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Using Head-Mounted Eye Tracking to Examine Infant Face Looking During Naturalistic Freeplay

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Abstract

Infants' attention to faces is a critical component of social development, yet little is known about how face looking unfolds during real-world interactions. Using head-mounted eye tracking and computer vision, we investigated the availability of faces in infants' field of view and their face-looking behaviors while playing with caregivers. Faces were visible only 23% of the time, and even then, infants looked at them only 19% of the time. Time series analyses revealed that face visibility is unrelated to face looking; Infants orient their head and body to bring a face into view when they intend to look at it, rather than looking because a face is present. Face looking is related to the face's visual properties and is only slightly influenced by parents' face looking. These findings highlight the active nature of infant face looking and suggest that it is shaped by both visual features and infants' own interest.

Keywords: head-mounted eye tracking; automatic face detection; infancy; social attention

Introduction

During face-to-face interactions, gaze plays a crucial role in social communication, signaling attention, engagement, and intent (Emery, 2000; Kleinke, 1986). Mutual gaze fosters connection, facilitates turn-taking in conversation, and helps interpret social cues, making it a fundamental aspect of human interaction (Argyle & Graham, 1976; Csibra & Gergely, 2006). However, adult-like, social attention takes time to develop. Examining how infants look at faces provides insight into the emergence of social attention and the factors that shape early engagement with social partners.

From the earliest months of life, infants prefer to look at faces presented in controlled settings (Figure 1A), such as images on screens or videos of social interactions (Farroni et al., 2005; Johnson, Dziurawiec, Ellis, & Morton, 1991; Ronga et al., 2025). Infants tend to fixate on faces longer than other visual stimuli, particularly when those faces are moving, making eye contact, or displaying exaggerated expressions (Batki, Baron-Cohen, Wheelwright, Connellan, & Ahluwalia, 2000; Farroni, Csibra, Simion, & Johnson, 2002; Frank, Vul, & Johnson, 2009; Pipp & Haith, 1977). These early patterns of face looking provide a foundation for later social interactions, supporting the development of joint attention, emotion recognition, and social learning (Atagi & Johnson, 2020; Brooks & Meltzoff, 2002, 2005; Pascalis, de Haan, & Nelson, 2002). Disruptions in face looking, such as reduced attention to faces and eyes, have been linked to difficulties in social engagement and likelihood for autism spectrum disorder (Merin, Young, Ozonoff, & Rogers, 2007).

Although face looking plays a foundational role in early social interactions, much of the existing research has been conducted in controlled laboratory settings, where infants are seated in front of a screen and presented with artificial stimuli. While these studies have been instrumental in identifying characteristics of face looking, they do not capture how infants encounter and attend to faces in everyday contexts. In natural settings, face looking is constrained by the availability of faces and by infants' actions and posture. Infants cannot learn from faces if they do not look at them, but they also cannot look at faces if they aren't available.

Recent advances in wearable technology, such as head-mounted cameras, have provided a more ecologically valid perspective on infants' visual experiences (Figure 1B). These studies indicate a striking shift in visual input across the first two years: infants transition from viewing predominantly faces to predominantly hands (Fausey, Jayaraman, & Smith, 2016; Jayaraman, Fausey, & Smith, 2015). However, infants'

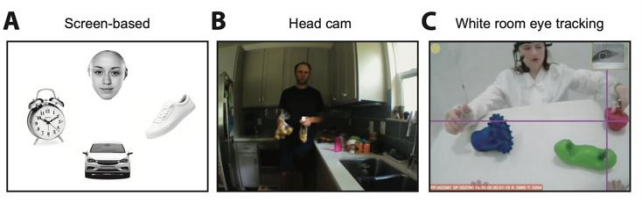


Figure 1: Traditional methods used to study face looking. A) Reconstruction of typical stimuli for screen-based face preference studies. B) Headcam worn by infant at home. C) Eye tracker worn by infant in White Room study in the lab.

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first-person view in everyday contexts is typically cluttered, containing many objects at once. Thus, face availability alone does not account for face-looking. Infants must actively choose to look at an available face or move their body to attend to a nearby but not in view face. Studies employing head-mounted eye trackers (Figure 1C) demonstrate that infants infrequently look at caregivers' faces during free play —less than 10% of the time (Franchak, Smith, & Yu, 2024; Yu & Smith, 2013, 2017). Notably, most of these studies rely on free-flowing behavior, but in a stripped-down "White Room" lab environment in which infants and parents are seated across from one another (Figure 1C; although see (Franchak, Kretch, & Adolph, 2018).

One key factor in the occurrence of natural face looking appears to be posture. When infants are sitting or standing, faces are more available (Long, Sanchez, Kraus, Agrawal, & Frank, 2022) and infants look at them more frequently (Franchak et al., 2018) compared to when lying prone, suggesting that physical constraints influence face-looking behavior. However, beyond posture, little is known about the real-time dynamics that shape when and why infants look at faces in everyday interactions. Given the well-documented importance of social attention for social development, it is striking how rarely infants look to caregivers' faces. What factors contribute to these moments of engagement? Do the same visual factors that facilitate infant attention to toys (e.g., size and distance to the center of the field of view) also facilitate attention to faces (Mendez, Yu, & Smith, 2024; Smith, Yu, & Pereira, 2011)?

The present study addresses these questions by examining both the availability of faces and the real-time dynamics of face looking in a naturalistic setting. We conducted the study in the Home-like Observational Multimodal Environment (HOME) lab, a space designed to resemble a functional apartment with a kitchen area, a living room, and a child-friendly play area (Figure 2). Parents and infants were invited to move freely within this space while playing with toys. Both



Figure 2: HOME Lab

participants wore head-mounted eye trackers (Figure 3), allowing us to capture their moment-to-moment gaze behavior. Additionally, we employed computer vision techniques (RetinaFace) to automatically track parents' faces in infants' first-person views (Figure 3), enabling precise measurement of face availability and measures of the size and location of the face at every moment. This study aims to address four primary questions:

1. What is the availability of caregivers' faces in infants' field of view during everyday play?
2. Given the availability of faces, how often do infants look at them?
3. How do the visual properties of faces influence infant attention?
4. When and why do infants look at their parents' faces? Is face-looking influenced by parent behaviors, such as parental gaze, speech, or object handling?

By investigating face-looking in a setting that more closely approximates infants' everyday experiences, this study aims to understand the factors that drive face looking and provide a more comprehensive understanding of how infants allocate attention to socially meaningful stimuli.

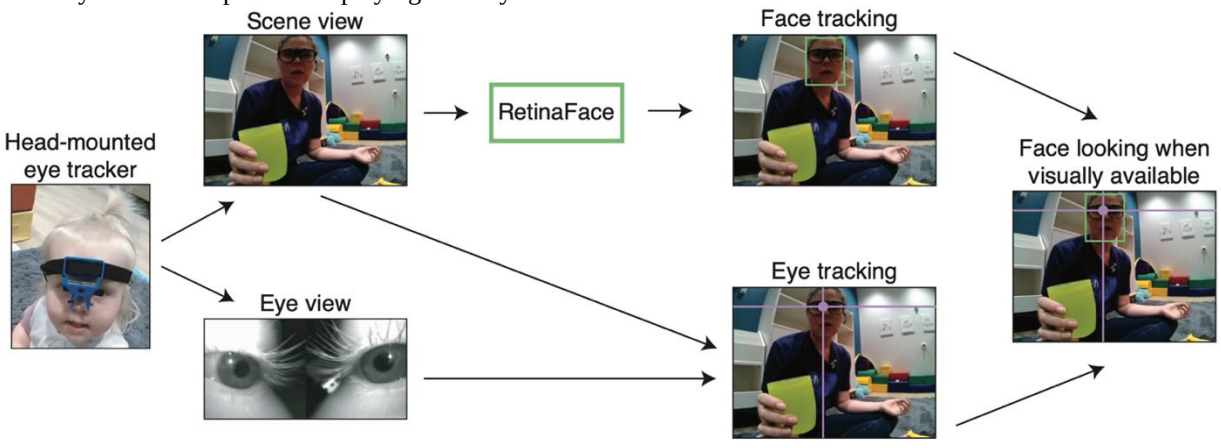


Figure 3: A dyad playing in the HOME Lab. Both wore head-mounted eye trackers that consisted of a scene camera and two eye cameras. The two views were automatically synced and calibrated by the Neon system to generate a gaze video where the purple crosshair represents where the infant is looking. RetinaFace was applied to the scene view to generate bounding boxes of the face's location for each frame. Eye tracking and face tracking data were put together to determine moments of face availability in infants' field of view and moments of face looking during availability.

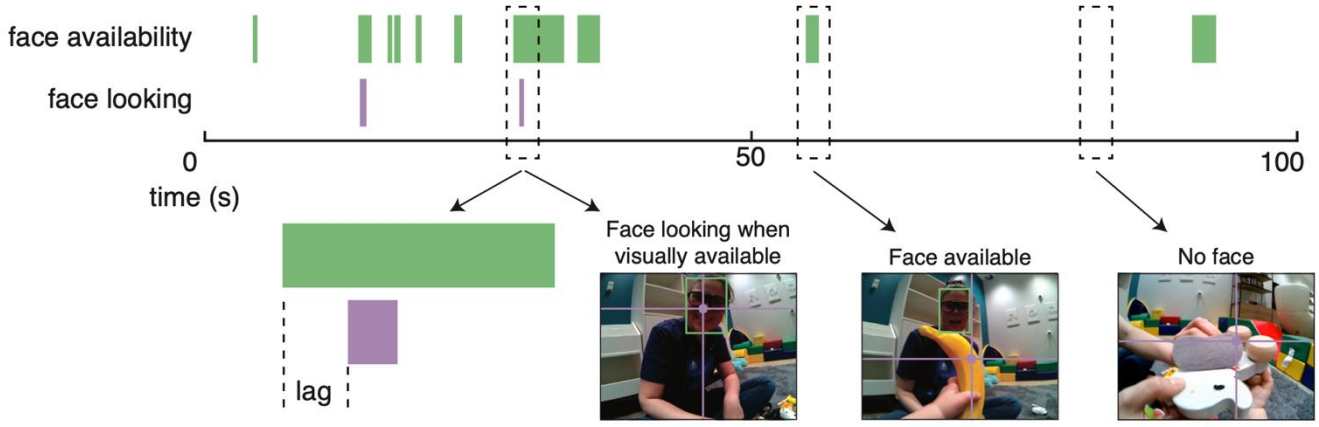


Figure 4: Data streams of face availability and face looking for a single infant. Lag from availability to looking was calculated as the difference between onsets. Photos show the infant's field of view during all possible combinations of availability and looking.

Method

Participants

The sample consisted of both cross-sectional and longitudinal data. Thirty-five parent-child dyads (15 female infants) participated between one and four times (spaced approximately three months apart), for a total of 57 play sessions. Nineteen dyads participated once, 11 participated twice, four participated three times, and one dyad participated in all four sessions. Child age ranged from 14 to 31 months (M = 21.25 months, SD = 4.70). Parents reported children's race as White (86%), Asian (6%), Native Hawaiian or Pacific Islander (3%), or multi-race (6%), and children's ethnicity as non-Hispanic (80%), or Hispanic (20%).

Procedure

Parents and children played in a home-like laboratory environment with 27 toys (animals, vehicles, and food items). Dyads wore head-mounted eye-trackers (Pupil Labs NEON; Figure 3) and parents were told to play like they usually would at home. Sessions lasted 10 minutes or until children removed the eye tracker (M = 8.22 minutes, range = 1.68 – 12.28). Each eye tracker consisted of three cameras, one that was centered on the forehead and recorded the participant's field of view and two that recorded the participant's eyes (Figure 3). Calibration was done automatically by the eye tracker after a small online correction by the experimenter.

Behavioral Coding

Following the play session, visual attention and manual actions for both parents and children were coded using Datavyu. The onset and offset of each fixation was automatically detected by Pupil Labs software and subsequently imported into Datavyu for coding. Coders then classified each fixation according to the region of interest (ROI), identifying whether infants were looking at a toy or a face; fixations directed elsewhere were excluded from analysis. Any fixation to the caregivers' face was counted as a face look. Manual actions were coded separately for the left and right hands, with any physical contact with an object included. Parental speech was automatically transcribed using Whisper software and then reviewed and corrected by coders to ensure accurate timing and eliminate typos and errors.

Face Tracking

We first used RetinaFace, a pretrained convolutional neural network in Python to automatically detect faces in the infants' point of view frame by frame (Deng, Guo, Ververas, Kotsia, & Zafeiriou, 2020; Yurkovic-Harding & Bradshaw, 2024). Next, we removed any face-in-view segment with fewer than five consecutive frames to account for random errors in face detection. In addition, any gap between two face-in-view segments that was fewer than five frames was smoothed using linear interpolation.

The algorithm provided information about the visual properties of faces. Given prior findings that infants attend most to objects that are large and centrally positioned (Mendez et al., 2024; Smith et al., 2011), we focused on these for analysis. Face size was the percentage of the screen the bounding box occupied. Face distance was the distance between the center of the screen and the closest edge of the bounding box. A value of 0 represents the center of the field of view and 1 represents a corner, with smaller values indicating greater proximity to the center.

Data Analysis

We used linear mixed effects models with the lme4 package in R. Given that some infants participated in multiple sessions and others participated only once, we accounted for the nested structure of the data by including random intercepts for both infant and session nested within infants. Child age was not a significant predictor in any model and did not improve model fit (evidenced by likelihood ratio tests) so it was removed from analyses.

Results

Face Availability

Across the 57 play sessions, caregivers' faces appeared in infants' field of view a total of 2,778 times. On average, faces were available six times per minute (M = 5.96, SD = 2.27), with each bout typically lasting only a few seconds (M = 2.31 seconds, SD = 3.22). Thus, caregivers' faces were visible for just a quarter of the total session duration (M = 23%, SD = 15; Figure 5A), highlighting the limited visual access infants had to their caregivers' faces during play.

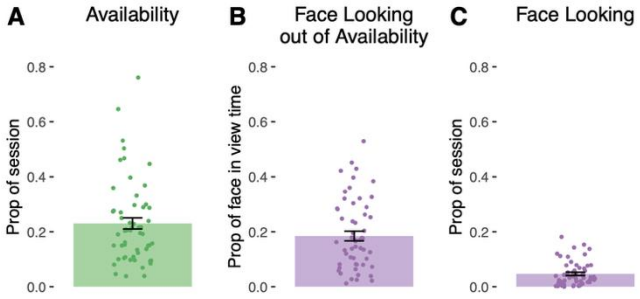


Figure 5: A) Visual availability of caregivers' faces in infants' field of view. B) Time infants spent looking at faces out of the time faces were available. C) Overall time infants spent looking at faces.

Face Looking

Even with the limited time that faces were available in the field of view, infants looked at them only 19% of the time (SD = 13%; Figure 5B). Thus, on average, infants spent just 5% of the total session looking at their caregivers' faces (SD = 4%; Figure 5C), a pattern consistent with previous findings (Franchak et al., 2018; Yu & Smith, 2013). Infants directed their gaze toward caregivers' faces an average of 2.34 times per minute (SD = 1.64).

When infants did look at caregivers' faces, they did so relatively quickly after the face entered their field of view (M = 1.19 seconds, SD = 2.66; first face look within a face availability bout). Indeed, nearly 40% of face looks occurred within 0.25 seconds of the face appearing (first bar in Figure 6), suggesting that infants were not simply responding to face availability. Instead, they actively oriented their heads and bodies to bring caregivers' faces into view when they intended to look at them. However, some face looks occurred after a lengthier delay, as indicated by the long tail.

Although infants' face looks were generally brief (M = 1.21 seconds, SD = 1.17), individual face looks were longer than individual toy looks (M = 1.04 seconds, SD = 1.64; b = -0.17, SE = 0.05, t = −3.58, p < .001 (Figure 7). Half of toy looks 0.5 seconds or under whereas half of face looks were 0.75 seconds or under. However, infants spent much more of the session looking at toys (M = 62%, SD = 16%) than they did faces, t = 26.87, p < .001.

Visual Properties of Attended Faces

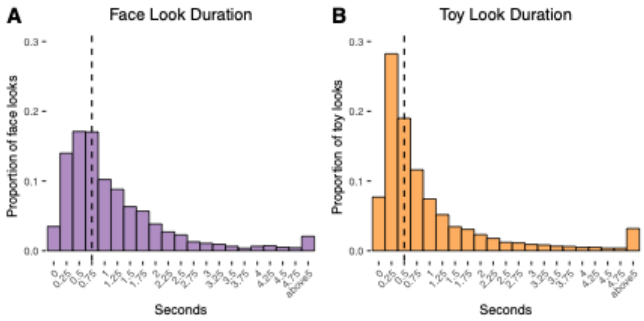


Figure 7: Infant look duration by target.

Even when infants attended to faces, the faces occupied a relatively small percentage of the visual field (M = 4% of the field of view, SD = 4; Figure 8A). For 50% of face looks, the face comprised 3% of the visual field or less.

However, the visual size of the face was related to infant looking behavior. Faces were bigger during moments when infants were looking at them, compared to moments when infants were attending elsewhere but the face was in view, b = 2.47, SE = 0.28, t = 8.91, p < .001. However, face size was not related to the duration of face looks, b = -2.20, SE = 1.59, t = -1.38, p = 0.17.

In addition, when infants attended to faces, those faces were likely to be positioned near the center of the field of view (M = 0.16, SD = 0.13; Figure 8B). For half of face looks, the closest point of the face to the center was within the middle 10% of the field of view.

Face location was also linked to looking behavior. Faces were more centrally positioned when infants were looking at them compared to moments when they were attending elsewhere but the face was in view, b = -1.29, SE = 0.04, t = -33.24, p < .001. Additionally, infants maintained attention on faces for longer durations when the face was more centrally positioned, b = -2.52, SE = 0.47, t = -5.24, p < .001.

When and Why Infants Look at Faces

This section reports our first attempt to better understand the circumstances under which infants look at faces. To achieve this goal, we analyzed the time courses of parents' speech, face looking and manual actions on objects around infant face looks. We operationally defined a 20-second window around a parent's behavior. At each 1/30-second interval (30 frames per second), we recorded whether the infant was looking at the parent's face (0 = no, 1 = yes). Averaged across all

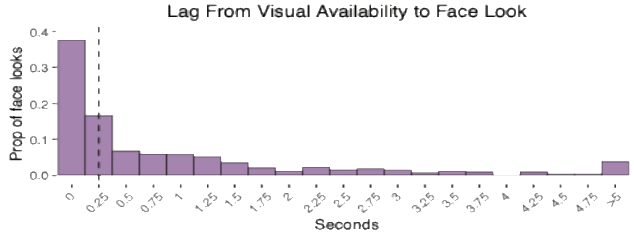


Figure 6: Lag between when face came into view and when infants looked at it.

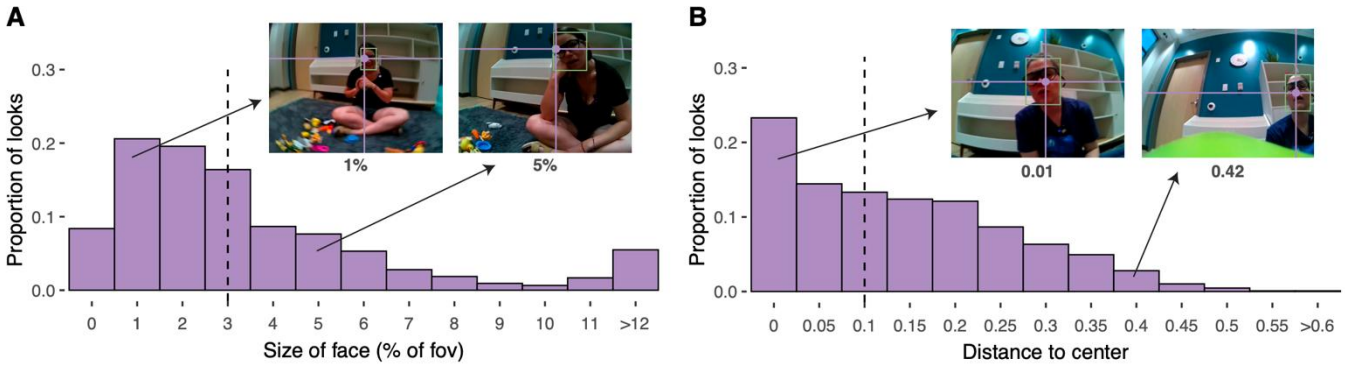


Figure 8: A) Size of caregivers' faces during moments of infant attention. Numbers indicate percentage of the visual field the face occupies. B) Distance from the center of the field of view to the closest point of the face bounding box. Smaller numbers indicate closer to center.

participants, this provides the probability of face looking at that moment. To determine if there was a significant change in face looking probability based on the behavior, we created a shuffled baseline by randomly reassigning the timing of the infant's face looking data within each session. We then performed t-tests at each time point, comparing the observed probability to the shuffled baseline with Bonferroni correction for multiple comparisons (Allopenna, Magnuson, & Tanenhaus, 1998; Yu & Smith, 2012). This analysis identified the specific time points where infant face looking first differed from baseline (and remained different).

Figure 9A illustrates the likelihood of an infant face look occurring within 10 seconds before and after a parent face look (purple line), compared to a shuffled baseline (grey

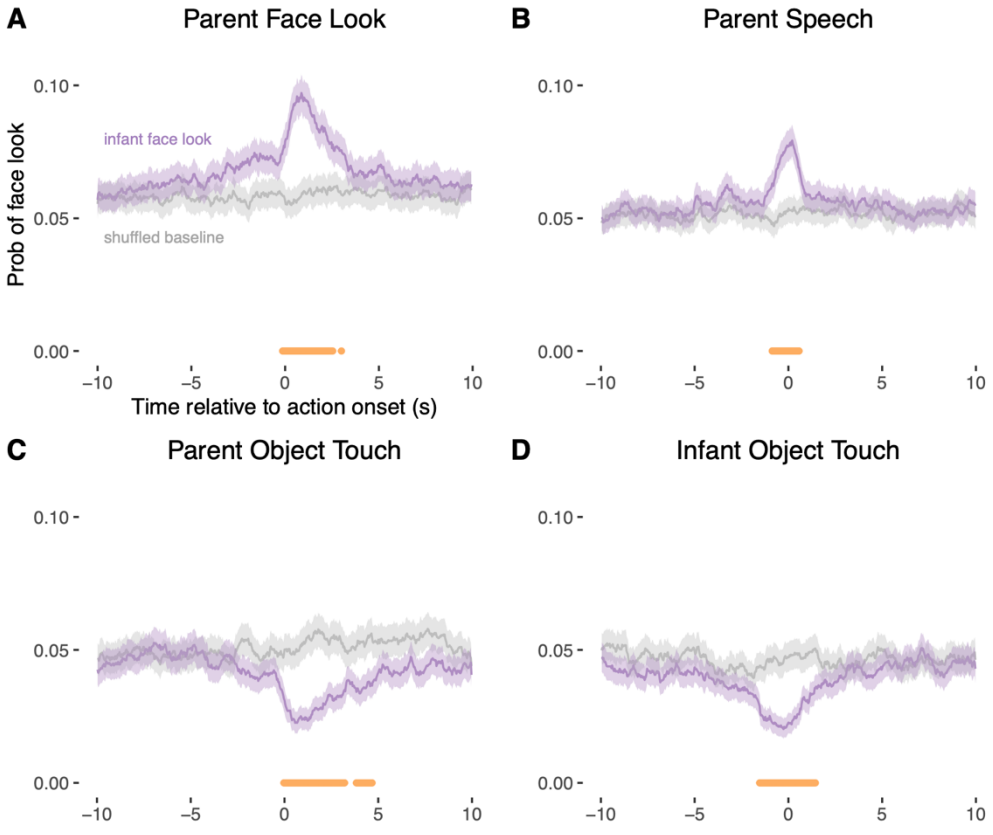


Figure 9: Timing relations between infant face looking and infants' and parents' behaviors. Purple lines indicate the probability that infants looked at parents' faces at that moment in time. Grey lines indicate a shuffled baseline of infant face looking. Orange dots indicate moments when the probability of face looking is significantly different from baseline ($p < .05$ with Bonferroni correction). A) Instances when parent looked at infants' faces. B) Instances of parent speech. C) Moments when parents touched an object. D) Moments when infants touched an object.

line). The orange markers at the bottom of the plot indicate that the probability of an infant face look began to significantly diverge from baseline at the onset of the parent's face look. This suggests that parental face looking has some influence on infants' likelihood of looking back. However, even at its peak, the probability increased by only 4%, indicating that parental face looking is not the primary driver of infant social attention. In contrast, infant face looking was associated with a 40% increase in parent face looking. Overall, 73% of infant face looks resulted in mutual gaze.

The relation between infant face looking and parent speech revealed a different pattern (Figure 9B). Infants were more likely to look at parents' faces shortly before parents spoke, suggesting that parents tended to initiate speech when infants were already attending to them, rather than speech prompting an infant face look. However, the increase in face looks prior to speech onset was modest (2.5%).

In contrast, infants were less likely to look at parents' faces around moments when either partner touched an object. Specifically, infants were 2.3% less likely to look at parents' faces right as parents touched a new object, potentially because they were focused on parents' movement (Figure 9C). Additionally, infants were 2.5% less likely to look at faces beginning 1.5 seconds before their own object touch, suggesting they were allocating attention and planning to their upcoming reach.

Discussion

Experimental studies show that infants prefer to look at faces and headcam studies show face availability in daily life. Yet free play studies in the lab show that infants rarely look at faces. Does this simply reflect less face availability? We show that the answer is no. In fact, for this age range, we found slightly greater face availability than in headcam work (Fausey et al., 2016), likely because headcam studies measure availability in different activities across the day, whereas our study focused on a specific context where dyads were engaged in play. However, the key is that infants still rarely looked at faces, even when they were available—a pattern also found by Yurkovic-Harding and Bradshaw (2024) with younger infants. Thus, the results based on headcam studies may overestimate the amount of time infants spend looking at faces.

When infants did look at faces, it was often immediately after a face appeared in view, suggesting that looking was not simply a response to face availability but may have involved an active repositioning process, though this remains untested. Future work using motion tracking could determine whether infants orient their heads or bodies to bring a face into view before looking. Another possibility is that parents move their faces into infants' field of view in ways that capture attention quickly. However, given that 40% of face looks occurred within 0.25 seconds of a face appearing, this explanation seems unlikely. If infants actively reposition their heads before looking, this suggests they track their caregiver's location, even when not directly looking—whether through peripheral vision, auditory cues, or working memory.

However, face availability and face looking likely vary across contexts, perhaps in part due to posture and body orientation (Franchak et al., 2018; Long et al., 2022). For example, when caregivers and infants are each engaging in their own activities, such as when a parent is cooking dinner and the infant is playing nearby, faces may be less available. But in this type of situation, face looks may be even more deliberate: if the face does appear in view, it is likely because the infant actively repositioned to make it happen. In contrast, structured interactions like mealtimes, where dyads sit across from each other, likely yield higher face availability rates. Even in these cases, however, face looks likely remain far less frequent than the near-universal face preference reported in controlled experiments.

As is the case with objects (Mendez et al., 2024; Smith et al., 2011), visual properties of faces were related to infant looking. Previous work has shown that infants adjust their posture and head orientation to center attended objects in their field of view and minimize motion to stabilize perception (Borjon, Abney, Yu, & Smith, 2021; Franchak et al., 2024). The results from the time series analyses suggest that a similar process may shape face looking: if infants bring a face into view, it would make sense for them to fully lift their gaze and center it. Visual size may also play a role—infants could be leaning forward to increase the apparent size of the face, or parents may be responding to mutual gaze by getting closer to the infant to enhance engagement.

Despite our detailed analysis of parent behaviors, no single variable strongly predicted face looking, suggesting that it serves multiple functions in social interaction. In any interaction, an individual can either send or receive information, and face looks likely serve both purposes. Infants may look at faces in response to social cues, such as a parent speaking or gesturing. Although, parents were highly engaged throughout the play sessions, and yet infants rarely looked at them, suggesting that only certain social cues elicit a gaze response. Infants may also initiate social engagement, seeking acknowledgment, validation, or input. Identifying which caregiver behaviors capture infants' attention is an important direction for future research.

Regardless of why infants looked at faces, they consistently received a response from their parents—most infant face looks led to mutual gaze. This highlights the bidirectional nature of face looking and suggests that even infrequent face-directed attention may have important consequences for social learning. Given that mutual gaze is a key mechanism for social exchange and information transmission (Argyle & Graham, 1976; Csibra & Gergely, 2006), understanding what drives these brief but meaningful moments of engagement is critical. Although further research is needed to fully predict when and why infants look at faces. Toward this goal, the present findings provide an important step in understanding how infants allocate attention in real-world social interactions.

Acknowledgements

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