Synchronization or Not: Developmental Characteristics of Basic Facial Expression Recognition in Infants (Postprint)

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Abstract

Facial expressions are emotional signals transmitted through muscular actions of the eyes, mouth, and other facial regions. Infants' accurate recognition of facial expressions constitutes a crucial means of communication with the external world and facilitates the development of emotional cognition. The development of basic facial expression recognition in infants exhibits asynchrony: discrimination of positive-valence expressions precedes that of negative-valence expressions, with 2-month-old infants able to discriminate positive-valence expressions and 4- to 6-month-old infants capable of discriminating different negative-valence expressions; the development of emotion perception ability precedes that of emotion understanding ability, as 7-month-old infants have preliminarily acquired emotion perception capabilities, whereas 12-month-old infants still cannot accurately differentiate the emotional meanings expressed by different negative-valence expressions. Infants' expression recognition is subject to dual influences from environmental and cognitive factors, reflecting the process from basic emotion activation to the formation of emotion schemas.

Full Text

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Abstract

Facial expressions are emotional signals transmitted through muscle movements of the eyes, mouth, and other facial features. Correct recognition of facial expressions serves as a crucial means for infants to communicate with the external world and facilitates the development of emotional cognition. The development of basic facial expression recognition in infants is characterized by asynchrony: recognition of positive-valence expressions emerges earlier than that of negative-valence expressions, with 2-month-old infants able to discriminate positive expressions and 4-6-month-olds able to differentiate various negative expressions. Furthermore, the development of emotional perception precedes emotional understanding—7-month-old infants possess preliminary emotional perception abilities, yet 12-month-olds still cannot accurately comprehend the emotional meanings conveyed by different negative-valence expressions. Infants' expression recognition is influenced by both environmental and cognitive factors, reflecting a developmental trajectory from basic emotion activation to the formation of emotion schemas.

Keywords: infant, facial expression, emotion recognition

2. Developmental Characteristics of Basic Facial Expression Recognition in Infants

The human brain appears to be innately sensitive to social stimuli, with infants showing stronger neural responses to facial images than to non-social images (Redcay & Warnell, 2018). Faces constitute one of the most important stimuli in infants' visual environment, providing them with vital social information that enables interaction with others and strengthens their connection to the surrounding world, thereby continuously enhancing their social skills (Bayet, 2022; Carnevali et al., 2022; Kim et al., 2022). Consequently, the development of facial expression recognition ability plays a significant role in infants' social development.

Over the past half-century, researchers have conducted extensive empirical studies on infant facial expression recognition. Initially focused on behavioral research, recent technological advances have enabled further investigation into the neural mechanisms underlying the development of facial expression recognition in infants. This paper systematically reviews empirical studies on infant facial expression recognition to examine whether the development of recognition abilities for the six basic facial expressions is synchronized—that is, whether they reach comparable developmental levels within the same timeframe. Additionally, we discuss factors influencing the development of infant expression recognition and explore its significance, offering a new perspective for practical applications.

2.1 Synchronized Development of the Six Basic Facial Expressions

Research indicates that newborn infants can imitate adult facial expressions within minutes of birth, though this does not signify genuine emotional understanding (Feldman, 2007/2013). Facial expression recognition encompasses two distinct capacities: emotional perception and emotional understanding. Emotional perception refers to the ability to visually discriminate between different types of emotional expressions through visual perception. Using looking-time paradigms (Ruba & Repacholi, 2020), researchers can observe whether infants can distinguish different facial expressions. These methods include paired-preference paradigms and habituation-recovery paradigms (Ruba & Repacholi, 2020; Young-Browne et al., 1977). In paired-preference tasks, infants are simultaneously presented with two static facial expression images; longer looking time toward one expression indicates discrimination ability (Ruba & Repacholi, 2020). In habituation-recovery paradigms, infants are first exposed to one expression until reaching a habituation criterion (typically defined by a set number of presentations or a decline in looking time to a predetermined standard), after which a new expression is presented. Recovered looking time to the novel stimulus demonstrates discrimination (Ruba & Repacholi, 2020; Young-Browne et al., 1977).

Emotional understanding refers to the capacity to interpret the emotional meaning conveyed by facial expressions. Social referencing experiments can determine whether infants can use facial expressions to understand emotions (Ruba & Repacholi, 2020). In these experiments, an experimenter displays an emotion toward a novel target (toy, scenario, or stranger), and researchers observe infants' behavioral responses (approach or avoidance) to assess their recognition abilities (Ruba & Repacholi, 2020). Other experiments using looking-time paradigms present infants with specific contexts where experimenters display facial expressions that are either consistent or inconsistent with the situation. If infants can identify the incongruence, they show longer looking times compared to consistent scenarios (Ruba, 2019).

Neuroimaging research in infants, constrained by age-related limitations, primarily employs event-related potentials (ERP) and functional near-infrared spectroscopy (fNIRS). These techniques record neurophysiological changes or cortical functional responses while infants view different facial expressions (Zhou & Zhang, 2017).

2.1.1 Development of Emotional Perception Studies demonstrate that 2-month-old infants can discriminate positive-valence expressions. In the "still-face" paradigm, experimenters first interact with infants for 30 seconds, then display 30-second static happy, neutral, and sad expressions. Two-month-olds show the longest looking time toward happy expressions (Rochat et al., 2002). Using habituation-recovery paradigms, 3-month-olds show renewed looking time to novel stimuli when comparing static happy-surprise expressions in adults and dynamic happy-sad expressions in infants, indicating discrimination between

happy-surprise and happy-sad expressions (Flom et al., 2018; Young-Browne et al., 1977). When examining angry, fearful, and surprise expressions across six pairings using habituation-recovery paradigms, 4-6-month-olds show renewed looking to novel stimuli in five of the six pairings, except when habituated to surprise and shown fear. Researchers conclude that infants can discriminate these three expressions, though their salience differs—anger and surprise convey more important information and appear more frequently in daily life than fear. Surprise expressions are particularly common, as mothers often use them to initiate interaction with infants. Consequently, 4-6-month-olds rarely encounter fearful expressions in daily life, explaining why they fail to recover looking time when habituated to surprise and presented with fear (Serrano et al., 1992). From 5 months onward, infants demonstrate categorical perception of basic expressions: when habituated to four faces showing varying intensities of happiness, 5-month-olds subsequently show longer looking toward a fearful expression than toward a novel intensity of happiness on a new face, indicating recognition that different faces and intensities belong to the same expression category (Bornstein & Arterberry, 2003). Using morphing technology to present between-category stimuli (e.g., sad vs. disgust) and within-category stimuli (e.g., varying sadness intensities), 5-month-olds show longer looking times for between-category pairs (happy-surprise, sad-anger, sad-disgust), demonstrating discrimination and categorical perception (White et al., 2019). Between 5-7 months, infants develop an attentional bias toward fearful expressions (Leppänen et al., 2018; Tuulari et al., 2020). Five-month-olds show longer looking times to fearful than to dynamic happy or neutral expressions (Heck et al., 2016; Miguel et al., 2019), and 7-9-month-olds similarly show the longest looking times to fearful expressions compared to static happy, angry, and neutral expressions (Dixon, 2019).

Infants' efficiency and skill in perceiving emotions through facial expressions improve rapidly. Comparing 3- and 5-month-olds in habituation-recovery paradigms reveals that 5-month-olds reach habituation more quickly for happy and sad expressions (Flom et al., 2018). Eye-tracking studies reveal strategic shifts in how infants scan faces: 7-month-olds attend more to structural facial information, showing increased fixation on the eyes, nose, and mouth regions (Soussignan et al., 2018). Compared to 3-month-olds, 7-month-olds employ adult-like scanning strategies, such as focusing on the eye region for fearful expressions and the mouth region for happy expressions (Segal & Moulson, 2020). Thus, emotional perception development shows asynchronous characteristics: from 2 months, infants discriminate positive expressions; by 4-6 months, they discriminate different negative expressions and demonstrate categorical perception; between 5-7 months, they show attentional biases toward fear; and by 7 months, they employ adult-like visual scanning strategies.

2.1.2 Development of Emotional Understanding Researchers investigate infants' facial expression recognition abilities through social referencing experiments and their responses to expression-context congruence. In social referencing tasks where experimenters express emotions toward target toys us-

ing facial and vocal cues, 5.5-month-olds preferentially touch toys associated with happy expressions and avoid those associated with fearful expressions (Vaillant-Molina & Bahrick, 2012). Ten-month-olds can understand the consistency between positive/negative expressions and contexts: when an experimenter's toy is taken away, they display angry expressions/vocalizations that are either context-consistent or happy expressions/vocalizations that are context-inconsistent. Ten-month-olds show longer looking times toward the experimenter in the inconsistent condition, indicating they can differentiate the emotional meanings of positive and negative expressions and understand that losing a toy typically elicits anger (Ruba, 2019). In social referencing experiments, 11-month-olds preferentially touch toys associated with happy expressions and avoid those associated with disgust expressions (Hertenstein & Campos, 2004). In the "visual cliff" paradigm, 1-year-olds show differentiated behaviors when recognizing different negative-valence expressions. Infants and mothers sit at opposite ends of a table covered with transparent plexiglass that creates a visual cliff illusion. To obtain a plush toy near the mother, infants must cross the visual cliff. When mothers display happy expressions, all infants cross; with sad expressions, one-third cross; with angry or fearful expressions, very few cross (Sorce et al., 1985). Although 1-year-olds show behavioral differences when recognizing different negative expressions, some researchers argue this reflects lower arousal from sad expressions rather than accurate recognition (Widen & Russell, 2010). Moreover, infants show no behavioral differences after seeing angry versus fearful expressions, suggesting this experiment cannot fully prove that 1-year-olds can distinguish the emotional meanings of different negative-valence expressions (Widen & Russell, 2010). Other studies find that even after 12 months, toddlers cannot accurately differentiate all negative expressions. When experimenters display anger, disgust, or fear in a toy-unavailable context, 14-month-olds show no significant differences in looking times across the three expressions, indicating they cannot yet accurately recognize anger (Ruba et al., 2019). Sixteen-month-olds still cannot appropriately reference angry or disgust expressions to guide avoidance behaviors in multimodal contexts involving facial, vocal, and bodily expressions (Walle et al., 2017).

Thus, emotional understanding development also shows asynchrony: by 5-6 months, infants can recognize the emotional meaning of positive expressions and show approach behaviors. However, emotional understanding develops more slowly than perception, and synthesizing relevant empirical evidence suggests that 12-month-olds still cannot accurately differentiate different negative-valence expressions. Emotional understanding places higher demands on cognitive development and depends on both cognitive maturation and environmental stimulation.

2.1.3 Development of Neural Mechanisms Within the first three months after birth, infants' cerebral cortex begins functioning (Feldman, 2007/2013). Functional magnetic resonance imaging (fMRI) studies with 4-6-month-olds viewing infant facial expressions from the cartoon "Baby Einstein" reveal face-

preferential regions in the fusiform gyrus, lateral occipital cortex, superior temporal sulcus, and medial prefrontal cortex that are structurally similar to adults (Deen et al., 2017). fNIRS studies show that while the face-processing network is activated in 5-month-olds, the facial expression processing system remains immature (di Lorenzo et al., 2019). In 5- and 7-month-olds, viewing happy and angry expressions activates temporal-parietal and frontal regions (Bayet et al., 2021). Seven-month-olds show differential temporal cortex responses to happy versus angry expressions, with left temporal activation for happy and right temporal activation for angry expressions, indicating hemispheric specialization for processing positive and negative valence (Nakato et al., 2011).

ERP research identifies N290, P400, and Nc as components related to infant expression recognition (Xie et al., 2018). N290 and P400 may be analogous to the adult N170 and relate to visual processing, while Nc changes reflect attentional processes, indicating attentional biases toward expressions (Munsters, 2017). Consistent findings show that from 7 months, infants show Nc amplitude differences for positive versus negative expressions, primarily manifesting as attentional biases toward fearful expressions (Ruba & Repacholi, 2020). Infants show stronger Nc amplitudes when viewing fearful versus happy expressions (Jessen & Grossmann, 2015; Segal & Moulson, 2020; Taylor-Colls & Pasco Fearon, 2015). Some research suggests this fear-specific attentional bias may emerge earlier: 5-month-olds already show N290 amplitude changes in the right fusiform gyrus when viewing fearful versus happy or angry expressions, becoming most pronounced at 7 months and disappearing by 12 months (Xie et al., 2018). This attentional bias has a preconscious automatic onset: when expressions are presented subliminally for 50-100 ms, 7-month-olds still show stronger Nc amplitudes for fearful versus happy expressions (Jessen & Grossmann, 2015). Comparing brain responses to dynamic happy and sad expressions in 8-10-month-olds and adults reveals infant brain activation patterns similar to adult emotional processing lateralization that strengthens with development (Rotem-Kohavi et al., 2017).

Neuroimaging studies demonstrate that humans have evolved a socially biased brain. In the first half of infancy, infants already possess adult-like brain regions and show face preferences, laying the groundwork for subsequent expression recognition development. At this stage, emotional understanding is rudimentary—infants cannot accurately comprehend the emotional meanings of different negative expressions. The negativity bias observed during this period may help infants rapidly learn to recognize negative emotions.

3. Factors Influencing the Development of Infant Expression Recognition

Infancy represents a critical period for brain development and is highly susceptible to environmental influences (Xu et al., 2021). Infants of mothers who receive positive care show greater Nc component activation when viewing happy expressions, indicating higher sensitivity to positive emotions (Taylor-Colls & Pasco

Fearon, 2015). When mothers experience anxiety during pregnancy or postpartum, infants show stronger attentional biases toward fearful expressions (Bowman et al., 2022; Kataja et al., 2018, 2019). Six-to-eight-month-olds rated by mothers as having higher negative emotionality show stronger medial prefrontal cortex (mPFC) activation when viewing happy, sad, and angry expressions, indicating greater emotional sensitivity compared to infants with lower negative emotionality ratings (Safyer et al., 2020). After mothers express sadness through facial and vocal cues, 9-month-olds significantly reduce play behavior and display more sad and angry expressions during subsequent play (Termine & Izard, 1988). By 12 months, greater maternal negative emotional expression correlates with smaller pupillary responses and lower emotional arousal when infants view facial expressions, while paternal negative emotionality shows no effect (Aktar et al., 2018). Thus, mother-infant relationships are crucial for developing expression recognition abilities.

Because infants spend most of their time with family members, family emotional expression and discussion likely significantly impact emotional perception (Ogren & Johnson, 2021a). A longitudinal eye-tracking study found that 4-month-olds from high-conflict families detect angry expressions on computer screens faster than infants from average-conflict families. However, by 12 months, these high-stress family infants show significantly lower sensitivity to angry expressions than infants from typical families (Burris et al., 2022). When family members are poor at expressing emotions, children may develop delayed expression recognition due to lack of environmental stimulation (Ogren & Johnson, 2021b). Nine-month-olds' ability to match happy and neutral facial and vocal expressions correlates positively with parents' ratings of family emotional expressiveness (Ogren et al., 2018). Socially disadvantaged children, such as those in welfare institutions or homeless children, show atypical expression recognition development (Lan & Moscardino, 2021; Doretto & Scivoletto, 2018), with related cognitive-neural mechanisms potentially emerging in infancy.

Social environments also influence infant expression recognition. Since the COVID-19 pandemic, researchers have found infants' face recognition abilities affected. Nine-to-14-month-olds born during Canada' s second pandemic wave could not recognize novel unmasked faces in habituation-recovery paradigms but could recognize novel masked faces, suggesting pandemic-related restrictions on face perception experience altered face processing abilities (Kim et al., 2022). Studies of 9-10-year-olds show mask-wearing impairs recognition of disgust, fear, and sad expressions (Carbon & Serrano, 2021). Review articles suggest that since infants now primarily see masked adults, they cannot access critical expression information from the mouth region, potentially impacting face and expression recognition development (Carnevali et al., 2022; Ruba & Pollak, 2020). Mask-wearing causes loss of some emotional information, and since infants are in a rapid learning period for understanding others' emotions, an environment of masked faces may disproportionately affect infants compared to other age groups (Carnevali et al., 2022; Ruba & Pollak, 2020).

Race and culture also influence expression recognition. Seven-month-olds across cultures adopt adult-like scanning strategies: Japanese adults and infants focus more on the eye region, while British adults and infants focus more on the mouth region (Geangu et al., 2016). In summary, family environment is crucial for expression recognition development. Families should provide rich, beneficial environmental stimulation, while mothers' emotional states directly impact infant development. Families and society should provide more support and scientific caregiving guidance.

4. Developmental Trajectory from Basic Emotions to Emotion Schemas

According to Izard (2007), children' s emotional cognition develops from basic emotions to emotion schemas. Basic emotions are evolutionarily prepared systems for environmental adaptation, with infants innately capable of expressing and recognizing them. Basic emotions are independent of postnatal cognitive development—once activated by the environment, infants possess corresponding recognition abilities. Emotion schemas develop postnatally through dynamic interaction between emotion and cognition, with both individual cognitive development (particularly language) and environmental stimulation playing important roles (Izard, 2007).

This review of behavioral and neuroimaging research reveals asynchronous development of basic facial expression recognition, partially supporting Izard' s view. On one hand, the human brain has evolved experience-expectant mechanisms for recognizing basic facial expressions. Infants show preferences for social information, such as face preferences (Redcay & Warnell, 2018). Two-month-olds show longer looking times toward mothers' positive expressions (Rochat et al., 2002). This positive bias helps infants obtain more protection from adults (Izard, 2007). From 5 months, infants develop a specific attentional bias toward fearful expressions (Ruba & Repacholi, 2020). This bias reflects an innate neural mechanism rather than learned understanding of signal meaning (Leppänen & Nelson, 2009). The fear-specific attentional bias is independent of environmental stimulation—infants rarely encounter fearful expressions before 6 months (Serrano et al., 1992), and 7-9-month-olds show this bias regardless of crawling ability, indicating it is unrelated to environmental changes from motor development (Dixon, 2019). This bias has a preconscious automatic onset (Jessen & Grossmann, 2015) and cross-cultural consistency (Geangu et al., 2016), suggesting it is an innate mechanism rather than environmentally produced.

On the other hand, experience-dependent mechanisms also operate in basic expression recognition development. Research shows mother-infant interaction, family environment, socioeconomic status, and social environment all influence expression recognition development. Experience-dependent mechanisms render the brain's emotional neural networks plastic (Leppänen & Nelson, 2009). From the second half of infancy, environmental factors and cognitive development become increasingly important, and infants begin forming individual emotion

schemas (Izard, 2007).

Overall, facial expression recognition ability plays a crucial role in forming emotion schemas, serving as both a communication and learning tool for infants. As a communication tool, expression recognition is essential for preverbal infants to interact with their environment (Leppänen & Nelson, 2006). As a learning tool, expression recognition ability in 3-year-olds with incomplete language skills predicts their emotional understanding development six months later. Researchers suggest expression recognition helps language-limited children learn complex emotional knowledge, serving a unique function for cognitive development that disappears once language is mastered (Strand et al., 2016). Expression recognition ability is vital for infant-environment interaction and cognitive development, influencing emotion schema formation. Long-term, stable emotion schemas constitute personality traits—maladaptive schemas cause social behavior problems. For example, children who develop anger schemas show processing biases, interpreting neutral emotional cues as angry and displaying more aggressive behaviors (Izard, 2007). Preschoolers' expression recognition deficits predict developmental problems—children with poor expression recognition at age 5 show more behavior problems and lower academic achievement at age 9 (Izard et al., 2001). These problems may originate in infancy, leading to atypical emotion schema development and long-term developmental issues.

5. Summary and Outlook

This review examined research on the development of infants' basic facial expression recognition abilities. Through behavioral and neuroimaging studies, we identified asynchronous development: (1) asynchronous development of positive and negative expression recognition, with positive expressions recognized earlier; (2) asynchronous development of emotional perception and understanding, with perception developing significantly faster. By 7 months, infants' emotional perception is established—they can discriminate basic expressions, demonstrate categorical perception, and employ adult-like scanning strategies. However, emotional understanding lags behind, with 12-month-olds still unable to accurately comprehend the emotional meanings of different negative expressions.

Based on this asynchrony and influencing factors, we propose that infant expression recognition development involves a transition from basic emotion activation to the emergence of emotion schemas. For preverbal infants, expression recognition is a vital means of environmental communication and social development. Future research should consider several directions:

First, investigate associations between behavioral and neural mechanisms. Current studies remain relatively independent; combining behavioral and neuroimaging approaches would provide more comprehensive understanding of infant development. Atypical expression recognition in preschool may originate in infancy. Since infant expression recognition affects emotion schema formation and lifelong development, understanding its developmental patterns

will enable earlier identification of problems.

Second, deeply examine how family environment influences expression recognition development. While maternal influence is confirmed, objective, systematic studies of mother-infant relationships are lacking. Current assessments rely heavily on parental self-report (Safyer et al., 2020). Future research should incorporate observational methods combined with neuroimaging to analyze mother-infant interaction patterns, providing scientific guidance for caregiving.

Finally, high-risk infants with medical conditions (e.g., hearing impairment, autism) or social disadvantage show atypical expression recognition development (Fan et al., 2020; Sidera et al., 2017; Lan & Moscardino, 2021). These infants lack research attention. fNIRS studies show that high-risk autism infants display atypical neural responses to social stimuli (e.g., peekaboo videos) at 4-6 months, with significantly reduced activation in inferior frontal and posterior temporal regions compared to low-risk infants (Lloyd-Fox et al., 2018). As a sensitive indicator of social stimuli, facial expression recognition can be used with neuroimaging to screen for problems earlier in infancy and implement interventions.

References

Aktar, E., Mandell, D. J., de Vente, W., Majdandzic, M., Oort, F. J., van Renswoude, D. R., ···Bogels, S. M. (2018). Parental negative emotions are related to behavioral and pupillary correlates of infants' attention to facial expressions of emotion. *Infant Behavior and Development*, 53, 101−111.

Bayet, L. (2022). How infants learn from a world of faces: Implications for racial biases and mask-wearing. *Policy Insights from the Behavioral and Brain Sciences*, 9(1), 65−72.

Bayet, L., & Nelson, C. A. (2019). The perception of facial emotion in typical and atypical development. In V. Lobue, K. Perez-Edgar, & K. A. Buss (Eds.), *Handbook of emotional development* (pp. 105−138). Cham: Springer Nature Switzerland AG.

Bayet, L., Perdue, K. L., Behrendt, H. F., Richards, J. E., Westerlund, A., Cataldo, J. K., & Nelson, C. A. (2021). Neural responses to happy, fearful and angry faces of varying identities in 5- and 7-month-old infants. *Developmental Cognitive Neuroscience*, 47, Article 100882. https://doi.org/10.1016/j.dcn.2020.100882

Bornstein, M. H., & Arterberry, M. E. (2003). Recognition, discrimination and categorization of smiling by 5-month-old infants. *Developmental Science*, 6(5), 585−599.

Bowman, L. C., Mccormick, S. A., Kane Grade, F., Xie, W., Bosquet Enlow, M., & Nelson, C. A. (2022). Infants' neural responses to emotional faces are

related to maternal anxiety. *Journal of Child Psychology and Psychiatry*, 63(2), 152−164.

Burris, J. L., Reider, L. B., Oleas, D. S., Gunther, K. E., Buss, K. A., Pérez Edgar, K., ···Lobue, V. (2022). Moderating effects of environmental stressors on the development of attention to threat in infancy. *Developmental Psychobiology*, 64(3), Article e22241. https://doi.org/10.1002/dev.22241

Carbon, C., & Serrano, M. (2021). The impact of face masks on the emotional reading abilities of children—a lesson from a joint school−university project. *i-Perception*, 12(4), 1−17. https://doi.org/10.1177/20416695211038265

Carnevali, L., Gui, A., Jones, E. J. H., & Farroni, T. (2022). Face processing in early development: A systematic review of behavioral studies and considerations in times of COVID-19 pandemic. *Frontiers in Psychology*, 13, Article 778247. https://doi.org/10.3389/fpsyg.2022.778247

Darwin. (2009). *The expression of the emotions in man and animals* (Zhou Bangli, Trans.). Beijing: Peking University Press. (Original work published 1872)

Decety, J., Steinbeis, N., & Cowell, J. M. (2021). The neurodevelopment of social preferences in early childhood. *Current Opinion in Neurobiology*, 68, 23−28.

Deen, B., Richardson, H., Dilks, D. D., Takahashi, A., Keil, B., Wald, L. L., ··· Saxe, R. (2017). Organization of high-level visual cortex in human infants. *Nature Communications*, 8, Article 13995. https://doi.org/10.1038/ncomms13995

di Lorenzo, R., Blasi, A., Junge, C., van den Boomen, C., van Rooijen, R., & Kemner, C. (2019). Brain responses to faces and facial expressions in 5-month-olds: An fNIRS study. *Frontiers in Psychology*, 10, Article 1240. https://doi.org/10.3389/fpsyg.2019.01240

Dixon, K. C. (2019). *Disentangling the negativity bias: 7-9-month-old crawling and non-crawling infants' responses to fearful and angry expressions* (Unpublished doctoral dissertation). University of Louisville.

Doretto, V., & Scivoletto, S. (2018). Effects of early neglect experience on recognition and processing of facial expressions: A systematic review. *Brain Sciences*, 8(1), Article 10. https://doi.org/10.3390/brainsci8010010

Ekman, P., & Friesen, W. V. (1971). Constants across cultures in the face and emotion. *Journal of Personality and Social Psychology*, 17(2), 124−129.

Fan, X., Bi, X., Xie, Y., & He, H. (2020). Attentional bias to threatening emotional faces in individuals with high-functioning autism. *Advances in Psychological Science*, 28(7), 1172−1186.

Feldman, R. (2013). *Development across the life span* (Su Yanjie & Zou Dan, Trans.). Beijing: World Book Publishing Beijing. (Original work published 2007)

Flom, R., Bahrick, L. E., & Pick, A. D. (2018). Infants discriminate the affective expressions of their peers: The roles of age and familiarization time. *Infancy*, 23(5), 692−707.

Geangu, E., Ichikawa, H., Lao, J., Kanazawa, S., Yamaguchi, M. K., Caldara, R., & Turati, C. (2016). Culture shapes 7-month-olds' perceptual strategies in discriminating facial expressions of emotion. *Current Biology*, 26(14), 663−664.

Heck, A., Hock, A., White, H., Jubran, R., & Bhatt, R. S. (2016). The development of attention to dynamic facial emotions. *Journal of Experimental Child Psychology*, 147, 100−110.

Hertenstein, M. J., & Campos, J. J. (2004). The retention effects of an adult' s emotional displays on infant behavior. *Child Development*, 75(2), 595−613.

Hu, J., Tang, Q., & Chen, X. (2017). Maternal sensitivity to infant distress. *Psychology Progress*, 7(1), 116−123.

Izard, C. E. (2007). Basic emotions, natural kinds, emotion schemas, and a new paradigm. *Perspectives on Psychological Science*, 2(3), 260−280.

Izard, C., Fine, S., Schultz, D., Mostow, A., Ackerman, B., & Youngstrom, E. (2001). Emotion knowledge as a predictor of social behavior and academic competence in children at risk. *Psychological Science*, 12(1), 18−23.

Jessen, S., & Grossmann, T. (2015). Neural signatures of conscious and unconscious emotional face processing in human infants. *Cortex*, 64, 260−270.

Kataja, E. L., Karlsson, L., Leppänen, J. M., Pelto, J., Häikiö, T., Nolvi, S., ··· Karlsson, H. (2018). Maternal depressive symptoms during the pre- and postnatal periods and infant attention to emotional faces. *Child Development*, 91(2), 475−490.

Kataja, E. L., Karlsson, L., Parsons, C. E., Pelto, J., Pesonen, H., Häikiö, T., ···Karlsson, H. (2019). Maternal pre- and postnatal anxiety symptoms infant attention disengagement from emotional faces. *Journal of Affective Disorders*, 243, 280−289.

Kim, K. K., Fang, W., Liu, A., Panesar, D., & Xiao, N. (2022). Altered development of face recognition among infants born amid the COVID-19 pandemic. *PsyArXiv*. Advance online publication. https://doi.org/10.31234/osf.io/n96fv

Lan, X., & Moscardino, U. (2021). Sensitivity to facial emotional expressions and peer relationship problems in Chinese rural-to-urban migrant early adolescents: An exploratory study. *Social Development*, 30, 205−224.

Leppänen, J. M., Cataldo, J. K., Bosquet Enlow, M., & Nelson, C. A. (2018). Early development of attention to threat-related facial expressions. *PLOS ONE*, 13(5), Article e0197424. https://doi.org/10.1371/journal.pone.0197424

Leppänen, J. M., & Nelson, C. A. (2006). The development and neural bases of facial emotion recognition. *Advances in Child Development and Behavior*, 34,

207−246.

Leppänen, J. M., & Nelson, C. A. (2009). Tuning the developing brain to social signals of emotions. *Nature Reviews Neuroscience*, 10(1), 37−47.

Lloyd-Fox, S., Blasi, A., Pasco, G., Gliga, T., Jones, E., Murphy, D., ···Johnson, M. H. (2018). Cortical responses before 6 months of life associate with later autism. *The European Journal of Neuroscience*, 47(6), 736−749.

Miguel, H. O., Mccormick, S. A., Westerlund, A., & Nelson, C. A. (2019). Rapid face processing for positive and negative emotions in 5-, 7-, and 12-month-old infants: An exploratory study. *British Journal of Developmental Psychology*, 37(4), 486−504.

Munsters, N. M. (2017). *I see you: The role of visual processing social behavior across development* (Unpublished doctoral dissertation). Utrecht University.

Nakato, E., Otsuka, Y., Kanazawa, S., Yamaguchi, M. K., & Kakigi, R. (2011). Distinct differences in the pattern of hemodynamic response to happy and angry facial expressions in infants −A near-infrared spectroscopic study. *NeuroImage*, 54(2), 1600−1606.

Ogren, M., Burling, J. M., & Johnson, S. P. (2018). Family expressiveness relates to happy emotion matching among 9-month-old infants. *Journal of Experimental Child Psychology*, 174, 29−40.

Ogren, M., & Johnson, S. P. (2021a). Factors facilitating early emotion understanding development: Contributions to individual differences. *Human Development*, 64(3), 108−118.

Ogren, M., & Johnson, S. P. (2021b). Primary caregiver emotional expressiveness relates toddler emotion understanding. *Infant Behavior and Development*, 62, Article 101508. https://doi.org/10.1016/j.infbeh.2020.101508

Perdue, K. L., Jensen, S. K. G., Kumar, S., Richards, J. E., Kakon, S. H., Haque, R., ···Nelson, C. A. (2019). Using functional near-infrared spectroscopy to assess social information processing in poor urban Bangladeshi infants and toddlers. *Developmental Science*, 22, Article e12839. https://doi.org/10.1111/desc.12839

Prunty, J. E., Keemink, J. R., & Kelly, D. J. (2021). Infants scan static and dynamic facial expressions differently. *Infancy*, 26(6), 831−856.

Redcay, E., & Warnell, K. R. (2018). A social-interactive neuroscience approach to understanding the developing brain. *Advances in Child Development and Behavior*, 54, 1−44.

Rochat, P., Striano, T., & Blatt, L. (2002). Differential effects of happy, neutral, and sad still-faces on 2-, 4- and 6-month-old infants. *Infant and Child Development*, 11(4), 289−303.

Rotem-Kohavi, N., Oberlander, T. F., & Virji-Babul, N. (2017). Infants and adults have similar regional functional brain organization for the perception of

emotions. *Neuroscience Letters*, 650, 118−125.

Ruba, A. L. (2019). *The development of emotion understanding in infancy* (Unpublished doctoral dissertation). University of Washington.

Ruba, A. L., & Pollak, S. D. (2020). Children' s emotion inferences from masked faces: Implications for social interactions during COVID-19. *PLOS ONE*, 15(12), Article e0243708. https://doi.org/10.1371/journal.pone.0243708

Ruba, A. L., & Repacholi, B. M. (2020). Do preverbal infants understand discrete facial expressions of emotion? *Emotion Review*, 12(4), 235−250.

Ruba, A. L., Meltzoff, A. N., & Repacholi, B. M. (2019). How do you feel? Preverbal infants match negative emotions to events. *Developmental Psychology*, 55(6), 1138−1149.

Safyer, P., Volling, B. L., Wagley, N., Hu, X., Swain, J. E., Arredondo, M. M., & Kovelman, I. (2020). More than meets the eye: The neural development of emotion face processing during infancy. *Infant Behavior and Development*, 59, Article 101430. https://doi.org/10.1016/j.infbeh.2020.101430

Segal, S. C., & Moulson, M. C. (2020). Dynamic advances in emotion processing: Differential attention towards the critical features of dynamic emotional expressions in 7-month-old infants. *Brain Sciences*, 10, Article 585. https://doi.org/10.3390/brainsci10090585

Serrano, J. M., Iglesias, J., & Loeches, A. (1992). Visual discrimination and recognition of facial expressions of anger, fear, and surprise in 4- to 6-month-old infants. *Developmental Psychobiology*, 25(6), 411−425.

Sidera, F., Amadó, A., & Martínez, L. (2017). Influences on facial emotion recognition in deaf children. *The Journal of Deaf Studies and Deaf Education*, 22(2), 164−177.

Sorce, J. F., Emde, R. N., Campos, J. J., & Klinnert, M. D. (1985). Maternal emotional signaling: Its effect on the visual cliff behavior of 1-year-olds. *Developmental Psychology*, 21(1), 195−200.

Soussignan, R., Dollion, N., Schaal, B., Durand, K., Reissland, N., & Baudouin, J. (2018). Mimicking emotions: how 3−12-month-old infants use the facial expressions and eyes of a model. *Cognition and Emotion*, 32(4), 827−842.

Strand, P. S., Downs, A., Barbosa-Leiker, C., Dubow, E. F., & Eccles, J. S. (2016). Does facial expression recognition provide a toehold for the development of emotion understanding? *Developmental Psychology*, 52(8), 1182−1191.

Taylor-Colls, S., & Pasco Fearon, R. M. (2015). The effects of parental behavior on infants' neural processing of emotion expressions. *Child Development*, 86(3), 877−888.

Termine, N. T., & Izard, C. E. (1988). Infants' responses to their mothers' expressions of joy and sadness. *Developmental Psychology*, 24(2), 223−229.

Tuulari, J. J., Kataja, E., Leppänen, J. M., Lewis, J. D., Nolvi, S., Häikiö, T., ···Karlsson, H. (2020). Newborn left amygdala volume associates with attention disengagement from fearful faces at eight months. *Developmental Cognitive Neuroscience*, 45, Article 100839. https://doi.org/10.1016/j.dcn.2020.100839

Vaillant-Molina, M., & Bahrick, L. E. (2012). The role of intersensory redundancy in the emergence of social referencing in 5½-month-old infants. *Developmental Psychology*, 48(1), 1−9.

Vaish, A., Grossmann, T., & Woodward, A. (2008). Not all emotions are created equal: The negativity bias in social-emotional development. *Psychological Bulletin*, 134(3), 383−403.

Walle, E. A., Reschke, P. J., Camras, L. A., & Campos, J. J. (2017). Infant differential behavioral responding to discrete emotions. *Emotion*, 17(7), 1078−1091.

White, H., Chroust, A., Heck, A., Jubran, R., Galati, A., & Bhatt, R. S. (2019). Categorical perception of facial emotions in infancy. *Infancy*, 24(2), 139−161.

Widen, S. C., & Russell, J. A. (2010). Young children's understanding of other's emotions. In M. Lewis, J. M. Haviland-Jones, & L. F. Barrett (Eds.), *Handbook of emotions* (pp. 348−364). New York: Guilford Press.

Xie, W., Mccormick, S. A., Westerlund, A., Bowman, L. C., & Nelson, C. A. (2018). Neural correlates of facial emotion processing in infancy. *Developmental Science*. https://doi.org/10.1111/desc.12758

Xu, J., Zhou, Y., Luo, W., Luo, Y., & Qin, S. (2021). Cognitive neuroscience of human emotion development: Future directions for mental health and education. *Science China: Life Sciences*, 51(6), 663−678.

Young-Browne, G., Rosenfeld, H. M., & Horowitz, F. D. (1977). Infant discrimination of facial expressions. *Child Development*, 48(2), 555−562.

Zhou, Y., & Zhang, D. (2017). Auditory processing related to infant emotion and social cognition. *Advances in Psychological Science*, 25(1), 67−75.

Note: Figure translations are in progress. See original paper for figures.