

THE UNIVERSITY OF CHICAGO

**The relationship between social network size and frontal alpha asymmetry
to strangers during infancy: The role of temperamental fear**

By:

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Abstract

Previous research has examined the relationship between children's social network size and social cognition. However, the relationship between social network size and social emotional development has been less examined. Hwang et al. (2021) found that infants with nonparental-care experience exhibited more positive frontal alpha asymmetry, an indicator of more approach tendency, to strangers than infants without such experience, suggesting the potential influence of social environment on infants' neural responses to strangers. The current study examined the association between 8- to 12-month-old infants' social network sizes and their frontal alpha asymmetry (FAA), while watching the actions of strangers. Additionally, this study explored the moderating effect of temperamental fear (i.e., infant's fearfulness or anxiety in response to novel or unfamiliar stimuli). This study used Electroencephalogram (EEG) to measure infants' FAA to strangers and used the Revised Infant Behavior Questionnaire (IBQ-R) and Child Social Network Questionnaire (CSNQ) reported by parents to measure infants' temperamental fear and social network sizes. The results revealed that infants with nonparental-care experience demonstrated more positive FAA to strangers than infants without such experience, which replicated previous findings. Furthermore, we found that larger social network sizes were associated with more positive FAA to strangers, and this effect was more significant when the strangers spoke a native language (English) rather than a foreign language (French). The moderating effect of fear was not significant in this relationship. These findings contribute to our understanding of the interplay between social environment and brain responses to strangers in the first year of life.

The relationship between social network size and frontal alpha asymmetry to strangers during infancy: The role of temperamental fear

Infants learn about the world from the people around them. An infant's social network allows them to explore the world and learn how to connect and communicate with others. It has been suggested that children with a larger social network size have better social-cognitive development (Burke et al., 2023). In the current study, we aim to expand these findings from the behavioral domain to the neural domain and focus on the relationship between social network and social emotional development. Specifically, this study examined the relation between children's social network size and their frontal alpha asymmetry, an indicator of approach/withdrawal tendency, to strangers during infancy. This study explored how social environments relate to social emotional development during the first year of life.

Literature Review

Social Network Size

Previous studies found that social networks play an important role in social cognition throughout infancy and childhood (Burke et al., 2022; Burke et al., 2023). Burke and colleagues (2023) examined the relation between a three-year-old's social network size and their perspective-taking skills. The researchers observed children's basic understanding that what they see may be different from what someone else sees (Burke et al., 2023). The results revealed that children with larger social networks displayed significantly better explicit perspective-taking skills. This finding indicates that a larger social network might improve a child's ability to consider things from another person's point of view or, alternatively, a child's better perspective-taking skills allows parents to encourage a larger social network for them (Burke et al., 2023).

Some indirect findings also support the role of social networks on the development of social cognition. Children aged 5-11 with at least one sibling are more likely to develop positive peer relationships because having a sibling allows children to have more opportunities to develop social and interpersonal skills during early childhood (Downey & Condron, 2004). These findings support the close relationship between children's social network size and social cognition. However, the connection between social network size and social emotional development has been less examined. In addition, most studies focused on older children, so the role of social network size during infancy remains unclear.

Hwang et al. (2021) found that nonparental-care experience, a factor that is closely related to social network size, is associated with infants' neural responses to strangers. Following this finding, we will focus on infants' neural responses, specifically frontal alpha asymmetry, to evaluate their social emotional reactions to strangers.

Frontal Alpha Asymmetry

Frontal alpha asymmetry (FAA) is an important neural indicator of infants' approach/withdrawal tendency (Davidson & Fox, 1982; Fox & Davidson, 1986; Fox, 1991; Gartstein et al., 2020; Harrewijn et al., 2019; Howarth et al., 2016). FAA is the measurement of the imbalance in cortical activation between the right and left frontal hemispheres, measured by psycho-physiological markers using electroencephalogram (EEG) (Davidson & Fox, 1982; Fox & Davidson, 1986; Fox, 1991). Since stronger alpha activity, or higher alpha frequency, is associated with decreased cortical activation, rightward or negative FAA signifies increased right hemispheric activation. Concurrently, leftward or positive FAA signifies increased left hemispheric activation (Vincent et al., 2021). FAA is a moderator reflecting fearful inhibition and impulsivity-anger (Liu et al., 2021), with left FAA being associated with higher levels of

activity/approach tendencies while right FAA is associated with higher levels of fear/withdrawal tendencies (Davidson & Fox, 1982; Fox & Davidson, 1986; Fox, 1991; Gartstein et al., 2020; Harrewijn et al., 2019; Howarth et al., 2016). Based on these findings, we will use FAA as a neural indicator of infants' approach/withdrawal tendency towards strangers.

It is advantageous to utilize FAA to study the relationship between social network size and infants' responses to strangers because neural indicators can be more sensitive than behavioral indicators (Davidson & Fox, 1982; Fox & Davidson, 1986; Fox, 1991; Harrewijn et al., 2019; Howarth et al., 2016). While behavioral changes of 8- to 12-month-olds might be too subtle to code, the sensitivity of neural indicators may be a better tool for capturing individual differences. Broadly speaking, FAA has been widely used for this exact purpose, to precisely and reliably expose individual differences in aspects such as motivation, affect, and depression severity, that behavioral differences may not fully reveal (Gollan et al., 2014). Furthermore, examining the relationship between social network size and FAA can enhance our understanding of how social networks may shape infant's brains.

Previous research found that infants who received nonparental-care showed more positive FAA, an indicator of approach motivation, to strangers (Hwang et al., 2021). Since infants who have nonparental-care experience are more likely to have a larger social network with more people from the daycare center (e.g, teachers, peers, etc.), this finding provides indirect evidence for the potential association between social network and FAA to strangers during infancy. Based on this finding, we expect that infants who react more negatively to strangers may exhibit more negative FAA to strangers, which is related to withdrawal behaviors. These withdrawal behaviors may discourage parents from introducing their infants to new people, resulting in a smaller social network. Additionally, a limited social network reduces an infant's opportunities for social

interaction, potentially increasing their distress when encountering strangers. These two factors may interact, leading to a positive association between infants' social network sizes and FAA to strangers. Furthermore, individual characteristics might moderate the relationship between social network sizes and FAA to strangers. In this study, we will focus on the role of temperamental fear.

The Role of Temperamental Fear

Temperament plays a large role in an infant's responses to strangers (Rubin et al., 2009). Temperament includes a person's emotional reactivity and behavioral style, with dimensions such as fear, activity level, vocal reactivity, sadness and soothability (Gartstein & Rothbart, 2003). Temperamental fear, as we will examine in this study, refers to an infant's fearfulness or anxiety in response to novel or unfamiliar stimuli (Gartstein & Rothbart, 2003). Infants with higher temperamental fear tend to exhibit more negative responses when interacting with others.

Children who are shy or display reticent dimensions of temperament will show more avoidance to strangers (Rubin et al., 2009). Furthermore, children with different temperament react to the same environment differently, or in other words, temperament can moderate the effect of the environment on child development. Ertekin and colleagues (2021) found that infants with a more reactive temperament, including higher levels of fear or irritability, may be more sensitive to the surrounding environment as they are more likely to be overwhelmed. More specifically, infants with a higher rate of recovery from distress, who are likely less fearful or irritable, were less impacted by adverse environments than infants with a low rate of recovery from distress.

Additionally, overall temperament can moderate children's social wariness towards strangers of the same race and different races than their own (i.e. 'ingroup' versus 'outgroup',

Hwang et al., 2023). Shyer children displayed greater social wariness towards strangers of a different race than of the same race to their own, while less shy children did not. These findings suggest that individual differences in temperament can have a moderating effect between social environment and children's responses to strangers.

Based on these findings, the current study will examine the moderating role of temperamental fear between social network size and infants' FAA to strangers, as fear is an important characteristic during the first year of life (Gartstein & Rothbart, 2003).

The Current Study

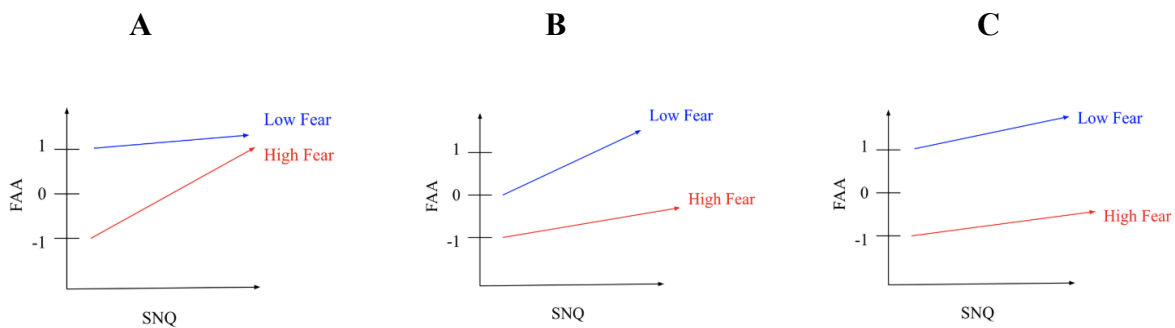
In order to identify how social environments relate to social emotional development during the first year of life, this study first reexamined the effect of nonparental-care experience on infants' FAA to strangers, in order to replicate the finding in Hwang et al. (2021). In line with the definition in Hwang et al. (2021) we defined the child as experiencing nonparental-care if they attend school/daycare, have a babysitter, nanny, or au pair, receive care from another family member, and/or have other adults besides their parents living in the same household. We used an infant's FAA as an indicator of the infant's neural response to strangers. Similar to the finding in Hwang et al. (2021), we predicted that experience with nonparental-care will correlate with more positive FAA (i.e. increased left frontal activation) toward strangers.

Next, we further examined the relationship between social network sizes and neural responses to strangers during infancy. Using similar methods, we predicted that larger social network size will correlate with more positive FAA toward strangers. In our exploratory analysis, we also compared the effect of nonparental care and social network size on infants' FAA to strangers.

Finally, we explored how temperament, especially fear, can moderate the relationship between social network size and an infant's responses to strangers. There were several possibilities. One possibility was that infants' temperamental fear may magnify the association between social network size and FAA to strangers, given that infants with greater fear were found to have more sensitivity to the influence of environments (Ertekin et al., 2021) (representation shown in Figure 1A). In addition, if infants show greater fear of novel stimuli and also exhibit more negative FAA to strangers, parents might be more reluctant to introduce new environments and new people to infants, leading to smaller social networks. Another possibility was that infants' temperamental fear might weaken the association between social network size and FAA to strangers (Figure 1B). Infants with greater fear might show negative FAA to strangers regardless of their social network sizes, while infants with less fear might be more likely to benefit from having a larger social network, thereby showing more positive FAA to strangers. The last possibility is that there was no moderating effect of temperamental fear (Figure 1C).

Figure 1

Moderating Effect Possibilities



Note. Each plot is an example of the possible moderating effect of temperamental fear between

FAA and social network size (SNQ). Plot A shows a magnifying effect of temperamental fear on the relationship between FAA and SNQ. Plot B shows a diminished effect of temperamental fear, weakening the association between FAA and SNQ. Plot C shows no moderating effect of temperamental fear.

Methodological Approaches

To answer the above questions, this study used video stimuli to reproduce an infant's reaction to strangers. For this method to be reliable, we presumed that infants respond in a similar fashion to video stimuli as they would to real-world interactions with strangers. From a very young age, infants are able to discriminate the perceptual differences between a two-dimensional person on a video screen and a real, three-dimensional person in front of them (DeLoache et al., 1979). Diener and colleagues (2008) completed two experiments to evaluate an infant's response to video stimuli and face-to-face interactions, attempting to elicit and compare infant emotional responses in both conditions. The researchers found that while infants did prefer the live event, looking for longer periods of time, their reactions to both conditions were similar. Infants who displayed high levels of fear while watching a three-dimensional event also had higher levels of fear while watching the same two-dimensional depiction. The researchers concluded that infants make sense of simple stimuli presented on video and respond both behaviorally and emotionally to them, although their responses are not as strong compared to real-world stimuli. Seeing as infants elicit a similar response to video stimuli of a stranger attempting to interact with them as they would a face-to-face stranger, we are fairly confident that the methods chosen for our study produced reactions from these infants that we would expect to see in real-world situations.

In this study, we observed an infant's stimuli-induced FAA: we manufactured an experience with a stranger and then calculated the child's FAA at a specific point in time. Resting-state FAA is usually used as a trait indicator while stimuli-induced FAA can be used as a momentary measure of a person's state (Kuper et al., 2019; Reznik & Allen, 2018; Sabu et al., 2022; Thibodeau et al., 2006). We did not collect extended baseline, or resting, FAA data to be able to reliably calculate a relationship nor make accurate conclusions. Therefore, our measure of infant FAA is the measure of a momentary response by the infant toward the stranger.

The data for the current study was extracted from an EEG study which examined infant's neural responses to strangers either speaking their native language, English, or a foreign language, French. We understood the two language conditions as stimulating an ingroup versus outgroup response because all of the participants in our study were native English speakers, living in a primarily English speaking home, with little to no exposure to the French language. We found this relevant because, along with examining the impact of receiving nonparental-care on infant FAA to strangers, Hwang et al., (2021) studied whether racial ingroup versus 'outgroup' strangers would impact an infants' neural response toward the stranger. The researchers found no effect of the ingroup versus outgroup condition. In other words, they found that infants with nonparental-care experience exhibited more positive FAA to strangers, regardless of whether the stranger was within their ingroup or outgroup (Hwang et al., 2021). Due to the lack of effect previously found, we observed infant FAA within both the native and foreign conditions because we believe the evidence of infant neural response to strangers will be apparent for both the native and foreign conditions. We additionally explored a potential moderating effect of language condition to further understand the relationship.

In summary, this study aimed to examine the connection between infants' social network sizes, temperamental fear, and their neural response to strangers. First, we examine the relationship between nonparental-care and infant FAA. Second, we examine the relationship between social network size and infant FAA to strangers. Third, we evaluate the moderating effect of temperamental fear within this relationship. This study contributes to the understanding of how early social environments are related to infants' brain responses and how individual temperament plays a moderating role. These factors are essential in understanding an infant's stranger anxiety/fear and are important for caregivers to take into consideration when scaffolding infants' social networks.

Methods

This study uses EEG recordings in combination with parent reports to measure an infant's social network size, temperamental fear, and FAA in response to strangers.

Participants

All participants in this study were recruited by the Infant Learning and Development Laboratory at the University of Chicago. A total of 111 parents of infants from 8 months to 12 months old were asked to participate in the study. Inclusion criteria was as follows: (1) 8 to 12 months of age, (2) English language spoken at least 80% of the time at home, (3) full-term; 37 weeks and beyond gestational age, and (4) no developmental delays. We chose this age range because this is when infants can show different responses to speakers of different languages, which was the original goal of the dataset. Among the 111 participants, 76 provided both EEG and social network data. From these 76, 72 participants provided temperamental data. The average age of infants in our study was 9.5 months ($SD = 1.2$) and 52% of our participants were male.

Among the parents in our sample, the majority reported having completed a graduate or professional degree (57%), as well as a large proportion reported having earned a Bachelor's degree (27.1%). Other levels of education represented included Associate's degree (2.8%), some college credit (12.1%), and high school graduate or GED completion (0.9%).

A G*Power analysis revealed that 76 infants should yield at least 80% power at an alpha rate of .05 to detect an effect larger than 0.18 for social network size on predicting FAA. Additionally, 72 infants should yield at least 80% power at an alpha rate of .05 to detect an effect larger than 0.18 for the moderating effect of temperamental fear.

Procedure

Our study used an Electroencephalogram (EEG) machine and related materials (i.e. infant EEG cap, software, and technical equipment) to measure the infant's neural processing of strangers, specifically alpha wave frequency. During the EEG task action trials, infants watched videos of two strangers grasping a toy alternatively. Each video included four parts, each one second in length: 1) first appearance: when the actress first looked at the camera, 2) looking down: when the actress looked down at the toy, 3) reaching: when the actress reached for the toy, and 4) grasping and lifting: when the actress grasped the toy and lifted it up to the middle of her chest. The toy was switched between trials to keep infants engaged. The actions of the two actresses in each video were synchronized. The study used a within-subjects design between the native condition, one stranger speaking English, and the foreign condition, the other stranger speaking French, and the order of two actresses and the language spoken by each actress was counterbalanced across participants.

To calculate FAA, we subtracted the natural log-transformed relative alpha power of the 6-9 Hz frequency band in the left hemisphere from the natural log-transformed relative alpha

power in the right hemisphere (Anaya et al., 2021; Vincent et al., 2021; Fox et al., 2001).

Relative alpha power is calculated as the proportion of alpha power relative to the total power from 3 to 30 Hz (Harrewijn et al., 2019; Vincent et al., 2021). Therefore, in our calculations of FAA, stronger left frontal activation was indicated by a more positive FAA score (Harrewijn et al., 2019; Vincent et al., 2021). We analyzed infant FAA during the specific action windows when the strangers were reaching toward the toy and grasping/lifting the toy. Our analyses focused on infants' neural responses during both the native and foreign language conditions which was a factor in our statistical model.

Infant social network information was measured by parent report using the Child Social Network Questionnaire (CSNQ): a demographic form for each person the child sees on a regular basis (Burke et al., 2022). For the purposes of this study, we were interested in the size of an infants' social network and calculated the number of people within each participants' social network. Additionally, we were interested in whether or not an infant had received nonparental-care which we classified as attending daycare, having a babysitter, nanny, or au pair, receiving care from an adult family member, and/or living with an adult family member that is not a parent.

In order to measure an infant's temperamental fear, parents were instructed to fill out the Revised Infant Behavior Questionnaire (IBQ-R): a parent report of a reaction on a seven point scale during the past one or two weeks (Gartstein & Rothbart, 2003). The fear subscale contains 16 items related to an infant's 'startle or distress to sudden changes in stimulation, novel physical objects or social stimuli; inhibited approach to novelty' (Gartstein & Rothbart, 2003). For example, the IBQ-R asks parents, "when introduced to an unfamiliar adult, how often did the

baby refuse to go to the unfamiliar person?” A response of 1 to 7 indicates ‘never’ to ‘always’. We used the average point rating across the 16 items as an infant’s temperamental fear score.

Analyses

This study used linear mixed models (LMM) to examine our hypotheses. First, to replicate the finding in Hwang et al. (2021), that receiving nonparental-care is related to more positive FAA toward strangers, we conducted a LMM on FAA of each action window (reaching, grasping/lifting), with nonparental-care experience and language condition (native speaker, foreign speaker) as the fixed effects and subject ID as a random effect.

Next, to examine the relationship between social network sizes and infants’ neural responses to strangers, we conducted a LMM, on FAA of each action window (reaching, grasping/lifting), with social network size and language condition (native speaker, foreign speaker) as the fixed effects and subject ID as a random effect.

Finally, to examine the moderating effect of temperamental fear between social network sizes and infants’ responses to strangers, we conducted a LMM on FAA of each action window (reaching, grasping/lifting), with social network size, temperamental fear, their interaction, and the language condition (native speaker, foreign speaker) as the fixed effects and subject ID as a random effect.

Infants with less than three valid trials for each condition were excluded from the data. Trials were excluded if, within the analysis window, infants were not looking at the screen.

Results

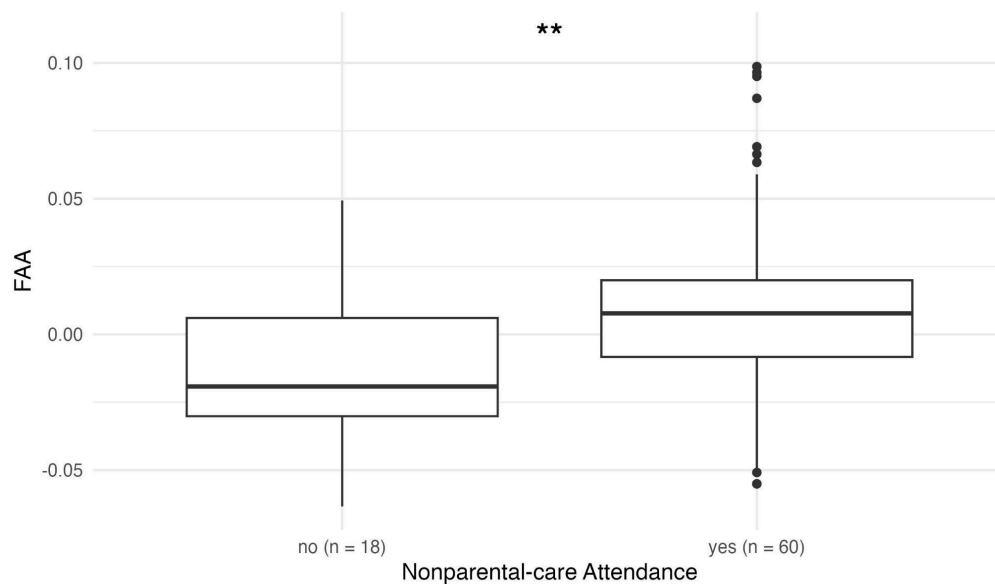
We first examined the relationship between infant FAA while viewing the actions of the stranger and nonparental-care attendance. We found that FAA was more positive for infants with

nonparental-care experience ($\beta = .02$, $SE = .01$, $p = .002$). Figure 2 displays the relationship between average FAA and nonparental-care attendance for each participant.

While our results are statistically significant, there is a wide gap among the sample sizes for the two groups. The group of infants who have nonparental-care experience ($N = 60$) is considerably larger than those who have not ($N = 18$).

Figure 2

Average FAA and Nonparental-care Attendance

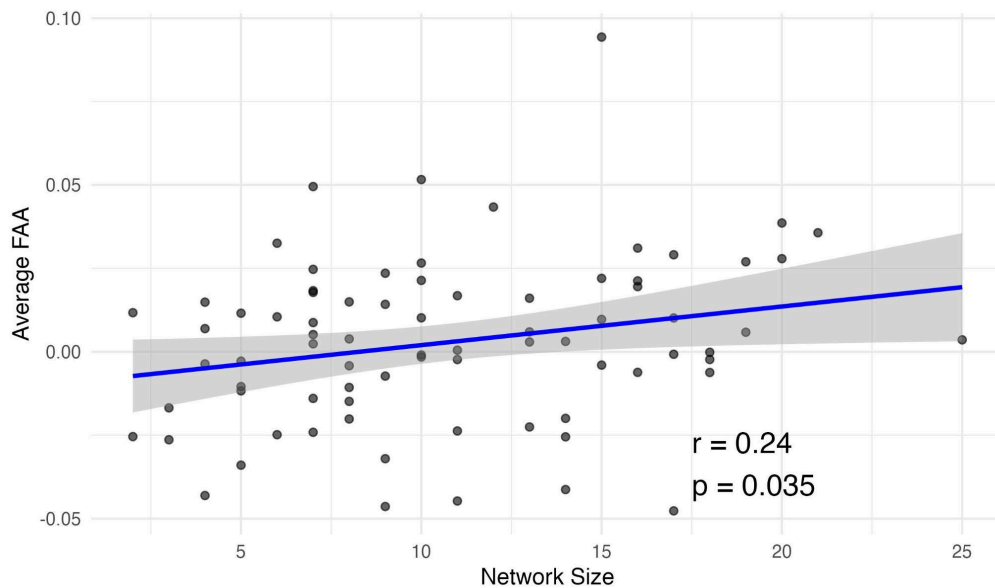


Note. Each point indicates the average FAA for each participant and whether or not they attend nonparental-care. Average FAA for the group of participants who do attend nonparental-care (“yes”) is more positive than average FAA for the group of participants who do not attend nonparental-care (“no”). ** indicates $p < .01$.

Next, we examined the relationship between average infant FAA and social network size for each participant. We found that larger social network size is associated with more positive FAA ($\beta = .001$, $SE = .001$, $p = .035$) (see Figure 3).

Figure 3

Average FAA and Social Network Size



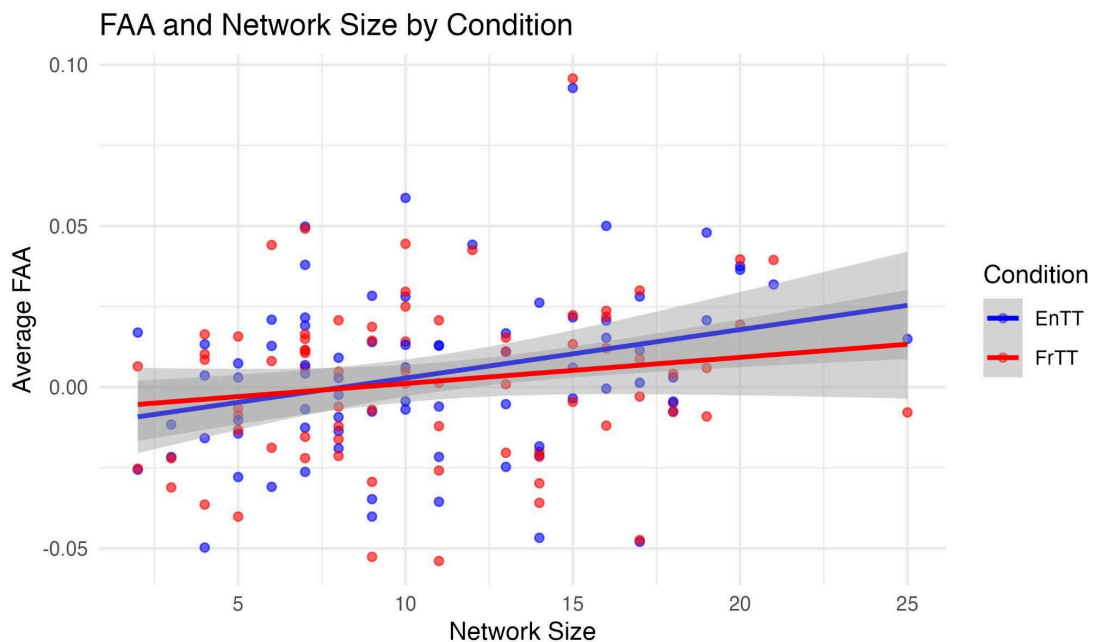
Note. Each data point represents each participant's average FAA with their social network size. The figure displays a positive correlation between social network size and average FAA to strangers.

We also explored the moderating effect of language condition within the relationship between FAA and social network size, and the effect is also statistically significant ($\beta = -.0007$, $SE = .0002$, $p = .006$). More specifically, the correlation between FAA and social network size is much stronger for the ingroup (native, English speaking) rather than outgroup (foreign, French speaking) condition (native condition: $\beta = -.002$, $SE = .001$, $p = .008$; foreign condition: $\beta = .001$, $SE = .001$, $p = .151$). The moderating effect of language condition was only significant for

the native condition. Figure 4 represents the relationship between average FAA and social network size, separated by language condition to demonstrate the moderating effect.

Figure 4

Average FAA and Social Network Size by Condition



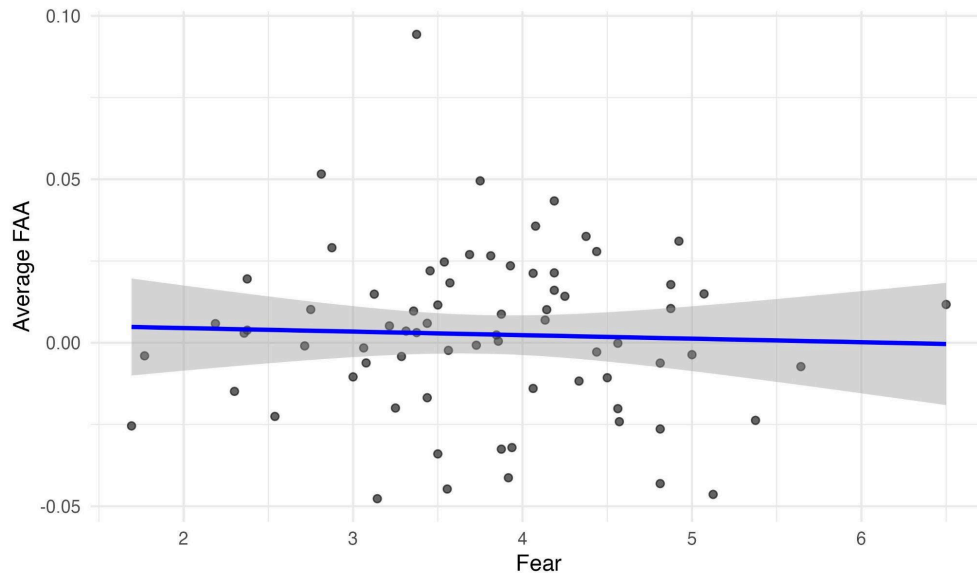
Note. Each participant has two data points: one blue and one red for the native and foreign conditions respectively. Each data point displays the participants' average FAA for the indicated language condition with their social network size. Average FAA is positively correlated with social network size for the native English condition, but we do not see as strong of a correlation between average FAA and network size in the foreign French condition.

We then explored the effect of social network size on FAA while controlling for nonparental-care attendance. We found that nonparental-care experience is significantly

correlated with FAA ($\beta = .018$, $SE = .006$, $p = .005$) and nonparental-care experience is directly associated with social network size ($\beta = .0008$, $SE = .0001$, $p = .09$).

Further, we controlled for each language condition. Within both the native and foreign conditions, we found that FAA and nonparental-care experience were significantly positively correlated (native: $\beta = .018$, $SE = .007$, $p = .009$; foreign: $\beta = .019$, $SE = .007$, $p = .007$). After controlling for nonparental-care experience, we found a substantially more significant relationship with FAA that is consistent across both the native and foreign language conditions. The effect of social network size on FAA after controlling for nonparental-care for the native condition remained significant ($\beta = .001$, $SE = .001$, $p = .035$); however, the effect of social network size on FAA for the foreign condition was almost completely irrelevant ($\beta = .001$, $SE = .001$, $p = .265$).

Finally, we explored the possible moderating effect of temperamental fear. We did not find a moderating effect of temperamental fear within the relationship between social network size and FAA ($p = 0.74$). There is also no significant relationship between fear and FAA ($p = .742$) (see Figure 5).

Figure 5*The Role of Temperamental Fear*

Note. Each point represents each participant's average FAA and the mean score of temperamental fear as reported by parents on the IBQ-R. There is no significant relationship between fear and FAA, and there is no moderating effect of temperamental fear.

Discussion

The aim of our study was to examine the relationship between social network size and neural responses to strangers from infants 8-12 months of age using their FAA. We set out to observe the effect of nonparental-care experience on FAA to strangers, explore the relationship between social network size and FAA to strangers during infancy, and to explore the potential moderating effect of temperamental fear within this relationship.

With regard to our first hypothesis, we successfully replicated the results from Hwang et al., (2021) and provided further evidence that infants with nonparental-care experience display more positive FAA to strangers. Our analysis shows a significant difference in average FAA for

infants who had received nonparental-care versus those who had not. These results could inform parents that exposing their infant to nonparental-care may impact their reactions to strangers.

We also found evidence to support our second hypothesis: a larger social network size is related to more positive FAA toward strangers. This result reveals infants with a larger social network size will be more likely to display approach tendencies toward strangers in their brains (Davidson & Fox, 1982; Fox & Davidson, 1986; Fox, 1991). It is likely that infant temperament shapes parents' behaviors and how they introduce their child to the world and people around them. For example, if an infant has a lower level of temperamental fear, parents are more likely to take them out of the house for socialization purposes and/or to seek nonparental-care in the form of daycare, babysitters, or other family members. On the other hand, it is possible that an infant with a larger social network size will have lower temperamental fear because of such social interactions which will encourage them to engage in more approach tendencies. At this point in time, we are unsure of the direction of this relationship and future studies should examine this further.

It is also possible that a parents' temperament affects how they raise their infants. For example, if a parent is socially withdrawn and has a high level of fear themselves, they are less likely to expose their infant to social interactions or nonparental-care. Recent research has explored the relationship between parents' temperament/personality and infants' neural responses, specifically maternal internalizing symptoms and child FAA (Sacks et al., 2025). There is evidence to support the connection between a mother's internalizing symptoms and more negative FAA in children. This is especially true at age 3 which was associated with more negative FAA at age 5 that predicted child internalizing symptoms at age 7. Therefore, it is

possible that maternal depression or anxiety shapes both how the parent introduces their infant to the world and the infants' neural responses. More research is needed on this relationship.

The correlation between FAA and social network size was significantly stronger for the native, English speaking, condition, while the relationship between FAA and social network size was not observed and not significant for the foreign, French speaking, condition. Further, while controlling for nonparental-care (school/daycare experience, babysitters, care from other family members) we can still see the effect of social network size on FAA in the overall model and within the native language condition. However, for the foreign language condition, after controlling for nonparental-care, the effect of social network size is no longer significant. One reason our results show a stark difference between the native and foreign conditions may relate to infant attention to the videos of the native versus foreign speakers. Infants may be more sensitive to the actions and information provided by native speakers. Infants show a different mental representation of a person's actions based on their linguistic group (Colomer et al., 2024). They are also more likely to imitate and engage with a native speaker as opposed to a foreign condition, and therefore display more engagement and attention when viewing the native speaker.

As a whole, these findings led us to conclude that rather than social network size as its own factor, the close relationships between the infant and the people in the network who provide childcare is more important in such an association with FAA to strangers. Infants who receive nonparental-care tend to have a larger social network size that continues to grow with age (Burke et al., 2022). Therefore, part of the effect we see from social network size is due to nonparental-care and vice versa. These findings expand upon the previous findings in Hwang et al. (2021), that an infant's neural response to strangers is about both the larger collection of

people within the infant's life and nonparental-care exposure. We suggest that whether other people, aside from the infant's parents, are involved in childcare is important for the infant's response to strangers. In the future, we can explore the effects of a closer relationship to the infant versus a more distant relationship and how such relationships may moderate the association between FAA and social network size.

Due to the evidence relating to our two hypotheses, we explored the moderating effect of fear in the relationship between FAA and social network size. Since FAA is a neural indicator of fear, we expected to see some effect of infant's temperamental fear within the relationship between FAA and social network size. However, we did not find a moderating effect of fear. There was no significant relationship between infant's average FAA and their parent-reported temperamental fear. As well, the language conditions did not reveal any differences between the relationship between FAA and fear.

One possible reason for the non-significant relation between fear and FAA is that our FAA was measured differently compared to previous studies. In previous studies, FAA was usually measured during the resting state while infants were watching some baseline videos like randomly moving objects (e.g., Vincent et al., 2019). This measurement is more likely to capture infants' general responses to novel stimuli or environment (Kuper et al., 2019; Sabu et al., 2022; Thibodeau et al., 2006). In our study, we measured state, or stimulus-induced, FAA, specifically to strangers. Meanwhile, the IBQ-R is measuring fear as a reliable, or resting, trait, and it focuses on infants' general responses to novel stimuli, so it is more closely related to the resting state FAA measured in previous studies (e.g., Vincent et al., 2019).

Limitations and Future Directions

The diversity of parent education in our study is not representative of the population. A majority of parents whose infants participated in this study reported to have earned a graduate or professional degree and the least amount of parents reported to have high school or GED completion. Level of education is significant in understanding the people involved in the study, the potential opportunities for socializing their child available to them, and their potential necessities of utilizing childcare. We therefore must be hesitant when generalizing our findings to the larger population.

While there is research to show that an infant's response to a video is similar to their response to a real-life situation (Diener et al., 2008), there is still evidence of differences in their reactions. Therefore, we have hesitations that the measured responses would match the responses to a real-world interaction with a stranger. As such, the paradigm within the study and the specific videos used to simulate real-world interactions were not designed to measure FAA because the infant participant is not engaged with the actor. Additionally, our video of one actress does not address the countless possibilities of interactions with strangers that an infant may encounter in the world. Future studies should use more socially interactive videos or real-world interactions in order to simulate a more accurate measure of FAA from the infant.

Future research should confirm the proposed relationship between social network size and an infant's neural response to strangers. We found a relationship between infant FAA and nonparental-care experience suggesting the impact of not just social network size, but the significant relationships of nonparental caregivers. To expand upon these findings, future research should look at the impact of close versus distant relationships in the infant's social network.

Although we did not find a mediating effect of temperamental fear in our study, future research should continue to study this effect and explore infants' behavioral responses to strangers. Seeing as FAA is the neural indicator of temperamental fear, we should expect to see some evidence of this relationship in a larger and more representative sample, and observe their behavioral reactions.

Implications

The findings of this study contribute to the understanding of the neurological reactions, and affecting factors, toward strangers during infancy. From our study and previous research, we understand that there is an interplay between social environment and infants' brain development (Kuper et al., 2019; Reznik & Allen, 2018; Sabu et al., 2022; Thibodeau et al., 2006). These findings suggest that exposing infants to a larger social network and nonparental-care experiences may be a way to reduce the likelihood of negative reactions to strangers in infancy and childhood. In turn, these findings may also suggest that infants' negative or positive responses to strangers can influence how parents build their social environment. If infants respond more positively to strangers, parents might be willing to introduce them to new people and build a larger social network for them. On the other hand, if infants respond negatively to strangers, parents may be reluctant to introduce them to new people and keep their social networks relatively small.

While it is not realistic for parents to understand or be aware of their child's FAA, it may be beneficial for parents to understand the approach versus withdrawal tendencies because such tendencies during infancy may have implications for their mental state and personality in the future. An infant who exhibits more positive FAA is more likely to be extraverted and display approach tendencies toward positive stimuli (Kuper et al., 2019; Reznik & Allen, 2018).

Additionally, it has been suggested that more negative resting FAA is related to later depression and anxiety (Thibodeau et al., 2006). Therefore, it is likely beneficial for parents to expand their child's social network and array of nonparental caretakers during infancy to encourage more positive FAA responses from their infant toward strangers. In turn, their child will likely exhibit more positive emotional and behavioral development.

Conclusion

Our research has provided further evidence of a correlation between an infant's social network size and their FAA toward strangers. Infants with a larger social network size and those with nonparental-care experience are more likely to display positive FAA toward strangers, which signifies greater approach tendencies for such infants. We did not find evidence of a moderating effect of temperamental fear in our study, which can be further investigated. These findings reveal the interplay between social environment and brain responses in the first year of life.

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