79), the simple slope age quadratic was statistically significant and negative (b = −0.09, SE = 0.01, t = −6.18, p < 0.001). At mean levels of newborn total attention (i.e., 84.63), the simple slope age quadratic was also statistically significant and negative but smaller in magnitude (b = −0.06, SE = 0.01, t = −6.70, p < 0.001). At high newborn total attention (1 SD above the mean, i.e., 109.47), the simple slope age quadratic remained statistically significant and negative but

TABLE 3 | Fixed and random effects of newborn overall attention (centered) predicting later overall attention.

Parameters	Estimate	Standard coefficient (β)	SE	p
Regression coefficient (fixed effects)				
Intercept (total fixation duration)	4.84	1.04e-04	0.36	< 0.001***
Age	1.03	1.35	0.12	0.001***
Age quadratic	−0.06	−1.09	0.00	0.001***
Newborn total	0.02	0.08	0.01	0.042*
Newborn total × age	−0.01	−0.36	0.01	0.034*
Newborn total × age quadratic	0.001	0.36	0.00	0.029*
Variance components (random effects)	Estimate	SD		
Residual	5.07	2.25		
Intercept	2.08	1.44		

Abbreviations: SD, standard deviation; SE standard error.
***$ps \leq 0.001$, *$ps < 0.05$.

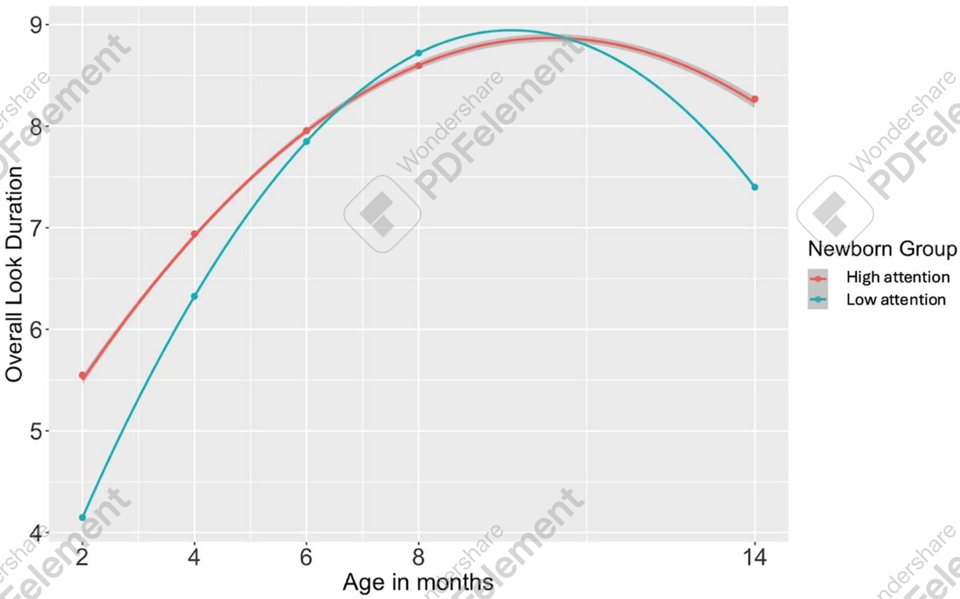

FIGURE 5 | Predicted values for overall infant attention (overall look duration in seconds) from 2 to 14 months for infants with high levels of newborn overall attention (above the median; red line), and low levels of newborn overall attention (below the median; light blue line).

was the smallest in magnitude ($b = -0.04$, SE = 0.01, $t = -3.19$, $p = 0.001$). These results indicate that the negative quadratic effect of age on the outcome variable decreased in magnitude as newborn total attention increased, suggesting that higher levels of newborn total attention may weaken the quadratic effect of age. This finding indicates that infants with higher newborn overall attention had higher initial levels of overall attention at 2 months and a steady increase in later attention from 2 to 14 months. In contrast, infants with lower newborn attention had a lower initial level of overall attention at 2 months, with a steep increase and then a decline (showing an inverted u-shaped pattern; Figure 5; Figure S9). Pseudo-R^2 values indicate that 27% of the variance in later infant overall fixation duration was explained at Level 1 (age), and 3.1% of the variance was explained at Level 2 (infant).

3.3 | Domain-Specific Attention Hypothesis

3.3.1 | Domain-Specific Hypothesis: Correlations

We found partial support for the domain-specific hypothesis in our examination of the developmental stability of interindividual differences in social and nonsocial attention within the newborn period. We found a positive correlation for newborn social attention between Visit 1 and Visit 2 ($r(65) = 0.359$, $p = 0.003$, Figure 6A). However, we did not detect a correlation in newborn nonsocial attention across the two visits, although it was in the predicted direction ($r(61) = 0.246$, $p = 0.056$; Figure 6B), failing to provide strong support for our prediction.

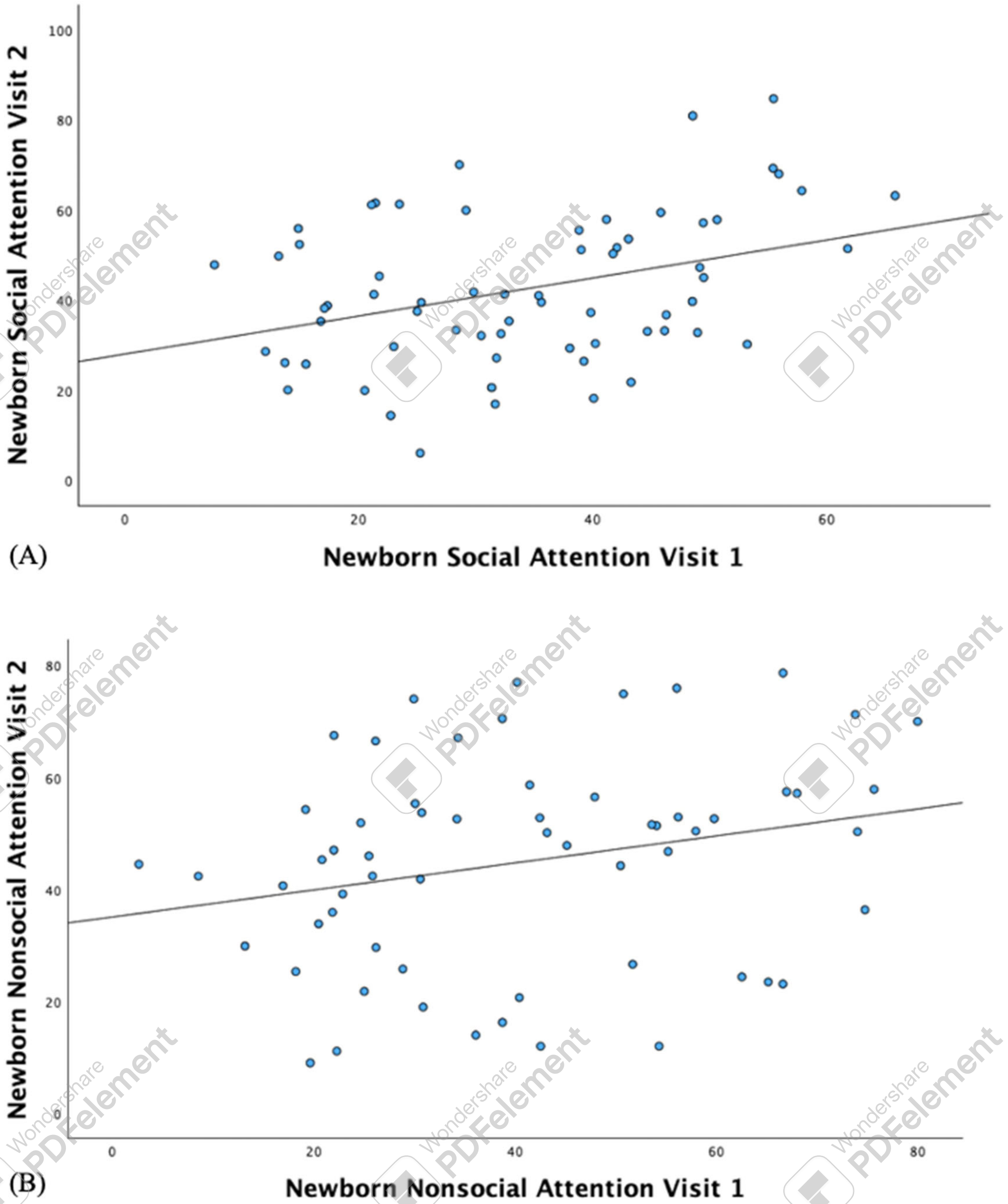

FIGURE 6 | Short-term developmental stability of interindividual differences in newborn social and nonsocial attention. Between Visits 1 (1–2 weeks of age) and 2 (3–4 weeks of age), we detected a positive correlation between newborn social attention (A), $r(65) = 0.359$, $p = 0.003$, but not between newborn nonsocial attention (B), $r(61) = 0.246$, $p = 0.056$.

3.3.2 | Domain Specific Attention Hypothesis: Later Infant (2–14 Months) Stability ICC

Across all five ages, the average ICC of a two-way mixed effects model was 0.43 (95 % CI = [0.22, 0.61]), indicating that 43% of the variance in infants' social attention was explained at the infant level, suggesting a small to moderate level of stability in social attention across 2, 4, 6, 8, and 14 months of age (Figure S8A).

In addition, across all five ages, the average ICC of a two-way mixed effects model was 0.31 (95 % CI = [.08, 0.50]), indicating that 31% of the variance in infants' nonsocial attention was explained at the infant level, suggesting a low level of stability in nonsocial attention across 2, 4, 6, 8, and 14 months of age (Figure S8B).

3.3.3 | Domain Specific Attention Hypothesis: Growth Curve Analysis

Our model examined whether newborn social attention and infants' ages predict infants' fixation duration to social stimuli at 2–14 months, while controlling for newborns' nonsocial attention. The intraclass correlation from the unconditional growth model

TABLE 4 | Fixed and random effects of newborn social attention (centered) predicting later social attention.

Parameters	Estimate	Standard. coefficient (β)	SE	p
Regression coefficient (fixed effects)				
Intercept	2.81	0.01	1.06	< 0.001***
Age	0.89	1.58	0.99	0.003*
Age quadratic	−0.26	−5.79	0.24	0.001***
Age cubic	0.02	4.34	0.01	< 0.001***
Newborn nonsocial	−0.00	3.48e-03	0.01	0.969
Newborn social	0.03	−0.03	0.03	0.171
Newborn social × age	−0.04	−1.09	0.02	0.051#
Newborn social × age quadratic	0.01	2.71	0.01	0.115
Newborn social × age cubic	−0.00	−1.68	0.00	0.171
Variance components (random effects)	Estimate	SD		
Residual	4.17	2.04		
Intercept	0.87	0.93		

Abbreviations: SD, standard deviation; SE standard error.
***$ps \leq 0.001$, *$ps < 0.05$, #$ps < 0.10$.

indicated that stability within infants accounted for 17% of the variability in infant social fixation duration from 2 to 14 months of age, highlighting the need for a multilevel model. After visually inspecting the plot of means (Figure S5) and conducting a likelihood test, we included nonlinear effects of age in our model (see Table S2 for results of likelihood ratio tests). The final model incorporated linear, quadratic, and cubic effects of age alongside the main effect of newborn social attention, as well as interactions between newborn social attention and the linear, quadratic, and cubic effects of age (Table 4). This model also controlled for newborn nonsocial attention in predicting the later social attention. This model revealed that there was a cubic trend of social fixation duration (showing an N-shaped pattern), with the time looking at the stimuli initially increasing from 2 to 4 months, then decreasing from 4 to 8 months, and finally increasing again from 8 to 14 months (Figure S5).

A growth curve model showed that infants' social attention levels from 2 to 14 months followed a cubic trajectory (b = 0.03, SE = 0.01, p = 0.017), which was not predicted by their newborn social attention (b = 0.00, SE = 0.00, p = 0.171; Table 4). These findings revealed that newborn social attention did not statistically significantly predict social fixation duration at 2 months or the trajectory of social fixation duration over time (2–14 months) in our sample. Pseudo-R^2 values indicate that 6.1% of the variance in fixation duration was explained at Level 1 (age), with no variance explained at Level 2 (infant). Therefore, we did not find support for our hypothesis that newborn social attention predicts later social attention.

Our last growth curve analysis examined whether interindividual differences in newborn nonsocial attention and age predict infants' fixation duration to nonsocial stimuli in later infancy. The intraclass correlation from the unconditional growth model indicated that stability within infants accounted for 12% of the variability in infants' nonsocial fixation duration from 2 to 14 months of age, highlighting the need for a multilevel model. After visually inspecting the plot of means (Figure S6) and conducting a likelihood test, we included nonlinear effects of age in our model (see Table S3 for results of likelihood ratio tests). The final model included linear and quadratic effects of age with an effect on newborn nonsocial attention and the interactions between newborn nonsocial attention with linear and newborn nonsocial attention with quadratic age effects when controlling for newborn social attention on later nonsocial attention (Table 5). The fixation duration to nonsocial stimuli revealed a quadratic trend with nonsocial fixation duration increasing initially and then decreasing until 14 months (showing an inverted u-shaped pattern; Figure S6).

This model showed that infants' nonsocial attention levels from 2 to 14 months followed a quadratic trajectory (b = −0.12, SE = 0.03, p < 0.001), which was not predicted by their newborn nonsocial attention (b = 0.00, SE = 0.00, p = 0.156). These findings revealed that newborn nonsocial attention did not statistically significantly predict nonsocial fixation duration at 2 months, nor did it predict the trajectory of nonsocial fixation duration over time (2–14 months). Pseudo-R^2 values suggest that 3.1% of the variance in nonsocial fixation duration was explained at Level 1 (age), with no variance explained at Level 2 (infant). Therefore, we did not find support for our hypothesis that newborn nonsocial attention predicts later nonsocial attention in our sample.

4 | Discussion

The current study examined interindividual differences in the development of infant social and nonsocial visual attention from the newborn period. While prior studies suggest meaningful

TABLE 5 | Fixed and random effects of newborn nonsocial attention (centered) predicting later nonsocial attention.

Parameters	Estimate	Standard. coefficient (β).	SE	*p*
Regression coefficient (fixed effects)				
Intercept	1.64	−7.85e-04	1.03	0.000***
Age	1.15	1.58	0.40	< 0.001***
Age quadratic	−0.07	−1.32	0.03	0.000***
Newborn nonsocial	0.04	0.01	0.02	0.058#
Newborn social	0.00	0.10	0.07	0.866
Newborn nonsocial × age	−0.01	−0.26	0.01	0.135
Newborn nonsocial × age quadratic	0.00	0.25	0.000	0.157
Variance components (random effects)	Estimate	SD		
Residual	5.39	2.32		
Intercept	0.76	0.87		

Abbreviations: SD, standard deviation; SE standard error.
***$ps < 0.001$, #$ps < 0.10$.

variability in newborn visual attention (e.g., Di Giorgio et al. 2016; Papageorgiou et al. 2015; Bradshaw et al. 2020), the developmental stability of these individual differences has not been studied longitudinally in low-risk, typically developing newborns. We found short-term developmental stability of individual differences in social and nonsocial attention within the newborn period (1–2 to 3–4 weeks) and within older infant ages (2–14 months), suggesting stable interindividual differences in different types of attention within and beyond the newborn period. We also found long-term developmental stability of interindividual differences in infants' overall attention (social and nonsocial attention combined) from the newborn period (1–2 to 3–4 weeks) through 14 months, with newborn attention predicting growth trajectories of later attention from 2 to 14 months of age, suggesting stable interindividual differences in visual attention from the newborn period through the first year. We did not, however, find long-term developmental stability of interindividual differences in social or nonsocial attention across this period (newborn though 14 months), suggesting that different mechanisms might underlie specific types of attention across these ages. Together, our findings strongly support the overall attention hypothesis and partially support the domain specific attention hypothesis, suggesting the newborn period may provide early insights into attentional development.

4.1 | Overall Attention

We found that newborns who looked longer at social stimuli also looked longer at nonsocial stimuli, similar to reports in newborn monkeys (Simpson, Paukner, et al. 2014) and older human infants (Wass and Smith 2014; White et al. 2022), as predicted by the overall attention hypothesis. Another study also that reported 2- to 3-day-old newborns' social attention predicted their nonsocial attention at 1 month of age (Barten and Ronch 1971), consistent with the interpretation that infants' attention to social and nonsocial stimuli is robustly linked, potentially reflecting stable interindividual differences in overall attention. We also found newborn overall attention (social and nonsocial combined) during Visits 1 and 2 were positively correlated. This finding is consistent with prior studies reporting developmental stability of interindividual differences in newborn overall attention from 1 day to 1 month of age using experimenter ratings (Horowitz et al. 1978; Worobey 1986). These studies and the current study, together, suggest stable interindividual differences in overall attention already in newborns.

Additionally, we found developmental stability of interindividual differences in overall attention starting from 2 months, earlier than previously reported (e.g., starting from 6–11 months; Heinicke et al. 1986; Rose and Feldman 1987; Rose et al. 2012; Ross-Sheehy et al. 2022). Infants may have stability even during the newborn period despite rapid development in visual acuity, attention control, and visual cortex maturation during this period (Graven and Browne 2008). Together, the current study and previous findings suggest that variability in infant overall attention may be a robust individual difference in early infancy.

Most notably, we found overall visual attention in the newborn period predicted trajectories of overall visual attention later in infancy from 2 to 14 months of age. That is, newborns who demonstrated high levels of overall attention continued to show higher levels at 14 months. This finding in low-risk, full-term, typically developing infants suggests that different patterns of newborn attention may be indicative of later developmental outcomes and aligns with previous research in high-risk and preterm populations (Bradshaw et al. 2020; Di Giorgio et al. 2016; Sigman et al. 1991). Our findings underscore that individual differences in infants' overall visual attention are meaningful and appear to be present from the newborn period, providing strong support for the overall attention hypothesis.

4.2 | Social and Nonsocial Attention

We found newborns who were more socially attentive at 1–2 weeks also were more socially attentive approximately 1–2 weeks later. Similarly, we also found a positive correlation for newborns' *nonsocial* attention across Visits 1 and 2 in the predicted direction, which approached, but did not reach, a traditional level of statistical significance. Together, these findings are in line with reports of newborns having stable interindividual differences in social (Barten et al. 1971) and nonsocial (Hood et al. 1996) attention from 2 to 3 days of age. Our findings demonstrate this stability lasts beyond the first days after birth, extending across the first month, in line with the domain specific attention hypothesis.

Similar to our findings in newborns, we found developmental stability of interindividual differences in social and nonsocial attention from 2 to 14 months of age, as predicted by the domain specific attention hypothesis. The current study used multiple dynamic (video) stimuli presented simultaneously, extending previous methods using photos presented one at a time, reporting stability of social attention from 3 to 11 months (e.g., Colombo et al. 1987; Peltola et al. 2013; Pyykkö et al. 2019; White et al. 2022; although no developmental stability of nonsocial attention from 6 to 9 months: Robledo et al. 2010). Together, these results suggest that interindividual differences in social and nonsocial attention are each developmentally stable across this period and may be sensitively captured with naturalistic video-based stimuli competing for attention.

For long-term stability, we found neither newborn social attention nor newborn nonsocial attention predicted later (2–14 month) social or nonsocial attention, respectively. These results may indicate either that these aspects of attention are not developmentally stable across this timespan, or that our methods were insensitive for detecting stability. Previous studies have also failed to detect associations between newborns' (2–3 days) and older infants' (4 months) social attention (Barten and Ronch 1971), and newborn (2 days) and older infants' (6 months) nonsocial attention (Hood et al. 1996). This apparent lack of developmental stability could be, at least in part, due to rapid changes from the newborn period to later infancy, including changes in the neural mechanisms that may be driving their behaviors (Colombo et al. 1987; Yan et al. 2024). For example, according to one model, newborns initially attend to faces using a subcortical mechanism (CONSPEC) driven by low-level visual features, but then around 2–3 months, a cortical mechanism (CONLERN) emerges, guiding attention to faces due to their social meaning (Portugal et al. 2024; Morton and Johnson 1991). This shift in underlying mechanism may explain why infants' social attention preferences are not stable from birth through early infancy. There may be a similar shift in the mechanisms guiding nonsocial attention across these ages (Hood et al. 1996).

4.3 | Methodological Considerations, Limitations, and Future Directions

While the current study offers an insight into interindividual differences in the age-related development of infant visual attention, it had some limitations. For example, our methods may have been insensitive in capturing long-term developmental stability of individual differences in social and nonsocial attention from the newborn period through 14 months. One potential reason is that our sample size—while larger than most longitudinal studies of newborns—was relatively small and may have prevented us from detecting small effect sizes. Another challenge of designing longitudinal studies is that the methods used in newborns are not always appropriate for older infants, which may have contributed to our failure to detect long-term developmental stability. In the current study, our goal was to use measures sensitive for capturing individual differences in attention, using naturalistic and age-appropriate stimuli; therefore, there were methodological differences between newborns and older infants assessments. For example, we assessed newborns with live stimuli, presented one at a time, each for 3 min, whereas we assessed 2- to 14-month-olds with video stimuli, presented two at a time, and for 10 s each. We chose these different paradigms because newborns are more responsive to live stimuli than videos (Slater et al. 2010), while older infants respond to videos similarly to real-world stimuli (Diener et al. 2008). Additionally, newborns, unlike older infants, have a more difficult time processing more than one stimulus at a time (Reynolds and Romano 2016), whereas older infants can better attend to multiple briefly presented stimuli (Ross-Sheehy et al. 2003). In sum, necessary methodological differences for newborns and older infants may have contributed to the lack of long-term stability in social and nonsocial attention.

The extent to which our findings may generalize to a broader range of social and nonsocial stimuli remains unclear. Different types of social stimuli (e.g., faces varying in their eye gaze, individual people vs. people interacting) may differentially hold attention (Magrelli et al. 2013; Klin et al. 2009; Simpson et al. 2020; Thiele et al. 2021). Similarly, nonsocial stimuli can vary in how much they attract attention based on low-level salience (e.g., contrast, brightness, shape) and complexity (Sasson et al. 2008). Future research using a broader range of stimuli—both social and nonsocial—will enhance visual attention measurement reliability (Byers-Heinlein et al. 2022) and help uncover the generalizability of our findings to the diverse types of stimuli infants encounter in everyday life (Curtindale et al. 2019; Wass and Smith 2014).

5 | Conclusions

There are remarkably few studies of normative newborn visual attention (Nagy 2011; Shultz et al. 2018), a period marked by significant increases in brain size (Holland et al. 2014), rapid visual cortex maturation (Graven and Browne 2008), and growing behavioral complexity (McGowan and Delafield-Butt 2023; Nagy et al. 2017). Here, we found evidence of long-term developmental stability of interindividual differences in typically developing infants' overall visual attention within and beyond the newborn period, providing strong support for the overall attention hypothesis. We also found short-term developmental stability of interindividual differences in social and nonsocial attention within the newborn period and from 2 to 14 months; however, we failed to detect long-term developmental stability of interindividual differences in social and nonsocial attention from newborns through 14 months, providing only moderate support of the domain specific attention hypothesis. This study highlights the importance of examining interindividual differences in developmental trajectories of visual attention from healthy, low-risk newborns through the first year after birth, which provides a basis for beginning to understand this variability in newborn attention and its potential cascading effects on later development.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

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

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Supporting Information

Additional supporting information can be found online in the Supporting Information section.

Supplementary Video 1: Example nonsocial (left) and social (right) video shown to 2–14-month-old infants. **Supplementary Materials**: dev70054-sup-0001-SuppMat.docx