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Yurkovic-Harding, Julia
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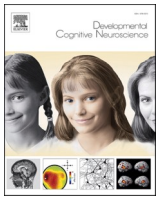

Multimodal pathways to joint attention in infants with a familial history of autism

Lauren M. Smith [a,*], Julia Yurkovic-Harding [b], Leslie J. Carver [a]

[a] University of California, San Diego - Department of Psychology, Ja Jolla, CA 92093, USA
[b] University of South Carolina - Department of Psychology, Columbia, SC 29208, USA

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ABSTRACT

Joint attention (JA) is an early-developing behavior that allows caregivers and infants to share focus on an object. Deficits in JA, as measured through face-following pathways, are a defining feature of autism spectrum disorder (ASD) and are observable as early as 12 months of age in infants later diagnosed with ASD. However, recent evidence suggests that JA may be achieved through hand-following pathways by children with and without ASD. Development of JA through multimodal pathways has yet to be studied in infants with an increased likelihood of developing ASD. The current study investigated how 6-, 9- and 12-month-old infants with (FH+) and without (FH-) a family history of ASD engaged in JA. Parent-infant dyads played at home while we recorded the interaction over Zoom and later offline coded for hand movements and gaze. FH+ and FH- infants spent similar amounts of time in JA with their parents, but the cues available before JA were different. Parents of FH+ infants did more work to establish JA and used more face-following than hand-following pathways compared to parents of FH- infants, likely reflecting differences in infant motor or social behavior. These results suggest that early motor differences between FH+ and FH- infants may cascade into differences in social coordination.

1. Introduction

Caregivers and their infants find ways to communicate with one another long before infants produce language. In addition to language, parents use nonverbal cues, such as gaze, to direct their infants' attention (Scaife and Bruner, 1975). Infants are able to follow these cues to establish joint attention (JA), or moments when the parent and child share attention on the same object or event (Bakeman and Adamson, 1984). JA is traditionally operationalized as triadic gaze shifting, using the social partner's face to guide their visual attention to the area of interest (Adamson and Bakeman, 1991; Mundy and Newell, 2007). However, recent evidence has identified that, during toy play, parents' faces are often not within their infants' field of view (Franchak et al., 2011) and 6- to 12- month-old infants gradually spend more time looking at toys (Northrup and Iverson, 2020). Triadic gaze shifts are therefore a less available pathway from which to engage in joint looking (Franchak et al., 2018). Instead, researchers have identified that other multimodal cues, specifically manual actions, are readily available and relatively easily-used cues for sharing attention to the same object (Abney et al., 2020; Elmlinger et al., 2019; Suarez-Rivera et al., 2022; Yu and Smith, 2013, 2017a, 2017b; Yurkovic-Harding et al., 2022). This multimodal approach suggests that JA can be achieved by either following another's gaze *or* hand movements and we find that in fact, infants are using hand movements more frequently as cues for, and pathways into, JA here defined as joint looking to an object (de Barbaro et al., 2016; Deák et al., 2014, 2018; Yu and Smith, 2013; Yu and Smith, 2017a, 2017b),.

A child's ability to engage in triadic interactions emerges over the first year of life (de Barbaro et al., 2013, 2016) and corresponds with the developmental growth of sensorimotor skills (Yu and Smith, 2017b). Infants and their parents use a variety of sensorimotor behaviors during play, and the use of those behaviors as a pathway into JA strengthens over developmental time (Xu et al., 2017). As infants' sensorimotor abilities strengthen, they have access to a larger variety of multimodal pathways into JA (Yu and Smith, 2017a). Relatedly, the rate at which infants engage in hand-eye coordination during play is predictive of the time spent in JA with their parents (Yu and Smith, 2017b) suggesting that the infant's attention and manual actions directly influence their social coordination during play. Considering how coordinated sensorimotor abilities predict later JA, it stands to reason that early deficits in JA may be linked to early sensorimotor impairments.

Autism spectrum disorder (ASD) is characterized by deficits in social

* Correspondence to: University of California, San Diego - Psychology Department, McGill Hall, 9500 Gilman Drive, La Jolla, CA 92093, USA.
E-mail addresses: l7smith@ucsd.edu (L.M. Smith), YURKOVIJ@mailbox.sc.edu (J. Yurkovic-Harding), ljcarver@ucsd.edu (L.J. Carver).

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abilities (American Psychiatric Association, 2013), with impairments in the use of face-following JA pathways being one of the most stable behavioral markers of ASD throughout the lifespan (Charman, 2003). To better understand how this impairment emerges, recent research has focused on studying infants with a familial history of ASD (FH+), given that having an older sibling with ASD increases the likelihood the infant will develop autism by approximately 18% (Hansen et al., 2019; Ozonoff et al., 2011). This research has demonstrated that deficits in JA emerge as early as 8- to 12-months in FH+ infants. Specifically, FH+ infants display deficits both in their ability to follow faces into JA (Presmanes et al., 2007) and in shifting their gaze between faces and objects (Nyström et al., 2019) relative to infants with no familial history of ASD (FH-). These deficits in JA predict a later ASD diagnosis (Charman, 2003; Nowell et al., 2018; Nyström et al., 2019; Thorup et al., 2016).

Interestingly, deficits in sensorimotor behaviors precede deficits in JA in FH+ infants. For example, researchers found that 6-month-old FH+ infants have poorer performance on tasks requiring fine motor abilities—importantly, reaching and grasping— when compared to FH- infants (Iverson et al., 2019; Landa et al., 2016). However, these differences in motor abilities do not persist over time and do not seem to affect social behavior at an early age, with little to no evidence of social impairment prior to 6 months (Ozonoff et al., 2010). Given that the infant's motor abilities support JA in naturalistic play settings, it stands to reason that early deficits in sensorimotor behaviors may cascade into later deficits in JA. For example, motor impairments can affect the speed and accuracy of motor responses (Ozonoff et al., 2008), further impacting JA. When an object captures attention and prompts a JA bid from a parent, infants with motor impairments may experience delays or inaccuracies in their motor responses, resulting in inconsistencies engaging in JA as the temporal window for shared attention may close before the individual can respond effectively.

There is a paucity of research on if and how individuals with ASD use sensorimotor pathways to establish JA. One study using head-mounted eye trackers in a naturalistic play setting has shown that, while playing with their parents, children ages 2–4 years old with and without ASD display similar motor behaviors and similar rates of JA achieved through multimodal pathways (Yurkovic et al., 2021; Yurkovic-Harding et al., 2022). Considering these motor impairments seen in infancy do not seem to persist into toddlerhood and gaze following is not the only way to enter into JA, it remains an open question, then, if there are transient differences in sensorimotor behavior at earlier ages—earlier than diagnosis is currently possible— that may be important for setting up the systems involved in JA. The current study is the first, to our knowledge, to explore the link between multimodal behaviors and JA as they appear in free play between FH+ infants and their parents. Specifically, we investigated the relation between sensorimotor behaviors and JA in infants with an older sibling with ASD. We remotely observed manual actions and gaze behavior of both infants and their caregivers during free play. Observations were made cross-sectionally at ages 6, 9, and 12 months.

In line with previous research, we hypothesized that infants in both groups will display low rates of attention to faces and high rates of attention to toys across all ages (Deák et al., 2018; Northrup and Iverson, 2020). Regarding manual action, it is anticipated that all infants will engage in high amounts of object touching; however, due to the emergence of motor deficits around 6 months of age, FH+ infants may touch toys less frequently than FH- infants. Traditional triadic JA abilities are expected to develop around 9 months of age, suggesting an anticipated increase in rates of JA in older infants. Consequently, if these traditional metrics accurately reflect JA in naturalistic settings, we expect distinctions in JA between infant groups. Regarding pathways leading into JA, it is anticipated that hand-following will become more prevalent with age, mirroring improvements in motor abilities. In the case of FH+ infants, potential difficulties in motor abilities may influence their capacity to direct their parent's attention through actions, distinguishing them from FH- infants. Parents of FH+ infants may engage in increased face looking, potentially as a response to heightened monitoring or because hands serve as a less reliable cue.

2. Methods

2.1. Participants

A total of 51 infants participated in a parent-child interaction recorded by researchers over Zoom with 38 dyads providing usable data (20 FH+ infants (8 females) and 18 FH- infants (6 females)). Thirteen infants were excluded due to either unstable internet or a recording setup that didn't provide visible gaze and hand movements from either the infant or the parent. Parents reported their infant's ethnicity: 71% of parents reported their infant's ethnicity as Caucasian, 16% as mixed, 3% as African American, 3% as Asian American/Pacific Islander, 5% as Mexican, and 1 did not report. The Census Bureau reported the median household income for 2021 was $70,000 (Census Bureau., 2022). It was reported that 29% of participants' household income was below the 2021 median income, 58% was above, and 5 parents preferred not to answer. Eligibility for FH+ infants was confirmed with documentation of their older siblings' ASD diagnosis via an individualized education program or clinician report.

All caregiver-infant dyads participated in a larger, more comprehensive study focusing on JA as well as social contingency, consisting of approximately 15 min of caregiver-infant interaction. The data reported here are based on an initial 5-minute warm-up play session. Electronic consent was obtained from parents prior to participating and they were compensated with a $10 gift card. Families were recruited mostly through social media and from SPARK Research Match. Participation was remote so families were located across the US.

2.2. Measures

The *Demographic Questionnaire* consisted of 24 questions regarding the caregiver's socioeconomic status, race, ethnicity, and primary language, and the infant's race and ethnicity. Caregivers completed the Developmental Profile-4. The Developmental Profile (an adaption of the Developmental Profile-3, Alpern, 2007) was used to assess the infant's current physical, adaptive behavior, social-emotional, cognitive, and communication development. This questionnaire was used to developmentally match the FH- and FH+ infants to account for developmental delays (FH+$M_{DP\text{-}4}$ =98, FH-$M_{DP\text{-}4}$ =103, average is 85–115). The Social Responsiveness Scale (Constantino and Gruber, 2012) is a parent-reported 65-item questionnaire used to assess social impairment shown by the FH+ infant's sibling. It reports 5 different subscales, each referring to an aspect of social behavior. This questionnaire has a high reliability coefficient of.95 and high predictive validity (.92) (Bruni, 2014).

2.3. Procedure

The caregiver was provided a link to schedule a Zoom session with the researchers. Before the meeting, the caregiver was asked to sign a consent form via DocuSign and complete online questionnaires. During the session, the caregiver was asked to place their infant in a stationary seat with a tray (e.g., a high-chair with a tray, booster seat) with the infant facing the camera and at least a partial view of the caregiver's face. Only 16% of participants (4 FH+, 2 FH-) were not able to accommodate this request and were seated on the floor or a bouncer without a tray. The position of the infant may have affected individual dyads' frequency in engaging in sensorimotor behaviors, though we did not expect this effect to be significant considering the relatively even distribution of seating options across age and familial history. The computer camera was positioned so that hands and faces were in view and gaze was detectable (see Fig. 1). The caregiver was then asked to select five toys the child enjoyed playing with (e.g., books, stuffed toys,

Fig. 1. Setup and positioning of the home environment. Infant and parent's face and hands are visible and only one object is available for play. Remaining toys are located off-screen but within parent reach.

blocks, rings, etc.). Limiting the toys available differs from previous micro-behavioral work that allows several toys at once (Yu and Smith, 2013; 2017), however, this procedure was modeled after de Barbaro and colleagues (2016) and facilitated later coding (de Barbaro et al., 2016). Each individual item counted as 1 toy (e.g., a truck with a driver was counted as two toys). The caregiver was instructed to play with their infant as they normally would, but to only play with one toy at a time; the remaining 4 toys were within parent reach, but out of the infant's reach. If the infant became tired of the toy, the caregiver could replace the toy with another. The infant did not have to play with all 5 toys but was asked to engage with at least 2 different toys throughout the session. Breaks were offered if the infant seemed distressed or the caregiver mentioned a break was needed. This interaction was recorded via Zoom for approximately 5 min. During the session, researchers turned off their audio and video to avoid distraction and stayed in the Zoom room for assistance if needed.

2.4. Video coding and data processing

Offline coding was completed by trained research assistants who were blinded to the familial history of each subject. Coders established > 80% reliability across 25% of subjects. Coders annotated both hand and gaze behaviors for infants and parents. Regions of interest included: faces, hands, toys, and off-screen. Gaze onset began the moment the infant/parent was looking at the region of interest and offset was set for the moment the gaze moved away from the region of interest. For manual actions of the hands, the onset began the moment any part of the hand made contact with the toy and the offset was set the moment the entire hand was removed from the toy. Unusable video was indicated if any of the following took place: the parent or infant was no longer in view, an additional family member came into the frame or made their presence known in the background, the caregiver began talking to the experimenter, the infant appears to be looking at the webcam/computer, and other events that distracted from the interaction. No other behaviors were coded during this time. The average usable video time for FH+ infants (M = 4.82 min) and FH- infants (M = 4.87 min) did not significantly differ (t(39) = .759, p = .452). Videos were coded at a frame rate of 30 frames per second.

Criteria for defining JA moments included when the infant and parent made eye contact with the same toy for a minimum of 500 ms, ignoring 300 ms gaze shifts away from the object. The moment preceding JA was defined as the 1 s before JA occurred. These criteria align with previously published values (Yu and Smith, 2017a; Yurkovic-Harding et al., 2022). Manual actions included moments when either one or both hands were on the toy.

2.5. Statistical analysis

We examined the effects of age (binned at 6mo, 9mo, and 12mo) and familial history group (FH+ or FH-) on the behaviors of interest using an analysis of variance (ANOVA) on linear mixed effects models (LME). These models treated age and group as fixed effects and included a random intercept for each participant where appropriate. An alpha of 0.05 was used to determine significance.

3. Results

3.1. Attention to faces

Gaze to faces is thought to be a critical pathway through which infants and parents can engage in JA. However, recent work shows that infants rarely attend to faces during parent-infant toy play. We, therefore, examined the percentage of the total session time wherein both dyad members looked at the other's face. Overall, infants looked at their parents' faces for an average of 15.4% (SD ± 12.1%) of the interaction. The analysis revealed no main effect of likelihood group (F(1,32) = 1.49, p = 0.23; Fig. 2A), age (F(2,32) = 0.69, p = 0.51; Fig. 2B), nor the interaction between age and group (F(2,32) = 0.08, p = 0.93; Fig. 2C).

Parents, however, spent a greater percentage of the interaction looking at infants' faces than the infants did at parents' faces (Parent = 51.0% (20.8%); t(37) = −11.94, p < 0.01). Parents of 12-month-olds looked marginally less at faces than parents of either 6-month-old or 9-month-old infants (6mo = 55.2% (± 20.7%), 9mo = 56.8% (± 21.8%), 12mo = 40.3% (± 16.6%); F(2,32) = 2.93, p = 0.07; Fig. 3B). The analyses did not reveal a significant main effect of group (F(1,32) = 0.19, p = 0.67; Fig. 3A) nor a significant interaction between age and group (F(2,32) = 0.78, p = 0.46; Fig. 3C).

3.2. Gaze behaviors and manual action

Infants spent the majority of time looking at toys during play (59.1% (± 20.2%)). This is significantly more time than infants spent looking at faces (t(37) = −9.54, p < 0.01). There was no effect of likelihood group (F(1,32) = 0.31, p = 0.58; Fig. 4A), age (F(2,32) = 0.73, p = 0.49; Fig. 4B), nor an interaction between age and group (F(2,32) = 0.53, p = 0.60; Fig. 4C).

Infants also spent most of their time touching toys (65.6% (± 30.8%)). FH- infants touched toys more often than FH+ infants (FH+ = 55.0% (± 26.3%); FH- = 77.3% (± 31.9%); F(1,32) = 5.92, p = 0.02; Fig. 5A). The analyses did not reveal a significant effect of age (F(2,32) = 0.17, p = 0.84; Fig. 5B) nor an interaction (F(2,32) = 0.34, p = 0.71; Fig. 5C).

Parents, on the other hand, spent much less time looking at toys than they did at faces (Toys = 27.9% (± 15.6%); t(37) = 5.50, p < 0.01). There was a significant main effect of age (6mo = 19.5% (± 11.1%), 9mo = 26.3% (± 14.9%), 12mo = 38.8% (± 15.0%); F(2,32) = 7.04, p < 0.01; Fig. 6B). Parents of 12-month-old infants looked at toys more frequently than parents of 9-month-old or 6-month-old infants. The analyses did not reveal a significant main effect of group (F(1,32) = 0.54, p = 0.47; Fig. 6A) nor an interaction between age and group (F(2,32) = 0.95, p = 0.40; Fig. 6C).

Parents touched toys for about half of the interaction (45.7% (± 23.9%)). There was no main effect of likelihood group (F(1,32) = 0.07, p = 0.79; Fig. 7A), age (F(2,32) = 0.39, p = 0.68; Fig. 7B), nor an interaction between age and group (F(2,32) = 0.60, p = 0.56; Fig. 7C).

3.3. Mutual face looks and joint attention

Dyads rarely looked to each other's face at the same time (4.7% (± 4.8%)). There was no main effect of age (6mo = 11.5% (± 10.2%), 9mo = 14.1% (± 10.0%), 12mo = 11.7% (± 11.8%); F(2,32) = .25, p = 0.78). The analyses did not reveal a significant main effect of group (F(1,32) = 1.84, p = 0.18) nor an interaction between age and group (F

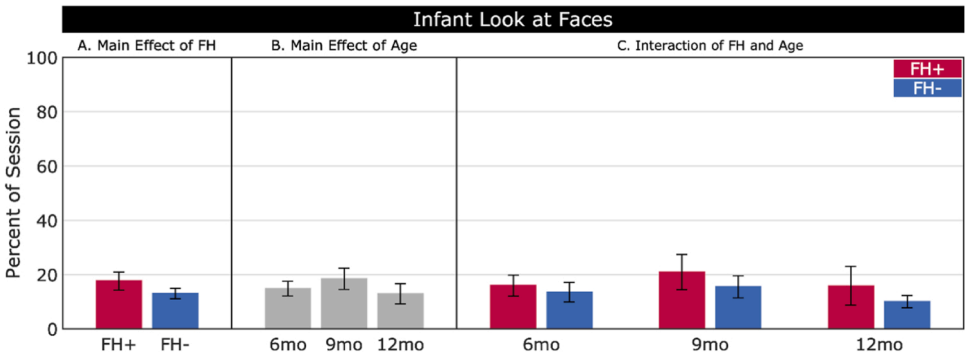

Fig. 2. Visual attention to faces for the infants faceted by familial history (A) age (B) and the interaction (C). The y-axis is the percent of the session spent looking at faces.

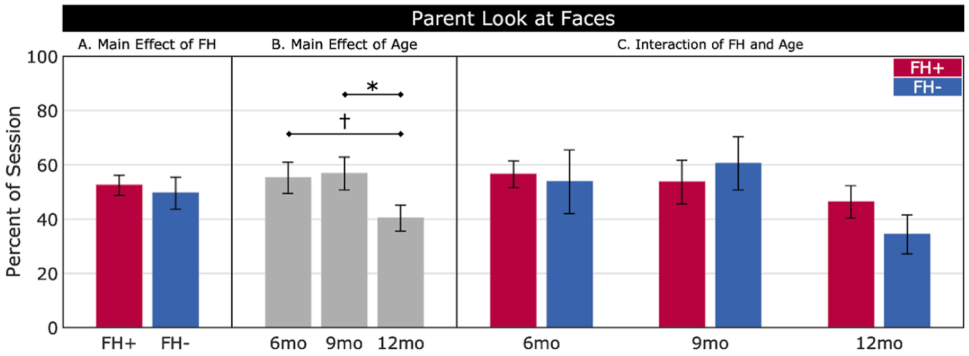

Fig. 3. Visual attention to faces for the parents faceted by infants' familial history (A) age (B) and interaction (C). The y-axis is the percent of the session spent looking at faces.

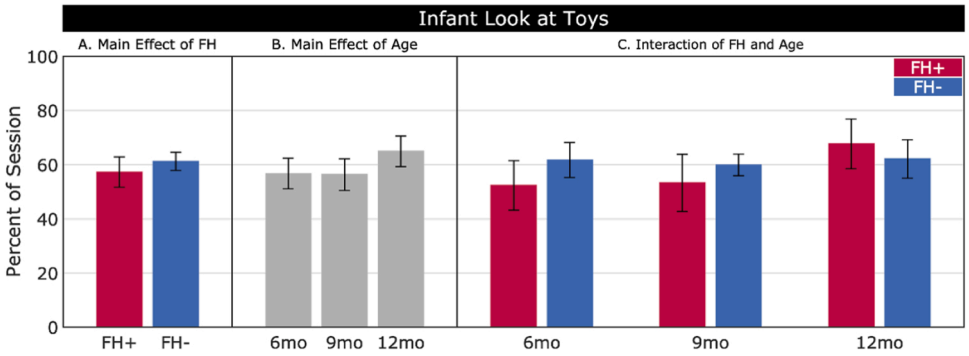

Fig. 4. Individual infant looks to toys faceted by familial history (A) age (B) and the interaction (C). The y-axis is the percent of the session the infant spent looking to a toy.

(2,32) = 0.02, p = 0.98).

Next, we assessed how often JA was achieved during dyadic toy play. In line with recent research, we broadly operationalized JA as the parent and infant looking at the same thing at the same time, regardless of the pathway used (Yu and Smith, 2013, 2017b; Yurkovic-Harding et al., 2022). Dyads spent 24% of the interaction in JA (23.9% (± 16.3%)), consistent with findings from other studies looking at both neurotypical 12-month-old infants as well as children with ASD. Frequency of JA steadily increased with age (6mo = 14.3% (± 9.6%), 9mo = 20.3% (± 12.8%), 12mo = 38.1% (± 16.4%); F(2,32) = 11.99, p < 0.01; Fig. 8B). This increase in frequency of JA coincides with decreases in infant attention to faces and increases in infant and parent attention to toys over the first year of life. The analyses did not reveal a significant main effect of group (F(1,32) = 0.00, p = 0.95; Fig. 8A) nor an interaction between age and group (F(2,32) = 0.34, p = 0.71; Fig. 8C).

Additionally, we examined how often infants led the JA moments, operationalized by looking to the toy first, with the parents' looks following. Infants led the majority of JA moments (74.70% (± 14.2%)). FH+ infants exhibited a marginal trend toward higher levels of leading JA than FH- infants (FH+ = 78.4% (± 11.9%), FH- = 70.9% (± 15.5%); F(1,30) = 2.93, p = 0.10). Additional analysis (see below) revealed that, although FH+ and FH- infants spent a similar amount of time in JA with their parents, the parents of FH+ infants more frequently followed their infant's lead into JA.

3.4. Behaviors preceding joint attention

Next, we examined if the pathways into JA changed with the increases in JA over age, or if the utilization of pathways differed by family history of ASD. To do so, we quantified the frequency with which face-

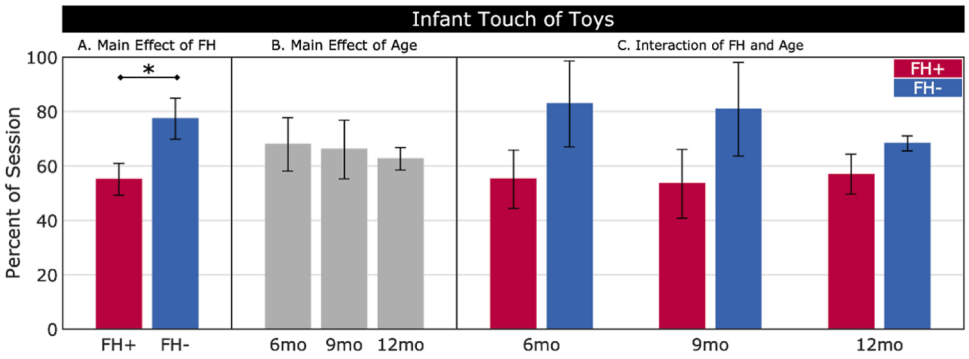

Fig. 5. Individual infant manual actions on toys faceted by familial history (A) age (B) and the interaction (C). The y-axis is the percent of the session the infant spent touching a toy. *$p < .05$.

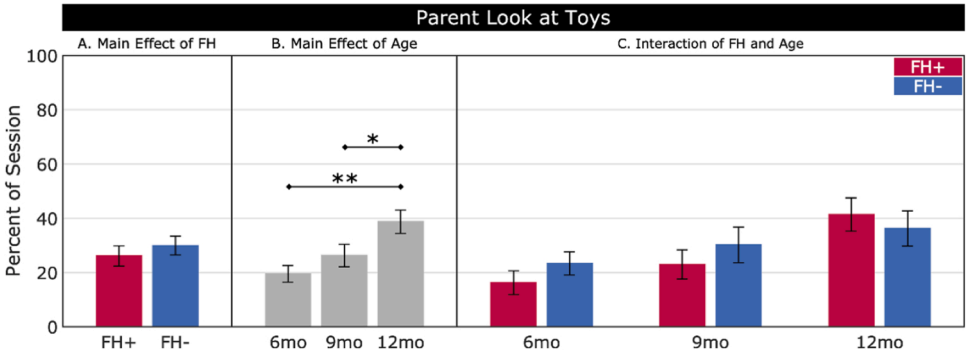

Fig. 6. Individual parent looks to toys faceted by their infant's familial history (A) age (B) and the interaction (C). The y-axis is the percent of the session the parent spent looking to a toy. * *$p < .01$.

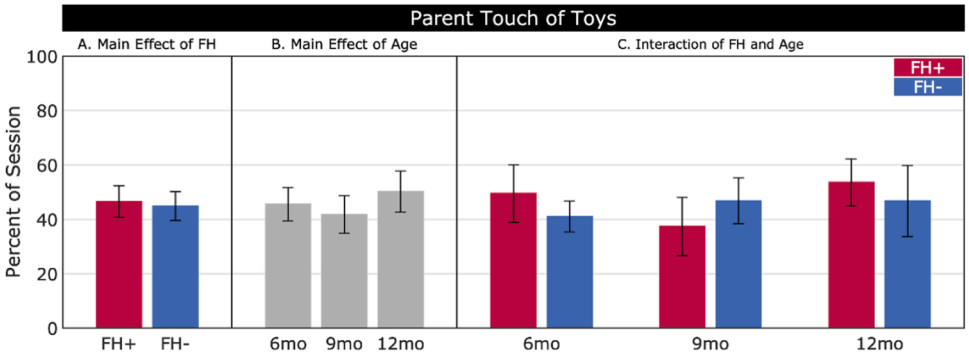

Fig. 7. Individual parent manual actions on toys faceted by familial history (A) age (B) and the interaction (C). The y-axis is the percent of the session the dyad spent touching a toy.

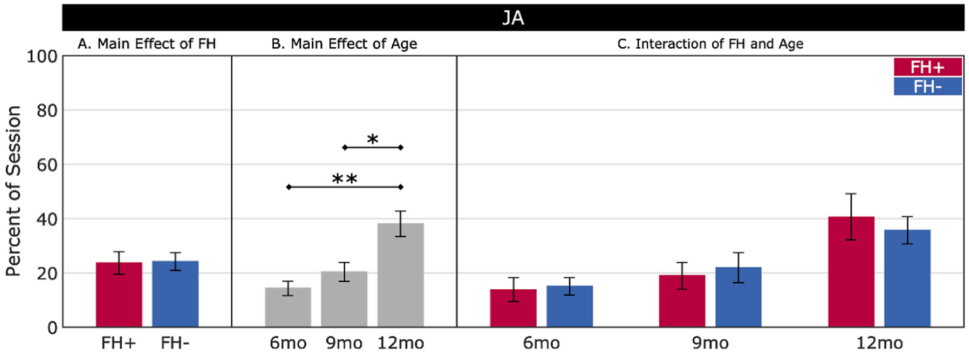

Fig. 8. Dyad visual attention to toys. The y-axis is the percent of the session infants and their parents spent looking to the same toy, or in JA. * *$p < .01$.

looking and manual action occurred in the 1 s preceding JA onset.

3.4.1. Cues for infants to follow into JA

We first examined the cues that infants used to follow their parents into parent-led JA, namely looks to the parent face or parent touching the toy. Infants utilized their parent's face as a cue before 28.2% (± 29.6%) of JA moments. There was no main effect of likelihood group ($F(1,29) = 0.28$, $p = 0.60$; Fig. 9A), age ($F(2,29) = 0.02$, $p = 0.98$; Fig. 9B), nor an interaction between age and group ($F(2,29) = 0.61$, $p = 0.55$; Fig. 9C) on the frequency at which infants looked at their parent's face before JA.

Parents touched the toy before 59.0% (± 31.1%) of parent-led JA moments. There was no main effect of likelihood group ($F(1,29) = 1.14$, $p = 0.29$; Fig. 9D), age ($F(2,29) = .50$, $p = 0.61$; Fig. 9E), nor an interaction between age and group ($F(2,29) = 0.55$, $p = 0.58$; Fig. 9F) on the frequency at which parents touched the toy of interest before JA. Infants utilized the hand-following pathway into JA more frequently than the face-following pathway ($t(35) = 3.98$ $p < 0.01$).

3.4.2. Cues for parents to follow into JA

We next examined the cues that parents used to follow their infants into infant-led JA, namely looking at their infant's face or the infant touching the toy. Parents looked at their infant's face before the majority of infant-led JA moments (76.5% (± 20.7%)). Parents of FH+ infants looked to their infant's face much more frequently than parents of FH- infants in the moments preceding JA (FH+ = 84.9% (± 11.9%), FH- = 68.1% (± 24.2%); $F(1,30) = 7.81$, $p < 0.01$; Fig. 10A). The analyses did not reveal a main effect of age ($F(2,30) = .50$, $p = 0.61$; Fig. 10B) nor an interaction between group and age ($F(2,30) = 0.52$, $p = 0.60$; Fig. 10C).

Infants often touched toys before infant-led JA (67.1% (± 18.8%)). There was a main effect of group on the frequency of infant toy touching before JA, with FH+ infants touching toys less frequently than FH- infants in the moments preceding JA (FH+ = 59.1% (± 19.9%), FH- = 75.2% (± 14.1%); $F(1,30) = 8.94$, $p < 0.01$; Fig. 10D). The analyses did not reveal a main effect of age ($F(2,30) = 1.27$, $p = 0.30$; Fig. 10E) nor an interaction between group and age ($F(2,30) = 0.01$, $p = 0.99$; Fig. 10F).

Parents of FH+ infants used their infant's face as a pathway into JA more frequently than parents of FH- infants, possibly because FH+ infants touched toys less and therefore did not provide as many multimodal signals of their attention to their parents.

4. Discussion

In this study, we employed Zoom as a novel method to investigate the role of multimodal behaviors in how 6, 9, and 12-month-old FH+ infants engaged in social interactions with their parents. Specifically, our goal was to gain insights into if and how early differences in motor abilities impacted the frequency of JA and the strategies used to achieve JA. By remotely observing parent-infant dyads during 5 min of free play, we successfully replicated established findings demonstrating that typically developing infants spend less time looking at faces and more time attending to toys from ages 6–12 months. We found that FH+ and FH- infants showed similar age-related increases in JA and were more likely to follow their parent's hands than face into JA. Notably, we found that FH+ infants touched toys less frequently than FH- infants. Parents of FH+ infants appeared to compensate for this by placing a greater emphasis on following facial cues to achieve similar amounts of JA as observed in FH- dyads. This study provides novel insights into typical and atypical mechanisms underlying JA in infancy.

It is important to note that we used a broad operationalization of JA in the current study rather than the traditional, face-following operationalization. Infants in the current study rarely attended to their parent's face, reflecting recent evidence that parent faces are not easy to access in many of the day-to-day contexts that make up an infant's social world (Franchak et al., 2011, 2018). In contrast, hands provide accurate information about where the social partner is attending and are frequently and efficiently used to establish coordinated visual attention, or JA (Yu and Smith, 2016, 2017a, 2017b; Yurkovic-Harding et al., 2022). In fact, infants are able to infer their social partner's intention from the hands before they are able to do so from the face, and

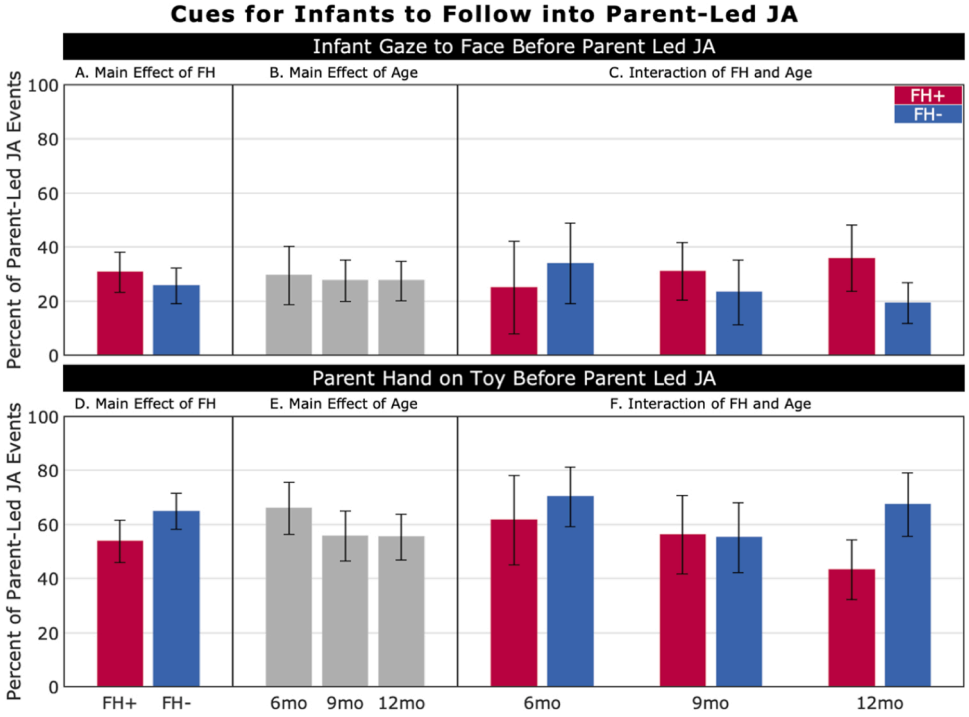

Fig. 9. Multimodal cues for infants to JA. The y-axis is the percent of JA moments that were parent-led. Infants could follow their parent into JA moments by (A-C) looking to the parent's face or (-F) the parent touching the object.

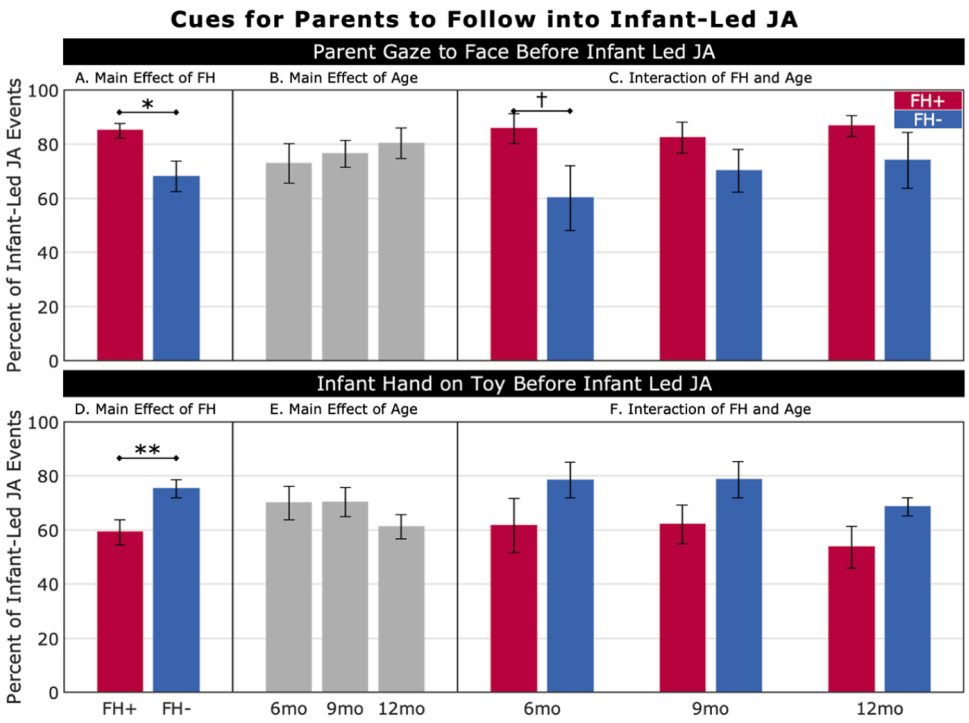

Fig. 10. Multimodal cues for parents to JA. The y-axis is the percent of JA moments that were infant-led. Parents could follow their infant into JA by (A-C) looking to the infant's face or (D-F) the infant touching the object.

hand-following may actually provide an important training ground for learning to use gaze cues for JA (Boyer et al., 2020). Therefore, a broad definition of JA may be more well suited to elucidating early mechanisms of both typical and atypical JA development (Adolph and West, 2022; Yurkovic-Harding et al., 2022). As such, definitions of JA have begun to shift from the traditional operationalization to instead define JA as any shared attention on an object regardless of behavioral pathway.

Because of the importance of hands in establishing JA, the consideration of an infant's visuomotor abilities is critical for understanding their JA skills. Similar to other studies of infants in their home environments, we did not observe any age-related differences in infant gaze and manual action (de Barbaro et al., 2016). We found one key difference in multimodal behaviors between FH+ and FH- infants: FH+ infants displayed markedly lower rates of actions on objects across all age groups. This finding is consistent with reports that motor deficits are among the earliest signs of ASD (Iverson et al., 2019). FH+ infants demonstrate both reduced and less accurate reaching and grasping behaviors than FH- infants (Landa et al., 2016; Sacrey et al., 2013, 2018). Interestingly, the difference in motor behaviors did not relate to differences in visual attention as evidenced by FH+ infants attending to toys for typical and high frequencies during the interaction. FH+ infants, therefore, are not less engaged with objects. The observed preference for visually attending to toys, along with the identified group differences in manual action on toys, lays the foundation for understanding how JA may be influenced by early differences in sensorimotor behavior.

JA showed a notable increase with age, with 12-month-old dyads engaging in more frequent JA compared to 9- and 6-month-old dyads. This developmental progression is in line with established theories pinpointing the emergence of JA around 9 months of age (Mundy et al., 2007, 2009). Contrary to prior work, we did not observe a difference between FH+ and FH- infants' engagement in JA at any age (Nyström et al., 2019; Ozonoff et al., 2010; Rozga et al., 2011). While this finding is inconsistent with research that focuses *solely* on face-following pathways in FH+ infants (Ozonoff et al., 2010; Rozga et al., 2011), it is congruent with recent research that explores hand-following pathways in children with ASD (Yurkovic-Harding et al., 2022). It is interesting to note that JA was largely infant-led for both FH+ and FH- infants, but FH+ infants led more of their JA instances than FH- infants. By ages 2- to 4-years, JA in children with ASD and TD children is equally infant-led and parent-led (Yurkovic-Harding et al., 2022), suggesting a role for heightened parental support for FH+ infants. FH+ infants may need more support in early development to be able to gain typical JA abilities in later childhood. Together, our results show that FH+ and FH- infants experience similar amounts of JA with differential amounts of parent support.

Beyond the amount of parental support, a distinct strategy emerged in the ways that parents followed their infant's attention. Specifically, FH+ parents exhibited a heightened reliance on their infants' faces, as opposed to their hands, to guide them into JA interactions. This is likely a result of the relatively low frequency of object touch among FH+ infants, such that hand-following cues were much less available to FH+ than FH- infants. Consequently, FH+ parent behavior is intimately linked to the behavioral patterns exhibited by their infants. Importantly, parents from both groups exhibited comparable levels of engagement with faces and toys during the interaction, so the heightened awareness that FH+ parents have is specific to moments where they are establishing JA. FH+ parents are likely engaging in more intense monitoring to create opportunities to engage with the object of their children's attention at any given time. This is consistent with research showing that parents of FH+ infants increase their responsivity to the infant during interactions (Doussard-Roosevelt et al., 2003; El-Ghoroury and Romanczyk, 1999; Talbott et al., 2015; Yoshida et al., 2020) in ways that support the infant's attention (Yoshida et al., 2020). This distinctive parent behavior substantiates our observation of comparable rates of JA between FH+ and FH- groups, as it is driven by fundamentally different underlying mechanisms.

These findings underscore the pivotal roles played by both parent and infant sensorimotor behaviors in shaping the conditions for early social interactions. During the first year, FH+ and FH- dyads consistently engaged with toys, reflecting comparable patterns of visual

attention and JA frequencies. However, differences in the infant's early ability to interact with objects laid the groundwork for distinct parent behaviors in establishing JA. This underscores how infants actively shape their social interactions through sensorimotor behaviors, and how parents, in turn, respond adaptively. While our small cross-sectional sample of FH+ infants doesn't fully represent the developmental trajectory of JA impairments seen in ASD, this work sheds light on behavioral distinctions in how FH+ dyads engage in JA. Future work should consider how the heightened monitoring and support from the caregiver influences later skills in FH+ infants. For example, parents who have an older child with ASD and are "on alert" for potential JA opportunities may be quick to look at their infants' faces when the infant is playing with the toy, making infant-led JA both more frequent and less effortful for the infant to establish. In turn, infants may rely less on the manipulation of toys to get their parents' attention. Parent behavior affects young infants' environment, opportunities for skill-building, and ultimately their developmental trajectories (Adolph and Franchak, 2017), and in light of these findings it is important to investigate how this increased attentiveness from parents affects long-term developmental outcomes in FH+ infants.

Observing infants interacting with their social partners in a familiar home environment via Zoom offers a valuable real-time perspective on how JA behaviors manifest. Our findings on looks to faces and JA in FH- infants are consistent with previous work using eye-tracking methodology, providing validity to remote platforms like Zoom, especially for observing populations for whom travel and unfamiliar settings may be burdensome. However, it's important to acknowledge limitations with using Zoom, such as potential unobserved distractions during the play session. To optimize coding, we restricted the infants' access to one toy at a time, which may have minimized age-related effects on bouts of JA, particularly in more dynamic play settings. This work will continue to offer valuable insight into the dynamic interplay between gaze behaviors, manual actions, and JA.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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