

Novel Insights into the Social Functions of the Medial Prefrontal Cortex during Infancy

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Abstract

The medial prefrontal cortex (mPFC) is thought to play a central role in human social perception, cognition, and behavior. In adults, the mPFC is involved in representing and interpreting the mental states in self and others. Developmental research using neuroimaging techniques like functional near-infrared spectroscopy and functional magnetic resonance imaging has begun to extend these findings into infancy. Novel evidence reviewed in this opinion demonstrates that infant mPFC (1) plays a specialized, proactive, and evaluative role in social perception, (2) is involved in connecting with other minds while interacting and when watching other minds interact, and (3) predicts overt social behavior beyond infancy. These findings suggest that, from early in human ontogeny, the mPFC plays a multi-faceted role in social perception, cognition, and behavior.

Key words: brain development; prefrontal cortex; social cognition; social interaction

Significance Statement

This opinion synthesizes recent neuroimaging evidence demonstrating that the medial prefrontal cortex (mPFC) is functionally specialized and actively engaged in social perception, cognition, and behavior starting from infancy. Findings reveal that the infant mPFC proactively processes socially relevant information, predicts emerging social behaviors, and supports both direct and observed social interactions. These novel insights critically add to our understanding of developing brain function and underscore the foundational significance of mPFC for early human social development.

Introduction

The medial prefrontal cortex (mPFC) plays a central role in human social cognition. Research with human adults has shown that the mPFC is involved in a variety of social cognitive processes, especially when thinking about the psychological attributes of self and others (Amodio and Frith, 2006). Subsequently, a body of developmental social neuroscience research with human infants has demonstrated that the mPFC is active from early in development, supporting social perceptual and cognitive processes in the developing human brain (see Grossmann, 2013, for a review). While previously thought to be functionally inactive in infancy (see Chugani, 2018, for a review arguing that it is not until 1 year of age that infant blood glucose levels increase in medial portions of the prefrontal cortex), studies using functional near-infrared spectroscopy (fNIRS) demonstrate that infants' mPFC responds sensitively to infant-directed facial and vocal social stimuli from early in the first year (see Grossmann, 2013, for a review).

Following this progress based on the utilization of fNIRS, Deen et al. (2017) obtained face-sensitive responses in the mPFC of 4–6-month-old infants using functional magnetic resonance imaging (fMRI). This further supports the notion of the mPFC playing a specialized role in processing social information from early in human development. This resulted in a conceptual proposal stipulating that the mPFC plays a role in processing faces as

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more than just a class of visual stimuli but also as signals of social interaction (Powell et al., 2018). Specifically, considering that infants' mPFC response to faces is strongest when the faces are dynamic and include cues of positive social attention like direct gaze and smiling and when the social interaction is contingent suggests that the mPFC may be involved in evaluating the social relevance of faces and thereby facilitate social engagement early in development (Powell et al., 2018). According to this proposal, mPFC involvement during face processing may contribute to the development of posterior (occipital and temporal) cortical face areas by directing infants' attention toward the faces of potential social partners (Powell et al., 2018).

Opinion

The current opinion serves the function to provide an update based on recent research concerning mPFC function in infancy and its role in developing social cognition. This was partly prompted by the recent publication of a fMRI study by Kosakowski et al. (2024), which identified face-selective activity in mPFC of infants, as young as 2 months old. Utilizing fMRI data from a large sample of awake infants aged 2–9 months, the researchers found that the mPFC exhibited significantly greater activation to videos of faces compared with videos of objects, bodies, and scenes. Confirming and extending prior work using fMRI with infants (Deen et al., 2017), face-selective responses in the mPFC were observed across this age range, supporting the view that the mPFC's involvement in processing faces as socially relevant stimuli emerges in infancy (Powell et al., 2018). In fact, there is also evidence to indicate that the mPFC is involved in face processing even before 2 months of age. Using electroencephalography (EEG) methods, newborns have been shown to display face-specific brain responses localized to various cortical brain regions, including the mPFC (Buiatti et al., 2019).

Beyond these important insights demonstrating the early ontogenetic emergence of mPFC involvement in social information processing, there now exists converging evidence attesting to the sophistication of the mPFC involvement in infant social cognition. EEG research with 4- and 9-month-old infants shows that the mPFC contributes to predictive face processing in infancy, showing anticipatory neural activity before the presentation of a face (Mento et al., 2022). In this study, 4- and 9-month-old infants exhibited a category-specific modulation of the contingent negative variation (CNV), an ERP component reflecting anticipatory activity, with a larger CNV elicited by human voices compared with nonhuman sounds when these cues predicted faces. These face-predictive effects were generated in several cortical regions, including the mPFC (Mento et al., 2022). This study further showed the CNV prior to face onset predicted the amplitude of the face-sensitive ERP component (P400; Mento et al., 2022), elicited over posterior brain regions, providing support for the view that mPFC drives specialized brain processes in face-selective regions in line with Powell et al.'s (2018) abovementioned proposal.

Further evidence for the sophistication of mPFC function in infancy comes from a study using a novel dual-brain fNIRS paradigm (Piazza et al., 2020). This study provides evidence that the mPFC plays a critical role in real-life social interactions during infancy by demonstrating significant neural coupling (intersubject correlation) between infants and adults. Specifically, using intersubject correlation analysis 9- to 15-month-old infants' mPFC responses displayed neural coupling (intersubject correlation) with an adult experimenter's mPFC responses during naturalistic face-to-face interactions, but not when the dyad was engaged in separate tasks (Piazza et al., 2020). Notably, the infants' mPFC activity preceded the adults' mPFC activity, particularly during moments of mutual gaze, suggesting that infants' brains play a leading and proactive role in the dynamics during such social interactions. These findings replicate and extend previous findings regarding mPFC's role in social interaction from screen-based experimental studies with infants (Grossmann, 2013) into real-life social interactions. Moreover, the findings from this study (Piazza et al., 2020) highlight the importance of the mPFC in actively facilitating dynamic and reciprocal social interactions between infants and adults, challenging the traditional view of early social interaction as primarily driven by adult input.

Infants' mPFC has also been shown to play a role in social evaluation and person perception (Krol and Grossmann, 2020). In this study, 11-month-old infants' brain responses were measured while they watched videos of four different individuals displaying either smiles or frowns, combined with direct or averted gaze. Following this impression formation phase, infants' looking preferences for the individuals (now displaying neutral

expressions) were assessed using eye-tracking. The findings from this study showed that infants' mPFC responses discriminated between smiling and frowning individuals only when the faces exhibited direct gaze (Krol and Grossmann, 2020). Furthermore, in this study, infants' mPFC activity during the impression formation phase predicted subsequent person preferences seen in looking behavior. These findings demonstrate that the mPFC is involved in forming impressions underpinning person perception.

There also exists evidence from longitudinal work showing that mPFC responses during infancy predict later social behavior in toddlerhood (Grossmann and Allison, 2024). This study used fNIRS to show that greater mPFC activity in response to social smiles, but not frowns, at 11 months predicted higher levels of sociability at 18 months. This finding suggests that early variability in mPFC response during positive social interactions is linked to individual differences in overt social behavior. The finding that infant mPFC activity predicts later sociability suggests that early neural responses to social cues may serve as a biomarker for emerging social tendencies rather than directly driving later behavior. A developmental mechanism could involve the mPFC's role in reinforcing positive social experiences, shaping early social motivation and engagement through repeated interactions (Grossmann and Allison, 2024).

Finally, recent work measured brain responses using fNIRS in infants aged 6–13 months as they viewed videos of third-party social interactions and compared the brain responses with when infants viewed two individual actions and inverted social interactions as control conditions (Farris et al., 2022). The results of this study demonstrate that infants exhibited greater activation in the mPFC when observing third-party social interactions compared with both control conditions. In conjunction with the prior work discussed above (Piazza et al., 2020), this suggests that infants' mPFC plays a role in flexibly supporting both first-person and third-person social interaction processing.

In summary, this suggests that mPFC (1) plays a role in social perception, starting early in human infancy (Buiatti et al., 2019; Kosakowski et al., 2024), (2) serves predictive and social-evaluative functions (Krol and Grossmann, 2020; Mento et al., 2022), (3) is involved in coupling with other brains during first-person social interaction (Piazza et al., 2020) and in processing third-person social interactions (Farris et al., 2022), and (4) longitudinally predicts social behavior beyond infancy (Grossmann and Allison, 2024). This paints a picture of infant mPFC as playing an active and multifaceted role in social perception, cognition, and behavior, earlier and more sophisticated than previously thought. This confirms and critically extends existing conceptual approaches that had hypothesized that mPFC plays a specialized role in social perception (Powell et al., 2018) and in social cognition (Grossmann, 2013) from early in human ontogeny. The novel evidence garnered from developmental social and cognitive neuroscience research with infants (1) challenges late maturational views of prefrontal cortex function and (2) also contests recent proposals, asserting developmental discontinuity between infants' and adults' brain functioning (Blumberg and Adolph, 2023; see Liu et al., 2023, for discussion).

Considering this progress, it appears important to flesh out pressing open questions that should be addressed in future work. First, in children and adolescents, the mPFC has been shown to display functional connectivity to other brain regions such as in the superior temporal sulcus and the temporoparietal junction during social tasks (McCormick et al., 2018). It is thus important to examine the functional connectivity from mPFC to other brain regions in infant-friendly, social perceptual, and social cognitive tasks.

Second, while the existing evidence suggests that mPFC function in infants is specialized in processing social cues, it is currently unclear what role more domain-general learning mechanisms might play in accounting for this specialization. For example, a recent study showed that, in infant as young as 3 months of age, mPFC exhibited increased activity in response to structured versus random sequences of (nonsocial) visual stimuli, particularly during the second half of exposure to the structured sequences (Ellis et al., 2021). This learning-related activity in the mPFC is consistent with its role in learning and memory processes in adults, suggesting that the mPFC, in concert with the hippocampus, supports statistical learning of nonsocial stimuli infancy. In this context, it is important to note that in a large meta-analysis of adult fMRI studies (Gilbert et al., 2006), memory processes were associated with more lateral activations of the mPFC, whereas studies involving social cognition (perspective taking and mentalizing) were associated with more medial activations of mPFC. In future research, it will thus be

important to assess and contrast statistical learning for social compared with nonsocial stimuli to determine whether social processing recruits specific subsections of the mPFC in infancy.

Third, while existing work suggests that mPFC plays a role in predictive processing (Mento et al., 2022), it remains to be seen whether mPFC modulates activity in posterior (face-selective) brain regions in a top-down manner as seen in adults using dynamic causal modeling from fMRI (Summerfield et al., 2006). While top-down cortical modulation in posterior brain regions has been studied in infants using fNIRS (Emberson et al., 2015), to date, there are no studies including measures from mPFC, which will be a critical extension of existing research.

Fourth, fMRI research with adults indicates that there are anatomically distinct subsections of the mPFC that map onto partly distinct processes involved in social perception, cognition, and behavior (Gilbert et al., 2006; Bzdok et al., 2013; Lieberman et al., 2019). It is thus important to more precisely map social functions in mPFC during infancy using high-resolution techniques, now also available for fNIRS (Collins-Jones et al., 2024), which is more infant-friendly than fMRI in its application as it is less restrictive in terms of noise, movement, etc. while allowing for a testing environment that better approximates infants' real-life social experiences. Employing a high-resolution mapping approach to mPFC function and systematically comparing between social and nonsocial conditions across age during infancy in future research will enable the examination of functional specialization (domain-specificity) for processing social information.

Fifth, current evidence suggests that mPFC coupling (intersubject correlation) between infants and adults during social interactions (Piazza et al., 2020) reflects a shared neural state, but the precise functional significance of this coupling remains to be fully understood. One possibility is that neural coupling in mPFC plays a critical role in shaping real-time social interactions, actively facilitating shared attention and communication. Alternatively, it may primarily reflect a correlate of shared experience, without exerting a causal influence on interaction dynamics. Future work should explore whether individual differences in mPFC coupling predict specific aspects of social exchanges, such as turn-taking, joint attention, or responsiveness, which could help clarify its mechanistic role. Additionally, experimental designs that manipulate the degree of interactional contingency (e.g., live vs prerecorded or delayed interactions) could provide further insights into whether mPFC coupling drives, rather than merely reflects, social coordination. Given the foundational role of the mPFC in social cognition from early infancy (see Grossmann, 2013, for a review), understanding the functional relevance of neural coupling in this region will be crucial for advancing theories of early social brain development.

Conclusion

Taken together, the current opinion suggests that the mPFC appears to serve as a key region in the human brain playing a multifaceted role in social perception, cognition, and behavior from early in human ontogeny. This supports the notion that humans are extraordinarily social primates (Tomasello et al., 2012), whose brains have evolved to actively learn, adapt, and benefit from living in interdependent, cooperative, and complex cultural groups.

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