SCUOLA DI DOTTORATO

UNIVERSITÀ DEGLI STUDI DI MILANO-BICOCCA

Department of Psychology

PhD program: Psychology, Linguistics and Cognitive Neuroscience

Cycle XXXIV

Curriculum: Mind, Brain and Behavior

PROCESSING EMOTIONAL FACES WITHIN CONTEXT:

EVIDENCE FROM INFANCY AND CHILDHOOD

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ACADEMIC YEAR 2020/2021

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Abstract

Facial expressions, by conveying information on individuals' internal state and intentions, play an important role in social interactions. The idea that faces alone convey all the necessary information about the expresser's emotional state in an unambiguous manner and independently of contextual factors was prevalent in the past decades (Calder et al., 1996; Smith et al., 2005) and drove the majority of literature on emotion perception to examine faces in isolation. Nonetheless, facial expressions are very rarely encountered in isolation in real life, and many recent adult studies indicate that the context in which they occur plays an essential part in their perception (for a review, see Aviezer et al., 2017; Wieser et al., 2014). Specifically, various forms of emotional and social context (e.g., emotional bodies or visual scenes, intrinsic social factors or past social experiences) were shown to have a significant influence on adults' recognition, evaluation, and neural processing of facial expressions (Aviezer et al., 2017; Iidaka et al., 2010; Jack et al., 2012; Pickett et al., 2004; Righart & De Gelder, 2006). However, research investigating the influence of context on the processing of emotional faces in developmental populations is extremely scarce, and although it suggests that contextual effects are also present in infancy and childhood, only a small subset of contextual cues have been examined so far.

Therefore, this doctoral dissertation aimed at providing a more comprehensive view of the influence of context on the processing of facial emotions at different developmental stages, by examining the effects of different contextual cues on the perception, neural processing and recognition of facial expressions in infants and children. The first part of this thesis focused on contextual emotional signals. Results indicated that the surrounding facial emotional context (Chapter 1) as well as emotional kinematics cues (Chapter 2) influenced 12-month-olds' attention and neural processing of emotional faces. The second part focused on contextual effects elicited by social cues in infants and children. They showed that

contextual cues of social inclusion and exclusion affected 13-months-old infants' neural processing of emotional faces (Chapter 3) as well as 5-, but not 7- nor 10-years-olds' recognition of facial expressions (Chapter 4).

Altogether, this thesis provides evidence that contextual effects can be elicited by various types of emotional and social cues (i.e., surrounding emotional faces, emotional kinematics, social inclusion and exclusion) in infants and children, and affect different levels of the processing of emotional faces (i.e., neural and behavioral). In addition, it suggests that these contextual effects vary as a function of the developmental stage of the perceiver (e.g., contextual effects were present only in 5-year-olds in Chapter 4). In sum, context seems to play an essential role in the processing of facial expressions in infancy and childhood, and should be granted particular attention in future developmental studies.

Abstract (Italian version)

Le espressioni facciali svolgono un ruolo importante nelle interazioni sociali, comunicando informazioni sullo stato d'animo e le intenzioni di chi le esprime. La maggioranza della letteratura sulla percezione delle emozioni ha preso in esame i volti emotivi isolandoli dal contesto, assumendo che essi siano di per sé sufficienti a veicolare , in maniera non ambigua ed indipendente dal contesto, le manifestazioni emotive (Calder et al., 1996; Smith et al., 2005) . Tuttavia, nella vita reale è assai raro osservare espressioni emotive isolate da un contesto e molti studi recenti che coinvolgono partecipanti adulti indicano che il contesto nel quale le espressioni emotive sono inserite svolge un ruolo essenziale nella loro percezione (Aviezer et al., 2017; Wieser et al., 2014). In particolare, negli adulti, è stato mostrato come varie forme di contesti emotivi e sociali (ad esempio, emozioni espresse tramite gestualità corporee e scene visive, fattori sociali intrinseci o precedenti esperienze sociali) modulano il riconoscimento, la valutazione e l'elaborazione neurale delle espressioni facciali (Aviezer et al., 2017; Iidaka et al., 2010; Jack et al., 2012; Pickett et al., 2004; Righart & De Gelder, 2006). Alcuni studi suggeriscono che anche nei primi anni di vita i fattori contestuali svolgano un ruolo nella percezione delle emozioni (citazioni). Tuttavia, la ricerca in questo ambito è estremamente scarsa e prende in esame una gamma di contesti fortemente limitata e selettiva.

Questa tesi di dottorato ha quindi l'obiettivo di fornire un quadro più completo sull'influenza del contesto nell'elaborazione delle espressioni facciali nel corso dello sviluppo, esaminando gli effetti di diversi contesti sulla percezione, e sul riconoscimento delle espressioni facciali nei bambini in età infantile prescolare e scolare. La prima parte di questa tesi prende in esame i segnali emotivi contestuali, verificando come la presenza di altre emozioni nel contesto possa modulare la percezione emotiva. I risultati mostrano che, in bambini di 12 mesi, sia i volti emotivi (Capitolo 1), sia le espressioni emotive cinematiche

(Capitolo 2) presenti nel contesto influenzano la percezione delle emozioni, modulando il comportamento visivo e l'attività neurale dei bambini. La seconda parte della tesi si concentra sugli effetti contestuali suscitati da circostanze sociali nei bambini in età infantile, prescolare e scolare. I risultati mostrano che le situazioni contestuali di inclusione ed esclusione influenzano l'elaborazione neurale delle espressioni facciali negli infanti di 13 mesi (Capitolo 3), e il loro riconoscimento nei bambini di 5 anni, ma non nei bambini di 7 e 10 anni (Capitolo 4).

La tesi nel suo complesso fornisce evidenze empiriche che dimostrano gli effetti contestuali generati da diverse situazioni emozionali e sociali (ad esempio, volti e azioni che esprimono una emozione nel contesto, inclusione ed esclusione sociale) in infanti e bambini, ed agiscano a diversi livelli dell'elaborazione delle espressioni emotive facciali (ad esempio, neurale e comportamentale). Inoltre, i risultati suggeriscono che questi effetti contestuali varino in funzione dell'età dei bambini (ad esempio, il Capitolo 4 mostra come gli effetti contestuali fossero presenti solo in bambini di 5 anni). Riassumendo, nelle prime fasi dello sviluppo il contesto sembra svolgere un ruolo chiave nella percezione delle espressioni facciali.

General Introduction: from emotional faces in isolation to emotional faces in context

“You have it written all over your face”. This expression, commonly used to say that someone’s feelings or thoughts are obvious from their facial expression, is representative of the importance we grant to the face when it comes to detecting others’ emotional states. Indeed, faces convey a lot of information about the expresser’s internal state that are essential for social interactions. However, the importance attached to the social signals conveyed by faces has often led to ignore the context in which emotions are expressed.

According to the “basic emotion” approach, humans possess a set of emotions that are universal biological states (Ekman, 1973; Izard, 1994; Yan et al., 2016), generated by dedicated neural circuits (Schyns et al., 2007; Smith et al., 2005) and expressed through the activation of specific facial muscles (Ekman, 1992). These facial expressions are considered reliable and unambiguous markers of emotions, well recognized by specialized neural processing in a rapid and automatic way (Calder et al., 1996; Meeren et al., 2005; Smith et al., 2005).

As a consequence, research on emotion processing have predominantly used stimuli representing isolated and decontextualized facial expressions, generally under the form of photographs of highly intense emotional faces involving specific configurations of facial muscles, to create standardized stereotypical expressions (Barrett et al., 2011). This approach, which offers a good control over the perceptual features of the stimuli, has allowed researchers to lay the foundations of emotion research as it has participated in the characterization of humans’ ability to decode facial emotions and helped defining specific developmental trajectories. In particular, research examining participants’ behavioral and neural responses to isolated facial expressions has demonstrated that emotion decoding abilities gradually develop throughout infancy and childhood (Camras & Allison, 1985; Leppänen & Nelson, 2009; Vicari et al., 2000) and it has also suggested that, although humans are generally accurate at decoding emotions, the developmental trajectories and the visual and neural processes seem to differ between emotion categories (Gao & Maurer, 2010; Hunnius et al., 2011a; Lappänen et al., 2007a; Quadrelli et al., 2019). Moreover, it has shown that early in life infants are capable to discriminate certain facial emotions (Grossmann et al., 2007; Kobiella et al., 2008; Leppänen et al., 2007a; Peltola et al., 2008; Vaish et al., 2008).

The "basic emotion" approach has thus allowed important advances in the field of emotion perception and it has been a necessary preliminary step towards the study of more complex forms of emotional expressions. However, facial expressions may not be as basic and unambiguous as previously assumed, and most importantly, their processing might not be immune to the influence of the surrounding context. In fact, facial expressions are rarely encountered in isolation in real life. They are almost consistently embedded within a context, which may modulate the way they are perceived and processed, and even influence their meaning and the behavioral response they elicit in the perceiver.

In the past decade, a small yet growing number of studies has evidenced the influence of context on the processing of facial expressions in adults. In particular, emotional cues, which directly inform on the affective context in which facial expressions are embedded, have been shown to have powerful effects. Contextual effects were found to be elicited by a variety of emotional cues such as bodies, voices, sounds, visual scenes, descriptions of social situations, or the presence other faces. Interestingly, these cues were found to modulate the processing of facial expressions at different levels, from their neural encoding, to their recognition and evaluation. For example, the presence of affective body cues was found to modulate adults' recognition of facial expressions, with participants failing to identify positive and negative emotions when presented with faces alone, but easily identifying the correct affective valence when faces were presented with their corresponding bodies (Aviezer et al., 2012). Similarly, listening to congruent affective prosody was shown to accelerate and improve adults' recognition of facial expressions (Dolan et al., 2001). In addition to modulate the recognition of facial expressions, emotional context was also found to influence their evaluation. For instance, emotional faces were rated as more fearful when presented with simultaneous sounds of human screams compared to neutral sounds (Müller et al., 2011), when combined with a description of a situation of danger (Carroll & Russell, 1996), and when accompanied by another face expressing anger and gazing at their direction, even when presented subliminally (Mumenthaler & Sander, 2012). Remarkably, emotional context was even shown to modulate the neural processing of facial expressions. For example, the neural response to neutral and fearful faces was enhanced when embedded in a fearful as compared to a neutral visual scene (Righart & De Gelder, 2006), and when paired with incongruent emotional sounds (Müller et al., 2011). Altogether, these studies illustrate the ambiguity of real-life facial expressions, and emphasize the importance of context on the perception of these emotional faces. They suggest that various forms (e.g., body, voices, visual scenes, etc.) and modalities (e.g., visual, acoustic) of emotional context can have an influence on adults' recognition, evaluation, and neural processing of emotional facial expressions.

Nonetheless, emotional cues are not the only form of context that can influence adults' processing of emotional faces. Indeed, when presented with the exact same facial configuration embedded within the exact same emotional context, different individuals might still have a different perception of a facial expression, as a consequence of the social context in which the perceiver is placed. Research on adults has shown that intrinsic social factors such as the perceivers' culture (Jack et al., 2012; Masuda et al., 2008) or implicit bias (Phelps et al., 2000) can have an influence on their perception, recognition and neural processing of facial emotions. Most importantly, social affective context also seem to play an important role in individuals’ emotional processing. Given that the processing of a face involves its comparison to previous memory representations, one may assume that the affective information extracted during an individual’s past social experiences and interactions will influence his or her processing of subsequent faces. Indeed, in a social conditional study, participants showed higher skin conductance and greater neural activation in responses to neutral faces that had previously been paired with a socially stressful voice (i.e., voice saying “*stupid*” loudly) than to neutral faces that had not been paired (Iidaka et al., 2010). In the same vein, previous social exclusion was found to improve adults’ recognition of emotional faces (Cheung et al., 2015; Pickett et al., 2004; Sacco et al., 2011a), and to modulate their attention and neural processing of facial expressions (DeWall et al., 2009a; Kawamoto et al., 2014a). These studies support the idea that inherent social factors and past social affective contextual cues modulate the processing and evaluation of emotions, as well as the induced neurophysiological response.

In sum, research on adults strongly suggest that the processing of emotional faces is highly influenced by the context in which they are expressed. Contextual cues, even when they are presented asynchronously or subliminally (Iidaka et al., 2010; Mumenthaler & Sander, 2012), and when they do not overtly convey emotional value (Cheung et al., 2015; Jack et al., 2012; Masuda et al., 2008; Pickett et al., 2004; Sacco et al., 2011a), considerably shape adults’ perception, recognition and evaluation of facial expressions. They can even impact very early automatic stages of the processing such as the sampling of information from the emotional faces (DeWall et al., 2009a), or their neural encoding (Kawamoto et al., 2014a; Müller et al., 2011; Righart & De Gelder, 2006). Thus, adults’ processing of emotional facial expressions seems to be inextricably linked to the processing of the contextual cues accompanying it.

However, research examining the influence of context on the processing of emotional faces during infancy and childhood is extremely scarce. Most of infant studies explored congruency effects in response to the pairing of emotional faces with voices and bodies of matching or mismatching affective content. They showed that infants' scanning pattern (Palama et al., 2018) and neural processing (Grossmann et al., 2006) of emotional faces was modulated by the presentation of affectively-congruent versus incongruent emotional voices. In addition, infants' neural response to emotional faces also varied in function of the affective content of body posture primes (Rajhans et al., 2016). In the same vein, research on children showed that their recognition of facial emotions was improved when paired with descriptions of emotional situations (Reichenbach & Masters, 2021; Widen & Russell, 2010). Thus, emotional context, whether it was presented concomitantly or asynchronously, seemed to significantly influence infants' attentional and neural processing, as well as children's recognition of emotional facial expressions.

To our knowledge, only a few studies investigated the influence of social context on the processing of facial expressions in infants and children. Geangu and colleagues' study (2016) evidenced the influence of culture on infants' perception of facial expressions by showing that Eastern and Western infants displayed different scanning patterns of emotional faces. In another study, familiar social context such as a peekaboo game was shown to facilitate infants' discrimination of facial emotions (Montague & Walker-Andrews, 2001). In addition, past social affective experience was shown to modulate children's recognition of facial emotions, with physically abused children recognizing angry faces faster than non-abused children, and the speed of recognition being associated with the degree of anger of the children's parents (Pollak et al., 2009). These studies constitute a first evidence that intrinsic social factors and surrounding social context can modulate infants' perception and discrimination of emotional faces, and that past social affective context can have an impact on children's recognition of facial emotions.

Altogether, this research on developmental population indicates that at least some kind of emotional and social contextual cues have an influence on infants' and children's processing of facial expressions. Nonetheless, more research is needed to investigate whether humans' processing of facial emotions, during every step of the development, is indeed indivisible from the processing of the contextual cues in which they are expressed. In addition to determine the nature of the cues inducing contextual effects at different developmental stages, a thorough examination of the direction of these effects should be carried out in order to point out some potential changes and evolution in the way context influences emotional processing throughout development.

This thesis aims to address these questions in order to provide a more comprehensive view of the influence of context on infants' and children's processing of facial emotions. It does so by examining: **a) different types of contextual cues**, namely, emotional (Part 1, Chapters 1 and 2) and social (Part 2, Chapters 3 and 4) contextual cues; **b) the influence of these cues on different aspects of facial emotional processing**, namely, the perception (Chapter 1), neural processing (Chapters 2 and 3), and recognition (Chapter 4) of facial expressions of emotion; and **c) at different developmental stages**, infancy (Chapters 1, 2, and 3) and childhood (Chapter 4).

The first part of the dissertation, consisting in two studies, investigates the influence of emotional contextual cues on infants' processing of emotional faces. Specifically, **Chapter 1, "*Infants' learning of a sequence of emotional faces*"**, explores the influence of the surrounding facial emotional context on infants' attention to emotional faces. Indeed, in their surrounding environment, infants constantly observe social interactions in which emotional faces succeed one another. Thus, rather than appearing in isolation, facial emotions are almost always embedded within a complex emotional context consisting of many other facial emotions. These facial emotions are usually expressed in a specific order to form a coherent sequence, which reflects the protagonists' internal states, and contributes to determine the overall meaning of the interaction. Therefore, this study aims to provide evidence that infants can detect the specific order in which different emotional faces are presented, and that this order has an influence on their attention to the different expressions, as reflected by their looking times. This would constitute a first indication that the complex facial emotional context in which facial expressions are embedded can modulate the way infants attend to these latter.

Chapter 2, "***Emotional actions exert an influence on infants' neural processing of emotional faces"***, investigates the influence of previous emotional kinematic context on infants' processing of emotional faces. Past research has shown that emotional contextual information presented under the form of voices or body postures modulated infant's scanning pattern and neural processing of facial expressions (Grossmann et al., 2006; Palama et al., 2018; Rajhans et al., 2016). This chapter aims to examine whether emotional action kinematics, similarly to voices and body posture, influences infants' neural response to emotional faces. It provides a direct measure of the underlying perceptual, attentional, and memory processes, by examining the event-related potentials (ERPs) elicited in response to facial expressions of anger and happiness primed with either congruent or incongruent emotional kinematic actions.

The second part of this thesis, also composed of two studies, investigates the influence of previous social context on infants' and children's processing of emotional faces. Importantly, rather than observing these contextual cues from a third-party point of view similarly to part 1, participants are directly involved in this social context. **Chapter 3, "*Social exclusion influences infants' neural processing of emotional faces*"**, investigates the effect of social exclusion on infant's neural processing of anger, fear and happiness. So far, only one study has provided evidence for the modulation of the neural processing of emotional face by social exclusion, in adult population (Kawamoto et al., 2014a). Given that in the first years of life the plasticity of the human brain is particularly high, allowing the development of typical cognitive and socio-emotional competences, it is fundamental to investigate the factors that could impede this development in infancy. To do so, our study involved infants in a real-life social interaction with the experimenters, in which they were either included or excluded. Then, their ERPs were measured while they viewed dynamic stimuli of faces expressing anger, fear and happiness, to provide a direct measure of the neural processing that could potentially be modulated by the previous social context. Importantly, we chose to involve infants in a real-life interaction, and to present them with dynamic stimuli to increase the ecological validity of our study. In addition, we presented them three different facial emotions to examine whether the influence of the social context varied in function of the emotion processed.

Finally, **Chapter 4,** ***"Social exclusion influences children's recognition of emotional faces",*** examines the effect of social exclusion on 5-, 7-, and 10-years-old children's recognition of emotional faces. Research on adults showed that the categorization and recognition of facial emotions improved after social exclusion (Cheung et al., 2015; Pickett et al., 2004; Sacco et al., 2011a), and that its influence on attention to facial expressions varied in function of the emotion (DeWall et al., 2009a). This study aims to investigate whether social exclusion also modulates the recognition of facial emotions in childhood, and whether this modulation varies across development. To do so, children participated in an online social interaction during which they were either included or excluded, and then completed a computer-based emotion recognition task. Importantly, we presented children with angry, fearful, and happy facial emotions in order to detect potential differences in the way social exclusion affected their recognition. In addition, 3 age groups (5-, 7- and 10-years-olds) were examined, so that we could analyze the developmental trajectory of children's reaction to social exclusion.

Based on previous research indicating that various stages of adults' processing of emotional faces seem to be consistently influenced by a variety of contextual cues (for a review, see Aviezer et al., 2017; Barrett et al., 2011) and on the few studies suggesting the existence of such influence in developmental populations (Geangu et al., 2016; Rajhans et al., 2016; Pollak et al., 2009), we expected to observe significant contextual effects in all four studies. This would provide evidence that, similarly to adults, a great diversity of contextual cues can affect different stages of the processing of emotional faces in infants and children, and that these effects are already present very early on in development. In addition, we predicted that these effects would vary according to the type of contextual cue and to the emotion observed. Finally, we expected differences in intensity and/or direction of the contextual effects for the different developmental ages, indicating potential changes in the way context influences emotional processing throughout development.

References

Abrams, D., Weick, M., Thomas, D., Colbe, H., & Franklin, K. M. (2011). On-line ostracism affects children differently from adolescents and adults: Ostracism: children, adolescents, adults. *British Journal of Developmental Psychology, 29*(1), 110–123. https://doi.org/10.1348/026151010X494089

Ambadar, Z., Schooler, J. W., & Cohn, J. F. (2005). Deciphering the Enigmatic Face: The Importance of Facial Dynamics in Interpreting Subtle Facial Expressions. *Psychological Science*, *16*(5), 403–410. https://doi.org/10.1111/j.0956-7976.2005.01548.x

Aslin, R. N., Saffran, J. R., & Newport, E. L. (1998). Computation of Conditional Probability Statistics by 8-Month-Old Infants. *Psychological Science, 9*(4), 321–324. https://doi.org/10.1111/1467-9280.00063

Augusti, E.-M., Melinder, A., & Gredebäck, G. (2010). Look who’s talking: Pre-verbal infants’ perception of face-to-face and back-to-back social interactions. *Frontiers in Psychology*, *1*. https://doi.org/10.3389/fpsyg.2010.00161

Aviezer, H., Ensenberg, N., & Hassin, R. R. (2017). The inherently contextualized nature of facial emotion perception. *Current Opinion in Psychology*, *17*, 47–54. https://doi.org/10.1016/j.copsyc.2017.06.006

Aviezer, H., Trope, Y., & Todorov, A. (2012). Body Cues, Not Facial Expressions, Discriminate Between Intense Positive and Negative Emotions. *Science, 338*(6111), 1225–1229. https://doi.org/10.1126/science.1224313

Barrett, L. F., Mesquita, B., & Gendron, M. (2011). Context in Emotion Perception. *Current Directions in Psychological Science, 20*(5), 286–290. https://doi.org/10.1177/0963721411422522

Batty, M., Meaux, E., Wittemeyer, K., Rogé, B., & Taylor, M. J. (2011). Early processing of emotional faces in children with autism: An event-related potential study. *Journal of Experimental Child Psychology, 109*(4), 430–444. https://doi.org/10.1016/j.jecp.2011.02.001

Baumeister, R. F., & Leary, M. R. (1995). The Need to Belong: Desire for Interpersonal Attachments as a Fundamental Human Motivation. *Psychological Bulletin, 117*(3), 34.

Baumeister, R. F., Twenge, J. M., & Nuss, C. K. (2002). Effects of social exclusion on cognitive processes: Anticipated aloneness reduces intelligent thought. *Journal of Personality and Social Psychology, 83*(4), 817–827. https://doi.org/10.1037/0022-3514.83.4.817

Bernstein, M. J., Young, S. G., Brown, C. M., Sacco, D. F., & Claypool, H. M. (2008). Adaptive Responses to Social Exclusion: Social Rejection Improves Detection of Real and Fake Smiles. *Psychological Science, 19*(10), 981–983. https://doi.org/10.1111/j.1467-9280.2008.02187.x

Bulf, H., Brenna, V., Valenza, E., Johnson, S. P., & Turati, C. (2015). Many faces, one rule: The role of perceptual expertise in infants’ sequential rule learning. *Frontiers in Psychology, 6*. https://doi.org/10.3389/fpsyg.2015.01595

Bulf, H., Johnson, S. P., & Valenza, E. (2011). Visual statistical learning in the newborn infant. *Cognition*, *121*(1), 127–132. https://doi.org/10.1016/j.cognition.2011.06.010

Calder, A. J., Young, A. W., Perrett, D. I., Etcoff, N. L., & Rowland, D. (1996). Categorical Perception of Morphed Facial Expressions. *Visual Cognition*, *3*(2), 81–118. https://doi.org/10.1080/713756735

Camras, L. A., & Allison, K. (1985). Children’s understanding of emotional facial expressions and verbal labels. *Journal of Nonverbal Behavior, 9*(2), 84–94. https://doi.org/10.1007/BF00987140

Carroll, J. M., & Russell, J. A. (1996). Do Facial Expressions Signal Specific Emotions? Judging Emotion From the Face in Context. *Journal of Personality and Social Psychology, 70*(2), 205.

Carter-Sowell, A. R., Chen, Z., & Williams, K. D. (2008). Ostracism increases social susceptibility. *Social Influence*, *3*(3), 143–153. https://doi.org/10.1080/15534510802204868

Cheung, E. O., Slotter, E. B., & Gardner, W. L. (2015). Are you feeling what I'm feeling? The role of facial mimicry in facilitating reconnection following social exclusion. *Motivation and Emotion*, *39*(4), 613–630. https://doi.org/10.1007/s11031-015-9479-9

Choudhury, S., Blakemore, S.-J., & Charman, T. (2006). Social cognitive development during adolescence. *Social Cognitive and Affective Neuroscience*, *1*(3), 165–174. https://doi.org/10.1093/scan/nsl024

Conte, S., Richards, J. E., Guy, M. W., Xie, W., & Roberts, J. E. (2020). Face-sensitive brain responses in the first year of life. *NeuroImage*, *211*, 116602. https://doi.org/10.1016/j.neuroimage.2020.116602

Csibra, G., Hernik, M., Mascaro, O., Tatone, D., & Lengyel, M. (2016). Statistical treatment of looking-time data. *Developmental Psychology*, *52*(4), 521–536. https://doi.org/10.1037/dev0000083

Curtis, W. J., & Cicchetti, D. (2013). Affective Facial Expression Processing in 15-Month-Old Infants Who Have Experienced Maltreatment: An Event-Related Potential Study. *Child Maltreatment*, *18*(3), 140–154. https://doi.org/10.1177/1077559513487944

Dawson, G., Webb, S. J., Carver, L., Panagiotides, H., & McPartland, J. (2004). Young children with autism show atypical brain responses to fearful versus neutral facial expressions of emotion. *Developmental Science, 7*(3), 340–359. https://doi.org/10.1111/j.1467-7687.2004.00352.x

De Haan, M., Johnson, M. H., & Halit, H. (2003). Development of face-sensitive event-related potentials during infancy: A review. *International Journal of Psychophysiology*, *51*(1), 45–58. https://doi.org/10.1016/S0167-8760(03)00152-1

de Haan, M., & Nelson, C. A. (1999). Brain Activity Differentiates Face and Object Processing in 6-Month-Old Infants. *Developmental Psychology*, *35*(4), 1113.

De Haan, M., Pascalis, O., & Johnson, M. H. (2002). Specialization of Neural Mechanisms Underlying Face Recognition in Human Infants. *Journal of Cognitive Neuroscience*, *14*(2), 199–209. https://doi.org/10.1162/089892902317236849

Dennis, T. A., Malone, M. M., & Chen, C.-C. (2009). Emotional Face Processing and Emotion Regulation in Children: An ERP Study. *Developmental Neuropsychology*, *34*(1), 85–102. https://doi.org/10.1080/87565640802564887

DeWall, C. N., Maner, J. K., & Rouby, D. A. (2009a). Social Exclusion and Early-Stage Interpersonal Perception: Selective Attention to Signs of Acceptance. *Journal of Personality and Social Psychology*, *96*(4), 729.

DeWall, C. N., Maner, J. K., & Rouby, D. A. (2009b). Social exclusion and early-stage interpersonal perception: Selective attention to signs of acceptance. *Journal of Personality and Social Psychology*, *96*(4), 729–741. https://doi.org/10.1037/a0014634

Di Lorenzo, R., van den Boomen, C., Kemner, C., & Junge, C. (2020). Charting development of ERP components on face-categorization: Results from a large longitudinal sample of infants. *Developmental Cognitive Neuroscience*, *45*, 100840. https://doi.org/10.1016/j.dcn.2020.100840

Dolan, R. J., Morris, J. S., & de Gelder, B. (2001). Crossmodal binding of fear in voice and face. *Proceedings of the National Academy of Sciences*, *98*(17), 10006–10010. https://doi.org/10.1073/pnas.171288598

D’Souza, J., & Gurin, M. (2016). The universal significance of Maslow’s concept of self-actualization. *The Humanistic Psychologist*, *44*(2), 210–214. https://doi.org/10.1037/hum0000027

Durand, K., Gallay, M., Seigneuric, A., Robichon, F., & Baudouin, J.-Y. (2007). The development of facial emotion recognition: The role of configural information. *Journal of Experimental Child Psychology*, *97*(1), 14–27. https://doi.org/10.1016/j.jecp.2006.12.001

Eisenberger, N. I., Lieberman, M. D., & Williams, K. D. (2003). *Does Rejection Hurt? An fMRI Study of Social Exclusion*. *302*, 3.

Ekman, P. (1992). An argument for basic emotions. *Cognition and Emotion*, *6*(3–4), 169–200. https://doi.org/10.1080/02699939208411068

Farroni, T., Menon, E., Rigato, S., & Johnson, M. H. (2007). The perception of facial expressions in newborns. *European Journal of Developmental Psychology*, *4*(1), 2–13. https://doi.org/10.1080/17405620601046832

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, *39*(2), 175–191. https://doi.org/10.3758/BF03193146

Fawcett, C., & Gredebäck, G. (2013). Infants use social context to bind actions into a collaborative sequence. *Developmental Science*, n/a-n/a. https://doi.org/10.1111/desc.12074

Gao, X., & Maurer, D. (2009). Influence of intensity on children’s sensitivity to happy, sad, and fearful facial expressions. *Journal of Experimental Child Psychology*, *102*(4), 503–521. https://doi.org/10.1016/j.jecp.2008.11.002

Gao, X., & Maurer, D. (2010). A happy story: Developmental changes in children's sensitivity to facial expressions of varying intensities. *Journal of Experimental Child Psychology, 107*(2), 67–86. https://doi.org/10.1016/j.jecp.2010.05.003

Gardner, W. L., Pickett, C. L., & Brewer, M. B. (2000). Social Exclusion and Selective Memory: How the Need to belong Influences Memory for Social Events. *Personality and Social Psychology Bulletin*, *26*(4), 486–496. https://doi.org/10.1177/0146167200266007

Geangu, E., Hauf, P., Bhardwaj, R., & Bentz, W. (2011). Infant Pupil Diameter Changes in Response to Others' Positive and Negative Emotions. *PLoS ONE*, *6*(11), e27132. https://doi.org/10.1371/journal.pone.0027132

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), R663–R664. https://doi.org/10.1016/j.cub.2016.05.072

Gebhart, A. L., Newport, E. L., & Aslin, R. N. (2009). Statistical learning of adjacent and nonadjacent dependencies among nonlinguistic sounds. *Psychonomic Bulletin & Review*, *16*(3), 486–490. https://doi.org/10.3758/PBR.16.3.486

Gendron, M., Mesquita, B., & Barrett, L. F. (2013). *Emotion Perception: Putting the Face in Context*. Oxford University Press. https://doi.org/10.1093/oxfordhb/9780195376746.013.0034

Gonsalkorale, K., & Williams, K. D. (2007). The KKK won't let me play: Ostracism even by a despised outgroup hurts. *European Journal of Social Psychology, 37*(6), 1176–1186. https://doi.org/10.1002/ejsp.392

Grossmann, T., Striano, T., & Friederici, A. D. (2006). Crossmodal integration of emotional information from face and voice in the infant brain. *Developmental Science, 9*(3), 309–315. https://doi.org/10.1111/j.1467-7687.2006.00494.x

Grossmann, T., Striano, T., & Friederici, A. D. (2007). Developmental changes in infants' processing of happy and angry facial expressions: A neurobehavioral study. *Brain and Cognition*, *64*(1), 30–41. https://doi.org/10.1016/j.bandc.2006.10.002

Hannon, E. E., & Johnson, S. P. (2005). Infants use meter to categorize rhythms and melodies: Implications for musical structure learning. *Cognitive Psychology*, *50*(4), 354–377. https://doi.org/10.1016/j.cogpsych.2004.09.003

Hartgerink, C. H. J., van Beest, I., Wicherts, J. M., & Williams, K. D. (2015). The Ordinal Effects of Ostracism: A Meta-Analysis of 120 Cyberball Studies. *PLOS ONE*, *10*(5), e0127002. https://doi.org/10.1371/journal.pone.0127002

Hawes, D. J., Zadro, L., Fink, E., Richardson, R., O'Moore, K., Griffiths, B., Dadds, M. R., & Williams, K. D. (2012). The effects of peer ostracism on children's cognitive processes. *European Journal of Developmental Psychology*, *9*(5), 599–613. https://doi.org/10.1080/17405629.2011.638815

Hillyard, S. A., & Anllo-Vento, L. (1998). Event-related brain potentials in the study of visual selective attention. *Proceedings of the National Academy of Sciences*, *95*(3), 781–787. https://doi.org/10.1073/pnas.95.3.781

Hoehl, S., Palumbo, L., Heinisch, C., & Striano, T. (2008). *Infants' attention is biased by emotional expressions and eye gaze direction*. 4.

Hopkins, Z. L., & Branigan, H. P. (2020). Children show selectively increased language imitation after experiencing ostracism. *Developmental Psychology*, *56*(5), 897–911. https://doi.org/10.1037/dev0000915

Hunnius, S., de Wit, T. C. J., Vrins, S., & von Hofsten, C. (2011a). Facing threat: Infants' and adults' visual scanning of faces with neutral, happy, sad, angry, and fearful emotional expressions. *Cognition & Emotion*, *25*(2), 193–205. https://doi.org/10.1080/15298861003771189

Hunnius, S., de Wit, T. C. J., Vrins, S., & von Hofsten, C. (2011b). Facing threat: Infants' and adults' visual scanning of faces with neutral, happy, sad, angry, and fearful emotional expressions. *Cognition & Emotion*, *25*(2), 193–205. https://doi.org/10.1080/15298861003771189

Iidaka, T., Saito, D. N., Komeda, H., Mano, Y., Kanayama, N., Osumi, T., Ozaki, N., & Sadato, N. (2010). Transient Neural Activation in Human Amygdala Involved in Aversive Conditioning of Face and Voice. *Journal of Cognitive Neuroscience*, *22*(9), 2074–2085. https://doi.org/10.1162/jocn.2009.21347

Itier, R. J., & Taylor, M. J. (2002). Inversion and Contrast Polarity Reversal Affect both Encoding and Recognition Processes of Unfamiliar Faces: A Repetition Study Using ERPs. *NeuroImage*, *15*(2), 353–372. https://doi.org/10.1006/nimg.2001.0982

Izard, C. E. (1994). *Innate and Universal Facial Expressions: Evidence From Developmental and Cross-Cultural Research*. 288.

Jack, R. E., Garrod, O. G. B., Yu, H., Caldara, R., & Schyns, P. G. (2012). Facial expressions of emotion are not culturally universal. *Proceedings of the National Academy of Sciences*, *109*(19), 7241–7244. https://doi.org/10.1073/pnas.1200155109

Johnson, S. P., & Aslin, R. N. (1996). Perception of object unity in young infants: The roles of motion, depth, and orientation. *Cognitive Development*, *11*(2), 161–180. https://doi.org/10.1016/S0885-2014(96)90001-5

Kawamoto, T., Nittono, H., & Ura, M. (2014a). Social exclusion induces early-stage perceptual and behavioral changes in response to social cues. *Social Neuroscience*, *9*(2), 174–185. https://doi.org/10.1080/17470919.2014.883325

Kawamoto, T., Nittono, H., & Ura, M. (2014b). Social exclusion induces early-stage perceptual and behavioral changes in response to social cues. *Social Neuroscience*, *9*(2), 174–185. https://doi.org/10.1080/17470919.2014.883325

Kirkham, N. Z., Slemmer, J. A., & Johnson, S. P. (2002). Visual statistical learning in infancy: Evidence for a domain general learning mechanism. *Cognition*, *83*(2), B35–B42. https://doi.org/10.1016/S0010-0277(02)00004-5

Kirkham, N. Z., Slemmer, J. A., Richardson, D. C., & Johnson, S. P. (2007). Location, Location, Location: Development of Spatiotemporal Sequence Learning in Infancy. *Child Development*, *78*(5), 1559–1571. https://doi.org/10.1111/j.1467-8624.2007.01083.x

Kobiella, A., Grossmann, T., Reid, V. M., & Striano, T. (2008). The discrimination of angry and fearful facial expressions in 7-month-old infants: An event-related potential study. *Cognition and Emotion*, *22*(1), 134–146. https://doi.org/10.1080/02699930701394256

Koechlin, E. (1997). Numerical Transformations in Five-month-old Human Infants. *Mathematical Cognition*, *3*(2), 89–104. https://doi.org/10.1080/135467997387425

Kotsoni, E., de Haan, M., & Johnson, M. H. (2001). Categorical Perception of Facial Expressions by 7-Month-Old Infants. *Perception*, *30*(9), 1115–1125. https://doi.org/10.1068/p3155

Kuchuk, A., Vibbert, M., & Bornstein, M. H. (1986). The Perception of Smiling and Its Experiential Correlates in Three-Month-Old Infants. *Child Development*, 1054–1061.

Lakin, J. L., Chartrand, T. L., & Arkin, R. M. (2008). I Am Too Just Like You: Nonconscious Mimicry as an Automatic Behavioral Response to Social Exclusion. *Psychological Science*, *19*(8), 816–822. https://doi.org/10.1111/j.1467-9280.2008.02162.x

Leppänen, J. M., Moulson, M. C., Vogel-Farley, V. K., & Nelson, C. A. (2007a). An ERP Study of Emotional Face Processing in the Adult and Infant Brain. *Child Development*, *78*(1), 232–245. https://doi.org/10.1111/j.1467-8624.2007.00994.x

Leppänen, J. M., Moulson, M. C., Vogel-Farley, V. K., & Nelson, C. A. (2007b). An ERP Study of Emotional Face Processing in the Adult and Infant Brain. *Child Development*, *78*(1), 232–245. https://doi.org/10.1111/j.1467-8624.2007.00994.x

Leppänen, J. M., & Nelson, C. A. (2009). Tuning the developing brain to social signals of emotions. *Nature Reviews Neuroscience, 10*(1), 37–47. https://doi.org/10.1038/nrn2554

Li, W., Zinbarg, R. E., Boehm, S. G., & Paller, K. A. (2008). Neural and Behavioral Evidence for Affective Priming from Unconsciously Perceived Emotional Facial Expressions and the Influence of Trait Anxiety. *Journal of Cognitive Neuroscience, 20*(1), 95–107.

Ludemann, P. M., & Nelson, C. A. (1988). *Categorical Representation of Facial Expressions by 7-Month-Old Infants*. 10.

MacDonald, G., & Leary, M. R. (2005). Why Does Social Exclusion Hurt? The Relationship Between Social and Physical Pain. *Psychological Bulletin*, *131*(2), 202–223. https://doi.org/10.1037/0033-2909.131.2.202

Marinović, V., & Träuble, B. (2018). Vicarious social exclusion and memory in young children. *Developmental Psychology*, *54*(11), 2067–2076. https://doi.org/10.1037/dev0000593

Marinović, V., Wahl, S., & Träuble, B. (2017). “Next to you”—Young children sit closer to a person following vicarious ostracism. *Journal of Experimental Child Psychology, 156,* 179–185. https://doi.org/10.1016/j.jecp.2016.11.011

Masuda, T., Ellsworth, P. C., Mesquita, B., Leu, J., Tanida, S., & Van de Veerdonk, E. (2008). Placing the face in context: Cultural differences in the perception of facial emotion. *Journal of Personality and Social Psychology, 94*(3), 365–381. https://doi.org/10.1037/0022-3514.94.3.365

Meeren, H. K. M., van Heijnsbergen, C. C. R. J., & de Gelder, B. (2005). Rapid perceptual integration of facial expression and emotional body language. *Proceedings of the National Academy of Sciences, 102*(45), 16518–16523. https://doi.org/10.1073/pnas.0507650102

Meier, I. M., van Honk, J., Bos, P. A., & Terburg, D. (2020). *Social touch increases dominant gaze in social confrontations* [Preprint]. PsyArXiv. https://doi.org/10.31234/osf.io/ubyv3

Meyer, M., Baldwin, D. A., & Sage, K. (2011). *Assessing Young Children’s Hierarchical Action Segmentation*. 7.

Monroy, C., Meyer, M., Gerson, S., & Hunnius, S. (2017). Statistical learning in social action contexts. *PLOS ONE, 12*(5), e0177261. https://doi.org/10.1371/journal.pone.0177261

Monroy, C., Meyer, M., Schröer, L., Gerson, S. A., & Hunnius, S. (2019). The infant motor system predicts actions based on visual statistical learning. *NeuroImage, 185,* 947–954. https://doi.org/10.1016/j.neuroimage.2017.12.016

Montague, D. P. F., & Walker-Andrews, A. S. (2001). Peekaboo: A new look at infants’ perception of emotion expressions. *Developmental Psychology, 37*(6), 826–838. https://doi.org/10.1037/0012-1649.37.6.826

Müller, V. I., Habel, U., Derntl, B., Schneider, F., Zilles, K., Turetsky, B. I., & Eickhoff, S. B. (2011). Incongruence effects in crossmodal emotional integration. *NeuroImage*, *54*(3), 2257–2266. https://doi.org/10.1016/j.neuroimage.2010.10.047

Mumenthaler, C., & Sander, D. (2012). Social appraisal influences recognition of emotions. *Journal of Personality and Social Psychology*, *102*(6), 1118–1135. https://doi.org/10.1037/a0026885

Nelson, C. A., & De Haan, M. (1996). Neural correlates of infants' visual responsiveness to facial expressions of emotion. *Developmental Psychobiology*, *29*(7), 577–595. https://doi.org/10.1002/(SICI)1098-2302(199611)29:7<577::AID-DEV3>3.0.CO;2-R

Niedenthal, P. M., Halberstadt, J. B., & Margolin, J. (2000). Emotional state and the detection of change in facial expression of emotion. *Eur. J. Soc. Psychol.*, 12.

Nielsen, M. (2006). Copying actions and copying outcomes: Social learning through the second year. *Developmental Psychology, 42*(3), 555–565. https://doi.org/10.1037/0012-1649.42.3.555

Oakes, L. M. (2017). Sample Size, Statistical Power, and False Conclusions in Infant Looking-Time Research. *Infancy*, *22*(4), 436–469. https://doi.org/10.1111/infa.12186

Over, H., & Carpenter, M. (2009a). Priming third-party ostracism increases affiliative imitation in children. *Developmental Science*, *12*(3), F1–F8. https://doi.org/10.1111/j.1467-7687.2008.00820.x

Over, H., & Carpenter, M. (2009b). Eighteen-Month-Old Infants Show Increased Helping Following Priming with Affiliation. *Psychological Science*, *20*(10), 1189–1193. https://doi.org/10.1111/j.1467-9280.2009.02419.x

Palama, A., Malsert, J., & Gentaz, E. (2018). Are 6-month-old human infants able to transfer emotional information (happy or angry) from voices to faces? An eye-tracking study. *PLOS ONE*, *13*(4), e0194579. https://doi.org/10.1371/journal.pone.0194579

Palermo, R., O’Connor, K. B., Davis, J. M., Irons, J., & McKone, E. (2013). New Tests to Measure Individual Differences in Matching and Labelling Facial Expressions of Emotion, and Their Association with Ability to Recognise Vocal Emotions and Facial Identity. *PLoS ONE*, *8*(6), e68126. https://doi.org/10.1371/journal.pone.0068126

Peltola, M. J., Leppänen, J. M., Palokangas, T., & Hietanen, J. K. (2008). Fearful faces modulate looking duration and attention disengagement in 7-month-old infants. *Developmental Science*, *11*(1), 60–68. https://doi.org/10.1111/j.1467-7687.2007.00659.x

Phelps, E. A., O’Connor, K. J., Cunningham, W. A., Funayama, E. S., Gatenby, J. C., Gore, J. C., & Banaji, M. R. (2000). Performance on Indirect Measures of Race Evaluation Predicts Amygdala Activation. *Journal of Cognitive Neuroscience*, *12*(5), 729–738.

Pickett, C. L., Gardner, W. L., & Knowles, M. (2004). Getting a Cue: The Need to Belong and Enhanced Sensitivity to Social Cues. *Personality and Social Psychology Bulletin*, *30*(9), 1095–1107. https://doi.org/10.1177/0146167203262085

Pollak, S. D., Messner, M., Kistler, D. J., & Cohn, J. F. (2009). Development of perceptual expertise in emotion recognition. *Cognition*, *110*(2), 242–247. https://doi.org/10.1016/j.cognition.2008.10.010

Pollak, S. D., & Sinha, P. (2002). Effects of early experience on children’s recognition of facial displays of emotion. *Developmental Psychology*, *38*(5), 784–791. https://doi.org/10.1037/0012-1649.38.5.784

Pourtois, G., Dan, E. S., Grandjean, D., Sander, D., & Vuilleumier, P. (2005). Enhanced extrastriate visual response to bandpass spatial frequency filtered fearful faces: Time course and topographic evoked-potentials mapping. *Human Brain Mapping*, *26*(1), 65–79. https://doi.org/10.1002/hbm.20130

Quadrelli, E., Conte, S., Macchi Cassia, V., & Turati, C. (2019). Emotion in motion: Facial dynamics affect infants’ neural processing of emotions. *Developmental Psychobiology*, *61*(6), 843–858. https://doi.org/10.1002/dev.21860

Quadrelli, E., Monacò, S., Turati, C., & Bulf, H. (2020). Social context influences infants’ ability to extract statistical information from a sequence of gestures. *Infant Behavior and Development*, *61*, 101506. https://doi.org/10.1016/j.infbeh.2020.101506

Quadrelli, E., Roberti, E., Polver, S., Bulf, H., & Turati, C. (2021). Sensorimotor Activity and Network Connectivity to Dynamic and Static Emotional Faces in 7-Month-Old Infants. *Brain Sciences*, *11*(11), 1396. https://doi.org/10.3390/brainsci11111396

Rajhans, P., Jessen, S., Missana, M., & Grossmann, T. (2016). Putting the face in context: Body expressions impact facial emotion processing in human infants. *Developmental Cognitive Neuroscience*, *19*, 115–121. https://doi.org/10.1016/j.dcn.2016.01.004

Reichenbach, L., & Masters, J. C. (2021). *Children’s Use of Expressive and Contextual Cues in Judgments of Emotion*. 13.

Righart, R., & De Gelder, B. (2006). Context Influences Early Perceptual Analysis of Faces—An Electrophysiological Study. *Cerebral Cortex*, *16*(9), 1249–1257. https://doi.org/10.1093/cercor/bhj066

Roseberry, S., Richie, R., Hirsh-Pasek, K., Golinkoff, R. M., & Shipley, T. F. (2011). Babies Catch a Break: 7- to 9-Month-Olds Track Statistical Probabilities in Continuous Dynamic Events. *Psychological Science*, *22*(11), 1422–1424. https://doi.org/10.1177/0956797611422074

Rosenqvist, J., Lahti-Nuuttila, P., Laasonen, M., & Korkman, M. (2014). Preschoolers’ recognition of emotional expressions: Relationships with other neurocognitive capacities. *Child Neuropsychology*, *20*(3), 281–302. https://doi.org/10.1080/09297049.2013.778235

Rossion, B., & Caharel, S. (2011). ERP evidence for the speed of face categorization in the human brain: Disentangling the contribution of low-level visual cues from face perception. *Vision Research*, *51*(12), 1297–1311. https://doi.org/10.1016/j.visres.2011.04.003

Ruba, A. L., Johnson, K. M., Harris, L. T., & Wilbourn, M. P. (2017). Developmental changes in infants' categorization of anger and disgust facial expressions. *Developmental Psychology*, *53*(10), 1826–1832. https://doi.org/10.1037/dev0000381

Sacco, D. F., Wirth, J. H., Hugenberg, K., Chen, Z., & Williams, K. D. (2011a). The world in black and white: Ostracism enhances the categorical perception of social information. *Journal of Experimental Social Psychology*, *47*(4), 836–842. https://doi.org/10.1016/j.jesp.2011.03.001

Sacco, D. F., Wirth, J. H., Hugenberg, K., Chen, Z., & Williams, K. D. (2011b). The world in black and white: Ostracism enhances the categorical perception of social information. *Journal of Experimental Social Psychology*, *47*(4), 836–842. https://doi.org/10.1016/j.jesp.2011.03.001

Saffran, J. R. (2018). Statistical learning as a window into developmental disabilities. *Journal of Neurodevelopmental Disorders*, *10*(1), 35. https://doi.org/10.1186/s11689-018-9252-y

Saffran, J. R., Aslin, R. N., & Newport, E. L. (1996a). Statistical Learning by 8-Month-Old Infants. *Science*, *274*(5294), 1926–1928. https://doi.org/10.1126/science.274.5294.1926

Saffran, J. R., Aslin, R. N., & Newport, E. L. (1996b). Statistical Learning by 8-Month-Old Infants. *Science*, *274*(5294), 1926–1928. https://doi.org/10.1126/science.274.5294.1926

Saffran, J. R., Johnson, E. K., Aslin, R. N., & Newport, E. L. (1999). Statistical learning of tone sequences by human infants and adults. *Cognition*, *70*(1), 27–52. https://doi.org/10.1016/S0010-0277(98)00075-4

Saffran, J. R., & Kirkham, N. Z. (2018). Infant Statistical Learning. *Annual Review of Psychology*, *69*(1), 181–203. https://doi.org/10.1146/annurev-psych-122216-011805

Saffran, J. R., Pollak, S. D., Seibel, R. L., & Shkolnik, A. (2007). Dog is a dog is a dog: Infant rule learning is not specific to language. *Cognition*, *105*(3), 669–680. https://doi.org/10.1016/j.cognition.2006.11.004

Saylor, M. M., Baldwin, D. A., Baird, J. A., & LaBounty, J. (2007). Infants' On-line Segmentation of Dynamic Human Action. *Journal of Cognition and Development*, *8*(1), 113–128. https://doi.org/10.1080/15248370709336996

Schyns, P. G., Petro, L. S., & Smith, M. L. (2007). Dynamics of Visual Information Integration in the Brain for Categorizing Facial Expressions. *Current Biology*, *17*(18), 1580–1585. https://doi.org/10.1016/j.cub.2007.08.048

Smith, M. L., Cottrell, G. W., Gosselin, F., & Schyns, P. G. (2005). Transmitting and Decoding Facial Expressions. *Psychological Science*, *16*(3), 184–189. https://doi.org/10.1111/j.0956-7976.2005.00801.x

Song, R., Over, H., & Carpenter, M. (2015). Children draw more affiliative pictures following priming with third-party ostracism. *Developmental Psychology*, *51*(6), 831–840. https://doi.org/10.1037/a0039176

Stahl, A. E., Romberg, A. R., Roseberry, S., Golinkoff, R. M., & Hirsh-Pasek, K. (2014). Infants Segment Continuous Events Using Transitional Probabilities. *Child Development*, n/a-n/a. https://doi.org/10.1111/cdev.12247

Tager-Flusberg, H. (2010). The origins of social impairments in autism spectrum disorder: Studies of infants at risk. *Neural Networks*, *23*(8–9), 1072–1076. https://doi.org/10.1016/j.neunet.2010.07.008

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. https://doi.org/10.1111/cdev.12348

Teinonen, T., Fellman, V., Näätänen, R., Alku, P., & Huotilainen, M. (2009). Statistical language learning in neonates revealed by event-related brain potentials. *BMC Neuroscience*, *10*(1), 21. https://doi.org/10.1186/1471-2202-10-21

Thiele, M., Hepach, R., Michel, C., Gredebäck, G., & Haun, D. B. M. (2021). Social interaction targets enhance 13-month-old infants' associative learning. *Infancy*, *26*(3), 409–422. https://doi.org/10.1111/infa.12393

Tottenham, N., Tanaka, J. W., Leon, A. C., McCarry, T., Nurse, M., Hare, T. A., Marcus, D. J., Westerlund, A., Casey, B., & Nelson, C. (2009). The NimStim set of facial expressions: Judgments from untrained research participants. *Psychiatry Research*, *168*(3), 242–249. https://doi.org/10.1016/j.psychres.2008.05.006

Twenge, J. M., Baumeister, R. F., Tice, D. M., & Stucke, T. S. (2001). If you can't join them, beat them: Effects of social exclusion on aggressive behavior. *Journal of Personality and Social Psychology*, *81*(6), 1058–1069. https://doi.org/10.1037/0022-3514.81.6.1058

Vacaru, S. V., van Schaik, J. E., de Water, E., & Hunnius, S. (2020). Five-year-olds' facial mimicry following social ostracism is modulated by attachment security. *PLOS ONE*, *15*(12), e0240680. https://doi.org/10.1371/journal.pone.0240680

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. https://doi.org/10.1037/0033-2909.134.3.383

van Heijnsbergen, C. C. R. J., Meeren, H. K. M., Grèzes, J., & de Gelder, B. (2007). Rapid detection of fear in body expressions, an ERP study. *Brain Research*, *1186*, 233–241. https://doi.org/10.1016/j.brainres.2007.09.093

Vicari, S., Reilly, J. S., Pasqualetti, P., Vizzotto, A., & Caltagirone, C. (2000). Recognition of facial expressions of emotions in school-age children: The intersection of perceptual and semantic categories. *Acta Paediatrica*, *89*(7), 836–845. https://doi.org/10.1111/j.1651-2227.2000.tb00392.x

Vlach, H. A., & Johnson, S. P. (2013). Memory constraints on infants' cross-situational statistical learning. *Cognition*, *127*(3), 375–382. https://doi.org/10.1016/j.cognition.2013.02.015

Vuilleumier, P., & Pourtois, G. (2007). Distributed and interactive brain mechanisms during emotion face perception: Evidence from functional neuroimaging. *Neuropsychologia*, *45*(1), 174–194. https://doi.org/10.1016/j.neuropsychologia.2006.06.003

Warburton, W. A., Williams, K. D., & Cairns, D. R. (2006a). When ostracism leads to aggression: The moderating effects of control deprivation. *Journal of Experimental Social Psychology*, *42*(2), 213–220. https://doi.org/10.1016/j.jesp.2005.03.005

Warburton, W. A., Williams, K. D., & Cairns, D. R. (2006b). When ostracism leads to aggression: The moderating effects of control deprivation. *Journal of Experimental Social Psychology*, *42*(2), 213–220. https://doi.org/10.1016/j.jesp.2005.03.005

Watson-Jones, R. E., Legare, C. H., Whitehouse, H., & Clegg, J. M. (2014). Task-specific effects of ostracism on imitative fidelity in early childhood. *Evolution and Human Behavior*, *35*(3), 204–210. https://doi.org/10.1016/j.evolhumbehav.2014.01.004

Watson-Jones, R. E., Whitehouse, H., & Legare, C. H. (2016). In-Group Ostracism Increases High-Fidelity Imitation in Early Childhood. *Psychological Science, 27*(1), 34–42. https://doi.org/10.1177/0956797615607205

Widen, S. C., & Russell, J. A. (2008). Children acquire emotion categories gradually. *Cognitive Development*, *23*(2), 291–312. https://doi.org/10.1016/j.cogdev.2008.01.002

Widen, S. C., & Russell, J. A. (2010). Differentiation in preschooler's categories of emotion. *Emotion*, *10*(5), 651–661. https://doi.org/10.1037/a0019005

Wieser, M. J., & Brosch, T. (2012). Faces in Context: A Review and Systematization of Contextual Influences on Affective Face Processing. *Frontiers in Psychology, 3*. https://doi.org/10.3389/fpsyg.2012.00471

Wieser, M. J., Gerdes, A. B. M., Büngel, I., Schwarz, K. A., Mühlberger, A., & Pauli, P. (2014). Not so harmless anymore: How context impacts the perception and electrocortical processing of neutral faces. *NeuroImage*, *92*, 74–82. https://doi.org/10.1016/j.neuroimage.2014.01.022

Williams, K. D. (2007). Ostracism. *Annual Review of Psychology*, *58*(1), 425–452. https://doi.org/10.1146/annurev.psych.58.110405.085641

Williams, K. D. (2009). Ostracism: A Temporal Need-Threat Model. In *Advances in Experimental Social Psychology* (Vol. 41, pp. 275–314). Elsevier. https://doi.org/10.1016/S0065-2601(08)00406-1

Williams, K. D., Cheung, C. K. T., & Choi, W. (2000). Cyberostracism: Effects of being ignored over the Internet. *Journal of Personality and Social Psychology*, *79*(5), 748–762. https://doi.org/10.1037/0022-3514.79.5.748

Williams, K. D., & Nida, S. A. (2011a). Ostracism: Consequences and Coping. *Current Directions in Psychological Science, 20*(2), 71–75. https://doi.org/10.1177/0963721411402480

Williams, K. D., & Nida, S. A. (2011b). Ostracism: Consequences and Coping. *Current Directions in Psychological Science*, *20*(2), 71–75. https://doi.org/10.1177/0963721411402480

Wölfer, R., & Scheithauer, H. (2013). Ostracism in childhood and adolescence: Emotional, cognitive, and behavioral effects of social exclusion. *Social Influence*, *8*(4), 217–236. https://doi.org/10.1080/15534510.2012.706233

Yan, X., Andrews, T. J., & Young, A. W. (2016). Cultural similarities and differences in perceiving and recognizing facial expressions of basic emotions. *Journal of Experimental Psychology: Human Perception and Performance*, *42*(3), 423–440. https://doi.org/10.1037/xhp0000114

Zadro, L., & Gonsalkorale, K. (2014). Sources of Ostracism: The Nature and Consequences of Excluding and Ignoring Others. *Current Directions in Psychological Science*, *23*(2), 93–97. https://doi.org/10.1177/0963721413520321

Zadro, L., Hawes, D. J., Iannuzzelli, R. E., Godwin, A., MacNevin, G., Griffiths, B., & Gonsalkorale, K. (2013). Ostracism and Children: A Guide to Effectively Using the Cyberball Paradigm With a Child Sample. *International Journal of Developmental Science*, *7*(1), 7–11. https://doi.org/10.3233/DEV-1312112

PART I

The influence of emotional context on the processing of emotional faces

Chapter 1: Infants' learning of a sequence of emotional faces

Introduction

Our understanding of others' behaviors and mental states highly depends on a successful decoding of emotions. In particular, facial expressions of emotions play a crucial role in social interactions, especially for pre-verbal infants, who rely mainly on nonlinguistic cues to communicate. Observing their surrounding environment, infants constantly witness social interactions in which facial expressions of emotions succeed one another. These emotional expressions typically show some regularities in their order of presentation, with some emotions being regularly expressed consecutively, to form a coherent sequence. Indeed, the specific order in which emotions are displayed reflects the mental states of its protagonist and contribute to determine the overall meaning of the interaction. For example, if during a social interaction, individual 1 expresses anger towards individual 2, and individual 2 likewise responds with anger, the interaction is likely to turn to conflict. Instead, individual 2 responding with fear rather than anger signals that he or she feels threatened, and that the interaction might be interpreted differently, maybe suggesting that the two protagonists have unequal power within the relationship. Thus, being able to track regularities in sequences of facial expressions of emotions could potentially help infants structuring observed social interactions and facilitate their comprehension of the emotional context, as well as the nature of the social interactions. However, whether infants possess the ability to detect coherent patterns embedded in a sequence of different emotional faces has yet to be determined.

In other domains, previous research has shown that infants are able to extract predictable statistical regularities from a complex, continuous stream of elements. This capacity, referred to as statistical learning (SL), appears to rely on the transitional probabilities (TP) of a sequence of elements, that is, the probability of an item X to be followed by an item Y (Saffran et al., 1996a). It is thought to appear early on in development

(Bulf et al., 2011; Teinonen et al., 2009), and to support infants' comprehension and learning of relationships between the elements of a sequence, allowing the prediction of its upcoming stimuli (Kirkham et al., 2007).

SL was first evidenced in the linguistic domain, where 8-month-olds were able to segment words from a fluent artificial speech, using differences in TPs as the only cue for segmentation (Aslin et al., 1998; Saffran et al., 1996b). Likewise, SL was found to be at the basis of infants' capacity to track TPs in non-linguistic auditory sequences (Hannon & Johnson, 2005; Saffran et al., 1999) and visual sequences (Bulf et al., 2011; Kirkham et al., 2002, 2007). Moreover, it was demonstrated that infants can apply SL to many different categories of stimuli, such as animated objects (Stahl et al., 2014), human gestures (Quadrelli et al., 2020; Roseberry et al., 2011) and complex human actions (Meyer et al., 2011; Monroy et al., 2017, 2019; Saylor et al., 2007). Taken together, these findings suggest that SL is a domain-general mechanism (for a review see Saffran & Kirkham, 2018) that might operate similarly on different categories of stimuli, supporting infants' comprehension of the surrounding environment.

Interestingly, infants' capacity to detect regularities from a sequence of elements seems to be modulated by the content of the stimuli, and, in particular, by the presence of social signals (i.e., faces). For example, in their study, Bulf and colleagues (2015) presented 7-month-olds with photographs of neutral faces of different identities, whose order of presentation followed a specific repetition-based, rule-like pattern (i.e., ABB or ABA). Infants were capable of learning the rule of presentation and generalize it to new face identities when the faces were presented in an upright, but not inverted, configuration. Moreover, the affective content of the faces was shown to affect this capacity, which was maintained when identities displayed happy expressions, but was disrupted when identities displayed angry expressions (Quadrelli et al., 2019). These studies demonstrate that infants' ability to detect repetition-based regularities from sequences of facial emotions and identities is affected by the social content of the stimuli that make up the sequence.

Previous research has also demonstrated that the social context in which emotions are expressed considerably influences infants’ behavior and learning. For instance, Montague & Walker-Andrews (2001) demonstrated that, when displayed in the familiar context of a peekaboo game, 4-month-olds’ discrimination of emotions (happy/surprise vs. anger/fear/sadness) was facilitated. Furthermore, 18-months-olds were more prone to copy the specific action of a model that looked engaging and social (i.e., smiling, eye-contact), than a model that seemed aloof and disinterested (Nielsen, 2006). Besides, the mere presence of salient social cues was shown to greatly influence infants’ behavior and learning. For instance, 6-months-old infants preferred to attend to a typical face-to-face rather than an unconventional back-to-back social interaction, and made more gaze shifts between the two actors when they were facing each other (Augusti et al., 2010). Likewise, associative learning in 13-month-old infants was reinforced when target videos displayed a social interaction as compared to non-interactive control conditions (Thiele et al., 2021).

Taken together, the existing literature emphasizes the fundamental role of social cues on infants’ perception and understanding of others’ actions and interactions, and their significant influence on broader learning processes. Nonetheless, it remains unknown whether infants’ ability to detect regularities from their social environment extends to situations in which the sequence of social stimuli (e.g., faces) is statistically defined, and the only available cue is the TP between stimuli. Specifically, no study has previously investigated whether infants are able to track statistical regularities from a predictable sequence of emotional faces. Furthermore, in a natural environment, emotional facial expressions are more frequently embedded within contexts of social interactions involving at least two protagonists, rather than single isolated faces. The social context in which emotions are expressed can potentially influence the meaning of the interaction, as well as infants' behavior and learning.

The primary aim of our study was to investigate whether infants are capable of extracting statistical regularities from a sequence of emotional faces with differences in TPs as the only cue for segmentation. As a secondary aim, we also examined whether the degree of sociality of the stimuli modulates this ability. To this end, we presented infants with a sequence of videos representing two actresses expressing eight different emotional expressions: anger, happiness, fear, sadness, surprise, amusement, disgust and exasperation. Emotions were selected for their very distinct perceptual properties in order to be easily encoded and based on past research examining infants' emotion recognition abilities. Indeed, by 7 months of age, infants were shown to discriminate anger, happiness, fear, sadness, surprise and disgust (Farroni et al., 2007; Kotsoni et al., 2001; Ludemann & Nelson, 1988; Ruba et al., 2017), as well as different levels of intensity within a same emotion (e.g., mild versus extreme happiness, and mild versus extreme fear; Kuchuk et al., 1986; Ludemann & Nelson, 1988). Thus, in addition to the 6 basic emotions, we chose to present expressions of amusement (i.e., mild happiness), and exasperation. In each of the 8 videos, the two actresses first faced forward with a neutral expression, then expressed the same facial emotion, and subsequently turned either towards (*looking towards* condition) or away (*looking away* condition) from each other while maintaining the expression at its peak. The videos of the *looking towards* condition thus contained highly salient social cues, as the two actresses faced and looked at each other, while the *looking away* condition contained less salient social cues, as the two actresses looked away from each other (see Augusti et al., 2010 for a similar manipulation). As infants' SL abilities were shown to be limited by their attentional and memory resources (Bulf et al., 2011; Vlach & Johnson, 2013), we decided to test 12-months-olds, who are older than usual SL studies' participants (Aslin et al., 1998; Kirkham et al., 2002; Roseberry et al., 2011; Stahl et al., 2014), presuming that they possessed the cognitive resources necessary for the statistical learning of the complex sequence that was shown.

During the familiarization phase, infants were presented with a sequence organized in four fixed pairs of videos, each pair called unit, and arranged so that the TP between videos was higher within each pair (units) than across pairs (part-units). As units and part-units occurred with the same frequency during familiarization, TPs were the only cue for extracting the statistical structure of the sequence. Indeed, transitions between two videos within a unit occurred with a TP of 1.0, while transitions between two videos across units occurred with a TP of .05. During the test phase, units and part-units were presented in alternation, and infants' ability to discriminate them was assessed by measuring their looking times. We expected that 12-months-old infants would succeed in extracting the statistical regularities from the familiarization sequence, and thus look longer to the part-units than to the units, as found in previous infant studies using the same method (e.g., Stahl et al., 2014). In addition, we explored whether the degree of sociality of the stimuli might affect infants' capacity to extract statistical regularities.

Methods

Participants

Thirty-six healthy, full-term 12-months-old infants (19 females; *M* = 12.76 months, SD = 19 days, min age = 11.84, max age = 13.94) were included in the final sample. Half of the participants (N = 18) were randomly assigned to the *looking towards* condition, and the other half (N = 18) to the *looking away* condition. Sixteen additional participants were tested but excluded from the final sample, due to parental interference (N = 2), because they did not watch enough stimuli (N =12), or because looking times in at least one test trial exceeding ±2.5 standard deviations (SD) from the overall group mean (N = 2) (Johnson & Aslin, 1996; Koechlin, 1997). Based on existing literature using a similar procedure (e.g., Quadrelli et al., 2020; Roseberry et al., 2011; Saylor et al., 2007) and on an a priori power analysis performed using G*Power (Faul et al., 2007), a sample size of 32 participants was estimated in order to have 80% probability to detect a significant interaction ($\alpha = .05$) with a medium effect size ($r = .25$), following Cohen's guidelines (Cohen, 1977), in a repeated measures ANOVA. Participants were recruited from birth records of neighboring cities via written invitation. Written informed consent was given by the parents or caretakers of the infants. The procedure followed the ethical standards of the Declaration of Helsinki (BMJ 1991; 302: 1194) and was approved by the Ethical Committee of the University of Milano-Bicocca *(Protocol number: 421).*

Apparatus

The study took place in a testing booth isolated from external noise and light. Infants sat on their parent's lap, at a distance of about 60 cm from a 24-inch computer screen with a resolution of 1600 x 1200 pixels. The stimuli were displayed on the computer screen using E-Prime 2.0. Parents were instructed not to interact in any way with the infant throughout the entire experimental procedure. A video-camera hidden over the computer screen recorded the infant's face during the whole experiment, and fed into a digital video recorder and a TV monitor, both located on the other side of the testing booth, out of sight of the participant. A trained experimenter, blind to the stimulus sequence and assigned condition, observed the live video displayed on the TV monitor and performed the online coding of infants' looking times by pressing the computer mouse when the infant was looking at the screen. A second experimenter further carried out the offline coding of the looking times by examining the recording of the infant's face frame-by-frame. A Pearson correlation between the online and offline coding was computed on the total fixation times during test trials, resulting in an inter-observer agreement of $r = .99$, $p < 0.01$.

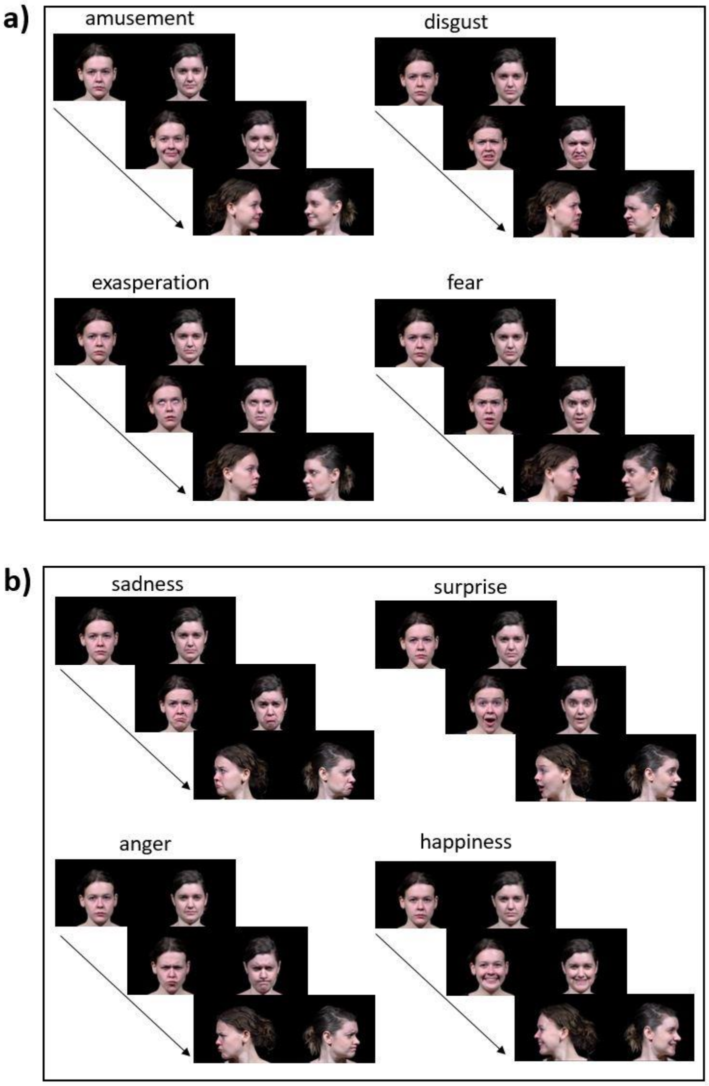

Fig. 1. Schematic representation of the 8 emotional facial expressions presented in the task. The top part of the figure (a) represents four examples of emotions within the *looking towards* condition and the bottom part of the figure (b) represents four examples of emotions within the *looking away* condition.

Stimuli

Stimuli consisted of 8 colored videos in which two Caucasian females first faced forward with a neutral expression, then simultaneously expressed the same facial emotion, and subsequently turned either towards (*looking towards* condition) or away (*looking away* condition) from each other while maintaining the expression at its peak (Figure 1). The videos displayed 8 different emotions: anger, happiness, fear, sadness, surprise, disgust, amusement and exasperation, and were chosen to be as naturalistic as possible (i.e., dynamic, involving two identities, with uncropped faces). Stimuli had a duration of 2000 ms and were created using the software Adobe Premiere Pro CC 2019 and Kinovea.

Procedure

Stimuli were embedded in a frame with a visual angle that subtended 11° x 20° at a viewing distance of 60 cm. The 8 videos were presented in a sequence and organized into four fixed pairs of videos called units (Figure 2). The four units were the same for all participants, so that the first video of a unit was always followed by the same second video. Thus, within units, the transitional probability (TP) between the first and second video was of 1.0. Similarly to previous studies (Stahl et al., 2014), during the familiarization phase, two of the units were presented 10 times (i.e., high frequency units), and the other two were presented 5 times (i.e., low frequency units), for a total of 30 units. The units were displayed in a random order, with the constraint that one unit could not be followed by itself. The last video of a high-frequency unit and the first video of a low-frequency unit formed the part-units and had an internal TP of 0.5. Part-units occurred the same amount of time as low-frequency units (Aslin et al., 1998).

An animated attention getter was presented at the beginning of the familiarization phase, to attract the infant's attention towards the screen. Once the infant looked at the screen, the experimenter started the stimulus presentation. During familiarization, anytime the infant looked away from the screen for more than 1 s, the stimulus presentation was interrupted and an audiovisual attention getter was displayed. As soon as the infant looked back to the screen, stimulus presentation resumed from where it had stopped. In this way, we ensured that all infants watched the entire familiarization. As each video lasted 2000 ms and was followed by a 200 ms inter-stimulus interval, the total duration of the familiarization phase was of 132 s. A 500 ms blank was displayed between the familiarization and the test phase.

The test phase consisted of 8 test trials divided in 2 blocks, each block being composed of 2 low frequency units and 2 part-units trials in alternation. As low frequency units and part-units occurred with the same frequency during familiarization, the only cue allowing the discrimination between units and part-units was their differing TPs. The test trials of a block were displayed in a loop, until the infants looked away for 1000 ms, or for a maximum duration of 22 s. Before each block, an attention getter was presented until the infant looked at the center of the screen. The order of the test trials (i.e., unit vs part-unit first) was counterbalanced among infants, and the same procedure was applied for both the *looking towards* and *looking away* conditions.

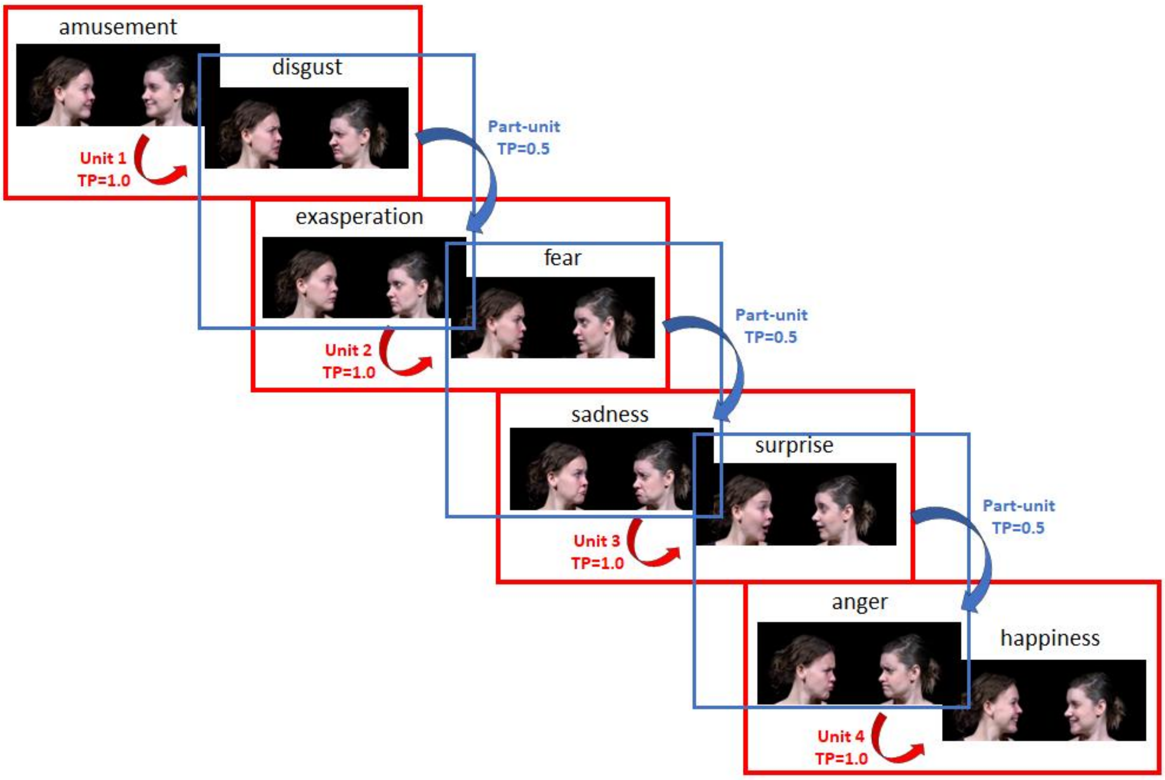

Fig. 2. Example of stimuli presented in the task for the *looking towards* condition. In the *looking away* condition, the two actresses turn away from each other instead of turning towards each other. Videos are organized in 4 pairs of facial emotions called units, with a transitional probability of 1 within each unit (highly predictable transitions), and a transitional probability of 0.5 between units (low predictable transitions).

Data analysis

A preliminary inspection of our data indicated that raw looking times at test were not normally distributed for both units and part-units (Ws > 0.86, *p*s < .05). As a consequence, data were logarithmically transformed for the statistical analyses, following Csibra et al. (2016) recommendations(Csibra et al., 2016).

We conducted a repeated measures Analysis of Variance (ANOVA) on logarithmically transformed looking times at test, with Block (first, second) and Trial type (units, part-units) as within-subjects factors and Condition (*looking towards*, *looking away*) and Trial order (units first, part-units first) as between-subjects factors. Planned comparisons were also conducted to explore infants' looking time patterns separately for both the *looking towards* and *looking away* conditions, by performing repeated measures ANOVAs on logarithmically transformed looking times at test, with Block (first, second) and Trial type (units, part-units) as within-subjects factors and Trial order (units first, part-units first) as between-subjects factors. These comparisons were planned a priori, based upon the existing literature and our predictions that SL would be facilitated in the *looking towards* condition, and impaired in the *looking away* condition. Pairwise comparisons were performed by applying t-tests and the Fisher's least significant difference procedure (Howell, 2012), and Holm–Bonferroni correction was used where appropriate (Abdi, 2010). The Greenhouse–Geisser correction for non-sphericity was used to adjust degrees of freedom as appropriate. Effect sizes were estimated using the η^2_p measure, and the data are reported as means and standard deviations (SDs). All statistical analyses were performed on Jamovi 1.6.15 (https://jamovi.org) using a two-tailed 0.05 level of significance. Following recent recommendations on best practices in infant looking-time research (Oakes, 2017), in order to strengthen our results, we also performed Bayesian analyses by using the default Cauchy prior ($r = 0.707$). Using the Jamovi formalism, the index next to the Bayes Factors (BF) indicates that the null hypothesis (H_0) is in the denominator and the alternative hypothesis (H_1) is in the numerator. Thus, BF_{10} is $p(\text{data}|H_1)/p(\text{data}|H_0)$, with $BF_{10} > 10$ considered as strong evidence for an effect, and $3 < BF_{10} < 10$ considered as moderate evidence.

Results

The main repeated measure ANOVA revealed a significant main effect of Block $F(1,32) = 7.40$, $p = .010$, $\eta^2_p = .188$, and a significant main effect of Trial Type, $F(1,32) = 7.28$, $p = .011$, $\eta^2_p = .185$. Infants looked significantly longer to the first block ($M = 63.17$ s, $SD = 23.38$) than to the second block ($M = 55.07$ s, $SD = 21.29$), and significantly longer to part-units ($M = 62.89$ s, $SD = 21.03$) than units ($M = 55.34$ s, $SD = 23.89$; Figure 3). Examination of the data for individual infants through binomial tests confirmed the results of the analysis on looking times, revealing that 25 out of the 36 twelve-month-old infants looked longer to the part-units compared to the units (25 vs. 11, $p = .029$). Two-tailed paired sample Bayesian t-tests confirmed the results obtained from frequentist analysis, showing moderate evidence for a difference between units and part-units ($BF_{10} = 4.27$) and moderate evidence for a difference between the first and the second block ($BF_{10} = 5.22$). The difference in looking times between the two blocks likely reflects a decrease in infants' attention during the second part of the study, which is commonly found in looking time paradigms using long familiarization phases. No other main or interaction effects reached statistical significance (all *ps* > .09).

Despite the absence of main effect or interaction of the factor Condition, we had planned to examine the *looking towards* and *looking away* conditions separately. The ANOVA performed on the *looking towards* condition revealed a significant main effect of Block $F(1,16) = 5.39$, $p = .034$, $\eta^2_p = .252$, and a significant main effect of Trial Type, $F(1,16) = 6.92$, $p = .018$, $\eta^2_p = .302$. Infants looked significantly longer to the first block ($M = 63.40$ s, $SD = 25.65$) than to the second block ($M = 54.35$ s, $SD = 23.31$), and significantly longer to part-units (*M* = 63.91 s, *SD* = 25.14) than units (*M* = 53.84 s, *SD* = 23.99) (Figure 3). Two-tailed paired sample Bayesian t-tests confirmed the results obtained from frequentist analysis, showing moderate evidence for a difference between units and part-units (BF_{10} = 3.96) and anecdotal evidence for a difference between the first and the second block (BF_{10} = 2.08). No other main or interaction effects attained statistical significance (all *ps* > .32). The ANOVA performed on the *looking away* condition did not reveal any main or interaction effects (all *p*s > .12). Two-tailed paired sample Bayesian t-tests further confirmed the lack of significant results resulted from the frequentist analysis, showing anecdotal evidence for the lack of difference between units (*M* = 56.84 s, *SD* = 24.40 s) and part-units (*M* = 61.87 s, *SD* = 16.62 s) in the *looking away* condition (BF_{10} = .57) (Figure 3).

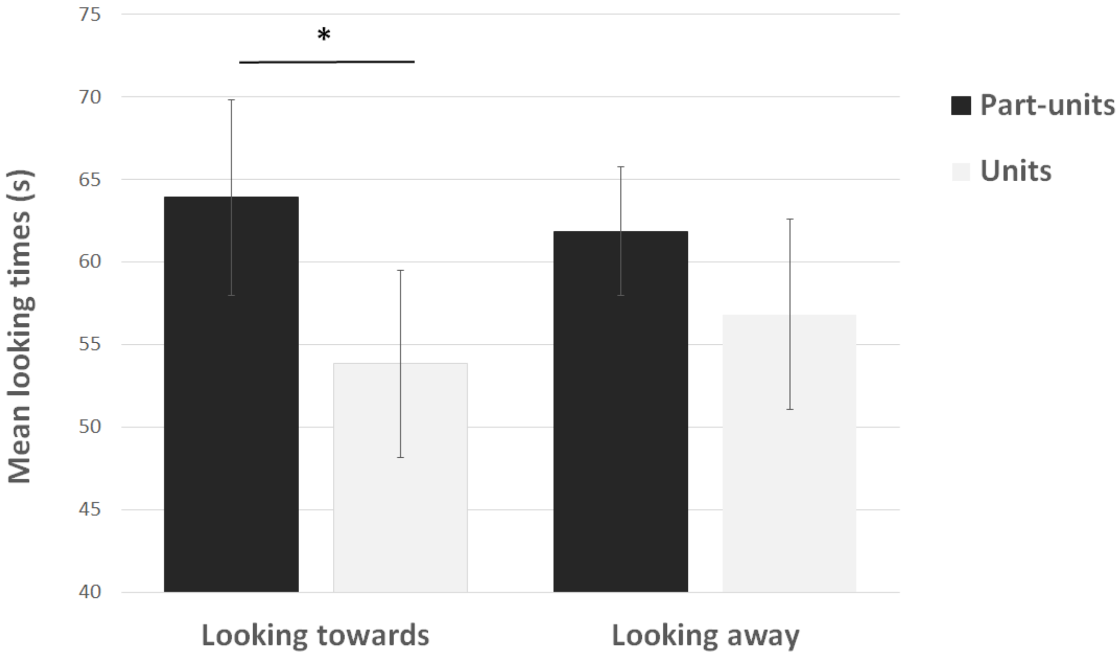

Fig. 3. Mean looking times (±SE) to units and part-units for the *looking towards* and the *looking away* conditions. Infants looked longer at the part-units than at the units only in the *looking towards* condition. * $p < 0.05$.

Discussion

The current study sought to determine whether 12-months old infants are capable of extracting statistical regularities from a sequence of interacting emotional faces, with differences in TPs as only cue for the segmentation. In addition, it investigated whether the degree of sociality of the stimuli modulates this ability. Results demonstrated that infants are indeed able to segment a continuous sequence of emotional faces relying solely on the differences in TPs between stimuli. These findings are in line with previous work showing that infants can apply SL to different categories of stimuli (e.g., auditory sequences, Hannon & Johnson, 2005; complex human actions, Monroy et al., 2017; human gestures, Quadrelli et al., 2020), extending it to sequences of emotional faces. They further support the view that SL is based on the same learning mechanisms across domains and modalities (Saffran & Kirkham, 2018), and allows infants to structure their surrounding environment, facilitating its comprehension. Future studies should investigate whether all emotions have the same impact on infants' ability to track statistics from a sequence of faces or whether some type of emotions or emotional pairs (e.g., the co-occurrence of emotional faces with positive vs. negative valence) might differently affect infants' learning abilities.

Importantly, the current study does not only extend the range of application of infants' SL, but also informs about its potential underlying mechanism. Indeed, as our design ensured that units and part-units occurred with the same frequency during familiarization, the only cue upon which infants could base their segmenting of the sequence of interacting emotional faces was the differing TPs. Together with previous research examining SL of other categories of stimuli (e.g., words, Aslin et al., 1998; gestures, Quadrelli et al., 2020; events, Stahl et al., 2014), our findings suggest that the computing of TPs might be a common mechanism underlying SL across domains and modalities. As the functioning of infants' SL appears to be strongly affected by the type of input to be learned (Krogh, Vlach, & Johnson, 2013), future studies should examine infants’ SL abilities with emotional stimuli from different domains, as for example emotional vocal expressions or emotional gestures.

Although no evidence for a difference between conditions was found in the main analysis, the examination of the *looking toward* and *looking away* conditions separately nevertheless hinted at potential differences in looking time patterns. Indeed, we found evidence for a difference between units and part-units in the *looking toward* condition, but not in the *looking away* condition, even if the trend in infants’ looking time patterns was similar in the two conditions. This suggests that the SL of a sequence of emotional faces might be marginally influenced by the degree of sociality of the stimuli, with highly salient social stimuli such as those displayed in the *looking towards* condition promoting infants’ SL, and less salient social stimuli such as those displayed in the *looking away* condition impairing it. This is in line with previous studies showing that social stimuli such as two actors facing or interacting with each other, as compared to actors sitting back-to-back, promoted infants’ SL of a gestures sequence (Quadrelli et al., 2020) and helped binding actions into a collaborative sequence (Fawcett & Gredebäck, 2013). Alternatively, the lack of evidence for SL in the *looking away* condition might be based on the familiarity, rather than the sociality of the stimuli. Indeed, it is quite uncommon for infants to witness social interactions in which the two protagonists express an emotion, and then turn away from each other. Thus, the stimuli of the *looking away* condition might have been too unusual for infants and disrupted their ability to extract the statistical regularities from the sequence of emotions. In sum, the design and results of our study does not allow us to draw a firm conclusion about whether and why SL was disrupted in the *looking away* condition. Future research should further examine the role of the sociality of the stimuli in infants’ SL, for example by manipulating different social cues while keeping constant the familiarity of the stimuli. Besides, SL abilities only diverged when looking at both conditions separately, but did not significantly differ when comparing them directly. These findings thus require replication to be confirmed, and more research is needed to uncover the different factors influencing infants' SL of emotional faces. Indeed, in the current study the stimuli of the *looking away* condition also contained several social cues. Even though the two actresses ended up looking away from each other, they started facing forward, looking towards the participants, and expressed the same emotion at the same time. Thus, infants could have interpreted the actresses' initial emotional expression (i.e., when facing forward) as directed to themselves, and their subsequent synchronicity of emotional behaviors as a social marker, considering the two actresses as acting jointly, rather than individually. Furthermore, infants' high familiarity (Gebhart et al., 2009) and perceptual expertise (Saffran et al., 2007) of faces, which are inherently social and highly salient per se, and the fact that our stimuli were presented in a very naturalistic way (i.e., dynamic and uncropped faces), similarly to what is observed in everyday life, might have promoted infants' learning. These facilitating factors, together with infants' increasing cognitive capacities at the end of the first year, might have decreased the possibility to find a more pronounced difference between the looking forward and looking away conditions. Future research could further clarify this issue investigating infants' SL using conditions that are more markedly contrasted in terms of level of sociality.

In conclusion, the current study presents evidence that 12-months old infants are capable of extracting statistical regularities from a highly complex sequence of emotional faces, using TPs as only cue for segmentation. Thus, SL seems to be a crucial mechanism which allows infants to structure their surrounding environment through the detection of statistical regularities (Saffran, 2018), providing a foundation for its comprehension. One essential aspect of infants' comprehension of their environment is the understanding of the social interactions surrounding them. These social interactions often consist in a succession of facial expressions of emotions, following specific patterns of occurrence, which determine the meaning of the interaction and reflect the mental states of its protagonists. The present study demonstrates that 12-months old infants are capable of extracting these specific patterns of occurrence, in order to structure the social interactions they observe. This structuring might be the first step towards a deeper comprehension of social interactions, nevertheless, further research is needed to uncover whether it could be a potential foundation for more complex reasoning such as the understanding of the protagonists' mental states (e.g., Saylor et al., 2007).

This chapter showed that the surrounding facial emotional context, in particular the specific order in which facial emotions are presented, influences 12-months-old infants' attention to these facial emotions. The next chapter will focus on another type of emotional context cues: action kinematics, and their influence on infants' neural processing of emotional faces.

References

Abdi, H. (2010). Holm's sequential Bonferroni procedure. *Encyclopedia of Research Design*, 1(8), 1-8.

Abrams, D., Weick, M., Thomas, D., Colbe, H., & Franklin, K. M. (2011). On-line ostracism affects children differently from adolescents and adults: Ostracism: children, adolescents, adults. *British Journal of Developmental Psychology*, *29*(1), 110–123. https://doi.org/10.1348/026151010X494089

Ambadar, Z., Schooler, J. W., & Cohn, J. F. (2005). Deciphering the Enigmatic Face: The Importance of Facial Dynamics in Interpreting Subtle Facial Expressions. *Psychological Science*, *16*(5), 403–410. https://doi.org/10.1111/j.0956-7976.2005.01548.x

Aslin, R. N., Saffran, J. R., & Newport, E. L. (1998). Computation of Conditional Probability Statistics by 8-Month-Old Infants. *Psychological Science*, *9*(4), 321–324. https://doi.org/10.1111/1467-9280.00063

Augusti, E.-M., Melinder, A., & Gredebäck, G. (2010). Look who's talking: Pre-verbal infants' perception of face-to-face and back-to-back social interactions. *Frontiers in Psychology*, *1*. https://doi.org/10.3389/fpsyg.2010.00161

Aviezer, H., Ensenberg, N., & Hassin, R. R. (2017). The inherently contextualized nature of facial emotion perception. *Current Opinion in Psychology*, *17*, 47–54. https://doi.org/10.1016/j.copsyc.2017.06.006

Aviezer, H., Trope, Y., & Todorov, A. (2012). Body Cues, Not Facial Expressions, Discriminate Between Intense Positive and Negative Emotions. *Science*, *338*(6111), 1225–1229. https://doi.org/10.1126/science.1224313

Barrett, L. F., Mesquita, B., & Gendron, M. (2011). Context in Emotion Perception. *Current Directions in Psychological Science*, *20*(5), 286–290. https://doi.org/10.1177/0963721411422522

Batty, M., Meaux, E., Wittemeyer, K., Rogé, B., & Taylor, M. J. (2011). Early processing of emotional faces in children with autism: An event-related potential study. *Journal of Experimental Child Psychology, 109*(4), 430–444. https://doi.org/10.1016/j.jecp.2011.02.001

Baumeister, R. F., & Leary, M. R. (1995). The Need to Belong: Desire for Interpersonal Attachments as a Fundamental Human Motivation. *Psychological Bulletin, 117*(3), 34.

Baumeister, R. F., Twenge, J. M., & Nuss, C. K. (2002). Effects of social exclusion on cognitive processes: Anticipated aloneness reduces intelligent thought. *Journal of Personality and Social Psychology, 83*(4), 817–827. https://doi.org/10.1037/0022-3514.83.4.817

Bernstein, M. J., Young, S. G., Brown, C. M., Sacco, D. F., & Claypool, H. M. (2008). Adaptive Responses to Social Exclusion: Social Rejection Improves Detection of Real and Fake Smiles. *Psychological Science, 19*(10), 981–983. https://doi.org/10.1111/j.1467-9280.2008.02187.x

Bulf, H., Brenna, V., Valenza, E., Johnson, S. P., & Turati, C. (2015). Many faces, one rule: The role of perceptual expertise in infants' sequential rule learning. *Frontiers in Psychology, 6*. https://doi.org/10.3389/fpsyg.2015.01595

Bulf, H., Johnson, S. P., & Valenza, E. (2011). Visual statistical learning in the newborn infant. *Cognition*, *121*(1), 127–132. https://doi.org/10.1016/j.cognition.2011.06.010

Calder, A. J., Young, A. W., Perrett, D. I., Etcoff, N. L., & Rowland, D. (1996). Categorical Perception of Morphed Facial Expressions. *Visual Cognition*, *3*(2), 81–118. https://doi.org/10.1080/713756735

Camras, L. A., & Allison, K. (1985). Children's understanding of emotional facial expressions and verbal labels. *Journal of Nonverbal Behavior, 9*(2), 84–94. https://doi.org/10.1007/BF00987140

Carroll, J. M., & Russell, J. A. (1996). Do Facial Expressions Signal Specific Emotions? Judging Emotion From the Face in Context. *Journal of Personality and Social Psychology, 70*(2), 205.

Carter-Sowell, A. R., Chen, Z., & Williams, K. D. (2008). Ostracism increases social susceptibility. *Social Influence*, *3*(3), 143–153. https://doi.org/10.1080/15534510802204868

Cheung, E. O., Slotter, E. B., & Gardner, W. L. (2015). Are you feeling what I'm feeling? The role of facial mimicry in facilitating reconnection following social exclusion. *Motivation and Emotion*, *39*(4), 613–630. https://doi.org/10.1007/s11031-015-9479-9

Choudhury, S., Blakemore, S.-J., & Charman, T. (2006). Social cognitive development during adolescence. *Social Cognitive and Affective Neuroscience*, *1*(3), 165–174. https://doi.org/10.1093/scan/nsl024

Conte, S., Richards, J. E., Guy, M. W., Xie, W., & Roberts, J. E. (2020). Face-sensitive brain responses in the first year of life. *NeuroImage*, *211*, 116602. https://doi.org/10.1016/j.neuroimage.2020.116602

Csibra, G., Hernik, M., Mascaro, O., Tatone, D., & Lengyel, M. (2016). Statistical treatment of looking-time data. *Developmental Psychology*, *52*(4), 521–536. https://doi.org/10.1037/dev0000083

Curtis, W. J., & Cicchetti, D. (2013). Affective Facial Expression Processing in 15-Month-Old Infants Who Have Experienced Maltreatment: An Event-Related Potential Study. *Child Maltreatment*, *18*(3), 140–154. https://doi.org/10.1177/1077559513487944

Dawson, G., Webb, S. J., Carver, L., Panagiotides, H., & McPartland, J. (2004). Young children with autism show atypical brain responses to fearful versus neutral facial expressions of emotion. *Developmental Science, 7*(3), 340–359. https://doi.org/10.1111/j.1467-7687.2004.00352.x

De Haan, M., Johnson, M. H., & Halit, H. (2003). Development of face-sensitive event-related potentials during infancy: A review. *International Journal of Psychophysiology*, *51*(1), 45–58. https://doi.org/10.1016/S0167-8760(03)00152-1

de Haan, M., & Nelson, C. A. (1999). Brain Activity Differentiates Face and Object Processing in 6-Month-Old Infants. *Developmental Psychology*, *35*(4), 1113.

De Haan, M., Pascalis, O., & Johnson, M. H. (2002). Specialization of Neural Mechanisms Underlying Face Recognition in Human Infants. *Journal of Cognitive Neuroscience*, *14*(2), 199–209. https://doi.org/10.1162/089892902317236849

Dennis, T. A., Malone, M. M., & Chen, C.-C. (2009). Emotional Face Processing and Emotion Regulation in Children: An ERP Study. *Developmental Neuropsychology*, *34*(1), 85–102. https://doi.org/10.1080/87565640802564887

DeWall, C. N., Maner, J. K., & Rouby, D. A. (2009a). Social Exclusion and Early-Stage Interpersonal Perception: Selective Attention to Signs of Acceptance. *Journal of Personality and Social Psychology*, *96*(4), 729.

DeWall, C. N., Maner, J. K., & Rouby, D. A. (2009b). Social exclusion and early-stage interpersonal perception: Selective attention to signs of acceptance. *Journal of Personality and Social Psychology*, *96*(4), 729–741. https://doi.org/10.1037/a0014634

Di Lorenzo, R., van den Boomen, C., Kemner, C., & Junge, C. (2020). Charting development of ERP components on face-categorization: Results from a large longitudinal sample of infants. *Developmental Cognitive Neuroscience*, *45*, 100840. https://doi.org/10.1016/j.dcn.2020.100840

Dolan, R. J., Morris, J. S., & de Gelder, B. (2001). Crossmodal binding of fear in voice and face. *Proceedings of the National Academy of Sciences*, *98*(17), 10006–10010. https://doi.org/10.1073/pnas.171288598

D’Souza, J., & Gurin, M. (2016). The universal significance of Maslow’s concept of self-actualization. *The Humanistic Psychologist, 44*(2), 210–214. https://doi.org/10.1037/hum0000027

Durand, K., Gallay, M., Seigneuric, A., Robichon, F., & Baudouin, J.-Y. (2007). The development of facial emotion recognition: The role of configural information. *Journal of Experimental Child Psychology*, *97*(1), 14–27. https://doi.org/10.1016/j.jecp.2006.12.001

Eisenberger, N. I., Lieberman, M. D., & Williams, K. D. (2003). *Does Rejection Hurt? An fMRI Study of Social Exclusion*. *302*, 3.

Ekman, P. (1992). An argument for basic emotions. *Cognition and Emotion*, *6*(3–4), 169–200. https://doi.org/10.1080/02699939208411068

Farroni, T., Menon, E., Rigato, S., & Johnson, M. H. (2007). The perception of facial expressions in newborns. *European Journal of Developmental Psychology*, *4*(1), 2–13. https://doi.org/10.1080/17405620601046832

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, *39*(2), 175–191. https://doi.org/10.3758/BF03193146

Fawcett, C., & Gredebäck, G. (2013). Infants use social context to bind actions into a collaborative sequence. *Developmental Science*, n/a-n/a. https://doi.org/10.1111/desc.12074

Gao, X., & Maurer, D. (2009). Influence of intensity on children’s sensitivity to happy, sad, and fearful facial expressions. *Journal of Experimental Child Psychology*, *102*(4), 503–521. https://doi.org/10.1016/j.jecp.2008.11.002

Gao, X., & Maurer, D. (2010). A happy story: Developmental changes in children’s sensitivity to facial expressions of varying intensities. *Journal of Experimental Child Psychology, 107*(2), 67–86. https://doi.org/10.1016/j.jecp.2010.05.003

Gardner, W. L., Pickett, C. L., & Brewer, M. B. (2000). Social Exclusion and Selective Memory: How the Need to belong Influences Memory for Social Events. *Personality and Social Psychology Bulletin*, *26*(4), 486–496. https://doi.org/10.1177/0146167200266007

Geangu, E., Hauf, P., Bhardwaj, R., & Bentz, W. (2011). Infant Pupil Diameter Changes in Response to Others’ Positive and Negative Emotions. *PLoS ONE*, *6*(11), e27132. https://doi.org/10.1371/journal.pone.0027132

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), R663–R664. https://doi.org/10.1016/j.cub.2016.05.072

Gebhart, A. L., Newport, E. L., & Aslin, R. N. (2009). Statistical learning of adjacent and nonadjacent dependencies among nonlinguistic sounds. *Psychonomic Bulletin & Review*, *16*(3), 486–490. https://doi.org/10.3758/PBR.16.3.486

Gendron, M., Mesquita, B., & Barrett, L. F. (2013). *Emotion Perception: Putting the Face in Context*. Oxford University Press. https://doi.org/10.1093/oxfordhb/9780195376746.013.0034

Gonsalkorale, K., & Williams, K. D. (2007). The KKK won’t let me play: Ostracism even by a despised outgroup hurts. *European Journal of Social Psychology, 37*(6), 1176–1186. https://doi.org/10.1002/ejsp.392

Grossmann, T., Striano, T., & Friederici, A. D. (2006). Crossmodal integration of emotional information from face and voice in the infant brain. *Developmental Science, 9*(3), 309–315. https://doi.org/10.1111/j.1467-7687.2006.00494.x

Grossmann, T., Striano, T., & Friederici, A. D. (2007). Developmental changes in infants' processing of happy and angry facial expressions: A neurobehavioral study. *Brain and Cognition*, *64*(1), 30–41. https://doi.org/10.1016/j.bandc.2006.10.002

Hannon, E. E., & Johnson, S. P. (2005). Infants use meter to categorize rhythms and melodies: Implications for musical structure learning. *Cognitive Psychology*, *50*(4), 354–377. https://doi.org/10.1016/j.cogpsych.2004.09.003

Hartgerink, C. H. J., van Beest, I., Wicherts, J. M., & Williams, K. D. (2015). The Ordinal Effects of Ostracism: A Meta-Analysis of 120 Cyberball Studies. *PLOS ONE*, *10*(5), e0127002. https://doi.org/10.1371/journal.pone.0127002

Hawes, D. J., Zadro, L., Fink, E., Richardson, R., O'Moore, K., Griffiths, B., Dadds, M. R., & Williams, K. D. (2012). The effects of peer ostracism on children's cognitive processes. *European Journal of Developmental Psychology*, *9*(5), 599–613. https://doi.org/10.1080/17405629.2011.638815

Hillyard, S. A., & Anllo-Vento, L. (1998). Event-related brain potentials in the study of visual selective attention. *Proceedings of the National Academy of Sciences*, *95*(3), 781–787. https://doi.org/10.1073/pnas.95.3.781

Hoehl, S., Palumbo, L., Heinisch, C., & Striano, T. (2008). *Infants' attention is biased by emotional expressions and eye gaze direction*. 4.

Hopkins, Z. L., & Branigan, H. P. (2020). Children show selectively increased language imitation after experiencing ostracism. *Developmental Psychology*, *56*(5), 897–911. https://doi.org/10.1037/dev0000915

Hunnius, S., de Wit, T. C. J., Vrins, S., & von Hofsten, C. (2011a). Facing threat: Infants' and adults' visual scanning of faces with neutral, happy, sad, angry, and fearful emotional expressions. *Cognition & Emotion*, *25*(2), 193–205. https://doi.org/10.1080/15298861003771189

Hunnius, S., de Wit, T. C. J., Vrins, S., & von Hofsten, C. (2011b). Facing threat: Infants' and adults' visual scanning of faces with neutral, happy, sad, angry, and fearful emotional expressions. *Cognition & Emotion*, *25*(2), 193–205. https://doi.org/10.1080/15298861003771189

Iidaka, T., Saito, D. N., Komeda, H., Mano, Y., Kanayama, N., Osumi, T., Ozaki, N., & Sadato, N. (2010). Transient Neural Activation in Human Amygdala Involved in Aversive Conditioning of Face and Voice. *Journal of Cognitive Neuroscience*, *22*(9), 2074–2085. https://doi.org/10.1162/jocn.2009.21347

Itier, R. J., & Taylor, M. J. (2002). Inversion and Contrast Polarity Reversal Affect both Encoding and Recognition Processes of Unfamiliar Faces: A Repetition Study Using ERPs. *NeuroImage*, *15*(2), 353–372. https://doi.org/10.1006/nimg.2001.0982

Izard, C. E. (1994). *Innate and Universal Facial Expressions: Evidence From Developmental and Cross-Cultural Research*. 288.

Jack, R. E., Garrod, O. G. B., Yu, H., Caldara, R., & Schyns, P. G. (2012). Facial expressions of emotion are not culturally universal. *Proceedings of the National Academy of Sciences*, *109*(19), 7241–7244. https://doi.org/10.1073/pnas.1200155109

Johnson, S. P., & Aslin, R. N. (1996). Perception of object unity in young infants: The roles of motion, depth, and orientation. *Cognitive Development*, *11*(2), 161–180. https://doi.org/10.1016/S0885-2014(96)90001-5

Kawamoto, T., Nittono, H., & Ura, M. (2014a). Social exclusion induces early-stage perceptual and behavioral changes in response to social cues. *Social Neuroscience*, *9*(2), 174–185. https://doi.org/10.1080/17470919.2014.883325

Kawamoto, T., Nittono, H., & Ura, M. (2014b). Social exclusion induces early-stage perceptual and behavioral changes in response to social cues. *Social Neuroscience*, *9*(2), 174–185. https://doi.org/10.1080/17470919.2014.883325

Kirkham, N. Z., Slemmer, J. A., & Johnson, S. P. (2002). Visual statistical learning in infancy: Evidence for a domain general learning mechanism. *Cognition*, *83*(2), B35–B42. https://doi.org/10.1016/S0010-0277(02)00004-5

Kirkham, N. Z., Slemmer, J. A., Richardson, D. C., & Johnson, S. P. (2007). Location, Location, Location: Development of Spatiotemporal Sequence Learning in Infancy. *Child Development*, *78*(5), 1559–1571. https://doi.org/10.1111/j.1467-8624.2007.01083.x

Kobiella, A., Grossmann, T., Reid, V. M., & Striano, T. (2008). The discrimination of angry and fearful facial expressions in 7-month-old infants: An event-related potential study. *Cognition and Emotion*, *22*(1), 134–146. https://doi.org/10.1080/02699930701394256

Koechlin, E. (1997). Numerical Transformations in Five-month-old Human Infants. *Mathematical Cognition*, *3*(2), 89–104. https://doi.org/10.1080/135467997387425

Kotsoni, E., de Haan, M., & Johnson, M. H. (2001). Categorical Perception of Facial Expressions by 7-Month-Old Infants. *Perception*, *30*(9), 1115–1125. https://doi.org/10.1068/p3155

Kuchuk, A., Vibbert, M., & Bornstein, M. H. (1986). The Perception of Smiling and Its Experiential Correlates in Three-Month-Old Infants. *Child Development*, 1054–1061.

Lakin, J. L., Chartrand, T. L., & Arkin, R. M. (2008). I Am Too Just Like You: Nonconscious Mimicry as an Automatic Behavioral Response to Social Exclusion. *Psychological Science*, *19*(8), 816–822. https://doi.org/10.1111/j.1467-9280.2008.02162.x

Leppänen, J. M., Moulson, M. C., Vogel-Farley, V. K., & Nelson, C. A. (2007a). An ERP Study of Emotional Face Processing in the Adult and Infant Brain. *Child Development*, *78*(1), 232–245. https://doi.org/10.1111/j.1467-8624.2007.00994.x

Leppänen, J. M., Moulson, M. C., Vogel-Farley, V. K., & Nelson, C. A. (2007b). An ERP Study of Emotional Face Processing in the Adult and Infant Brain. *Child Development*, *78*(1), 232–245. https://doi.org/10.1111/j.1467-8624.2007.00994.x

Leppänen, J. M., & Nelson, C. A. (2009). Tuning the developing brain to social signals of emotions. *Nature Reviews Neuroscience, 10*(1), 37–47. https://doi.org/10.1038/nrn2554

Li, W., Zinbarg, R. E., Boehm, S. G., & Paller, K. A. (2008). Neural and Behavioral Evidence for Affective Priming from Unconsciously Perceived Emotional Facial Expressions and the Influence of Trait Anxiety. *Journal of Cognitive Neuroscience, 20*(1), 95–107.

Ludemann, P. M., & Nelson, C. A. (1988). *Categorical Representation of Facial Expressions by 7-Month-Old Infants*. 10.

MacDonald, G., & Leary, M. R. (2005). Why Does Social Exclusion Hurt? The Relationship Between Social and Physical Pain. *Psychological Bulletin*, *131*(2), 202–223. https://doi.org/10.1037/0033-2909.131.2.202

Marinović, V., & Träuble, B. (2018). Vicarious social exclusion and memory in young children. *Developmental Psychology*, *54*(11), 2067–2076. https://doi.org/10.1037/dev0000593

Marinović, V., Wahl, S., & Träuble, B. (2017). “Next to you”—Young children sit closer to a person following vicarious ostracism. *Journal of Experimental Child Psychology, 156,* 179–185. https://doi.org/10.1016/j.jecp.2016.11.011

Masuda, T., Ellsworth, P. C., Mesquita, B., Leu, J., Tanida, S., & Van de Veerdonk, E. (2008). Placing the face in context: Cultural differences in the perception of facial emotion. *Journal of Personality and Social Psychology, 94*(3), 365–381. https://doi.org/10.1037/0022-3514.94.3.365

Meeren, H. K. M., van Heijnsbergen, C. C. R. J., & de Gelder, B. (2005). Rapid perceptual integration of facial expression and emotional body language. *Proceedings of the National Academy of Sciences, 102*(45), 16518–16523. https://doi.org/10.1073/pnas.0507650102

Meier, I. M., van Honk, J., Bos, P. A., & Terburg, D. (2020). *Social touch increases dominant gaze in social confrontations* [Preprint]. PsyArXiv. https://doi.org/10.31234/osf.io/ubyv3

Meyer, M., Baldwin, D. A., & Sage, K. (2011). *Assessing Young Children’s Hierarchical Action Segmentation*. 7.

Monroy, C., Meyer, M., Gerson, S., & Hunnius, S. (2017). Statistical learning in social action contexts. *PLOS ONE, 12*(5), e0177261. https://doi.org/10.1371/journal.pone.0177261

Monroy, C., Meyer, M., Schröer, L., Gerson, S. A., & Hunnius, S. (2019). The infant motor system predicts actions based on visual statistical learning. *NeuroImage, 185,* 947–954. https://doi.org/10.1016/j.neuroimage.2017.12.016

Montague, D. P. F., & Walker-Andrews, A. S. (2001). Peekaboo: A new look at infants’ perception of emotion expressions. *Developmental Psychology, 37*(6), 826–838. https://doi.org/10.1037/0012-1649.37.6.826

Müller, V. I., Habel, U., Derntl, B., Schneider, F., Zilles, K., Turetsky, B. I., & Eickhoff, S. B. (2011). Incongruence effects in crossmodal emotional integration. *NeuroImage*, *54*(3), 2257–2266. https://doi.org/10.1016/j.neuroimage.2010.10.047

Mumenthaler, C., & Sander, D. (2012). Social appraisal influences recognition of emotions. *Journal of Personality and Social Psychology*, *102*(6), 1118–1135. https://doi.org/10.1037/a0026885

Nelson, C. A., & De Haan, M. (1996). Neural correlates of infants' visual responsiveness to facial expressions of emotion. *Developmental Psychobiology*, *29*(7), 577–595. https://doi.org/10.1002/(SICI)1098-2302(199611)29:7<577::AID-DEV3>3.0.CO;2-R

Niedenthal, P. M., Halberstadt, J. B., & Margolin, J. (2000). Emotional state and the detection of change in facial expression of emotion. *Eur. J. Soc. Psychol.*, 12.

Nielsen, M. (2006). Copying actions and copying outcomes: Social learning through the second year. *Developmental Psychology, 42*(3), 555–565. https://doi.org/10.1037/0012-1649.42.3.555

Oakes, L. M. (2017). Sample Size, Statistical Power, and False Conclusions in Infant Looking-Time Research. *Infancy*, *22*(4), 436–469. https://doi.org/10.1111/infa.12186

Over, H., & Carpenter, M. (2009a). Priming third-party ostracism increases affiliative imitation in children. *Developmental Science*, *12*(3), F1–F8. https://doi.org/10.1111/j.1467-7687.2008.00820.x

Over, H., & Carpenter, M. (2009b). Eighteen-Month-Old Infants Show Increased Helping Following Priming with Affiliation. *Psychological Science*, *20*(10), 1189–1193. https://doi.org/10.1111/j.1467-9280.2009.02419.x

Palama, A., Malsert, J., & Gentaz, E. (2018). Are 6-month-old human infants able to transfer emotional information (happy or angry) from voices to faces? An eye-tracking study. *PLOS ONE*, *13*(4), e0194579. https://doi.org/10.1371/journal.pone.0194579

Palermo, R., O'Connor, K. B., Davis, J. M., Irons, J., & McKone, E. (2013). New Tests to Measure Individual Differences in Matching and Labelling Facial Expressions of Emotion, and Their Association with Ability to Recognise Vocal Emotions and Facial Identity. *PLoS ONE*, *8*(6), e68126. https://doi.org/10.1371/journal.pone.0068126

Peltola, M. J., Leppänen, J. M., Palokangas, T., & Hietanen, J. K. (2008). Fearful faces modulate looking duration and attention disengagement in 7-month-old infants. *Developmental Science*, *11*(1), 60–68. https://doi.org/10.1111/j.1467-7687.2007.00659.x

Phelps, E. A., O'Connor, K. J., Cunningham, W. A., Funayama, E. S., Gatenby, J. C., Gore, J. C., & Banaji, M. R. (2000). Performance on Indirect Measures of Race Evaluation Predicts Amygdala Activation. *Journal of Cognitive Neuroscience*, *12*(5), 729–738.

Pickett, C. L., Gardner, W. L., & Knowles, M. (2004). Getting a Cue: The Need to Belong and Enhanced Sensitivity to Social Cues. *Personality and Social Psychology Bulletin*, *30*(9), 1095–1107. https://doi.org/10.1177/0146167203262085

Pollak, S. D., Messner, M., Kistler, D. J., & Cohn, J. F. (2009). Development of perceptual expertise in emotion recognition. *Cognition*, *110*(2), 242–247. https://doi.org/10.1016/j.cognition.2008.10.010

Pollak, S. D., & Sinha, P. (2002). Effects of early experience on children's recognition of facial displays of emotion. *Developmental Psychology*, *38*(5), 784–791. https://doi.org/10.1037/0012-1649.38.5.784

Pourtois, G., Dan, E. S., Grandjean, D., Sander, D., & Vuilleumier, P. (2005). Enhanced extrastriate visual response to bandpass spatial frequency filtered fearful faces: Time course and topographic evoked-potentials mapping. *Human Brain Mapping*, *26*(1), 65–79. https://doi.org/10.1002/hbm.20130

Quadrelli, E., Conte, S., Macchi Cassia, V., & Turati, C. (2019). Emotion in motion: Facial dynamics affect infants’ neural processing of emotions. *Developmental Psychobiology, 61*(6), 843–858. https://doi.org/10.1002/dev.21860

Quadrelli, E., Monacò, S., Turati, C., & Bulf, H. (2020). Social context influences infants’ ability to extract statistical information from a sequence of gestures. *Infant Behavior and Development*, *61*, 101506. https://doi.org/10.1016/j.infbeh.2020.101506

Quadrelli, E., Roberti, E., Polver, S., Bulf, H., & Turati, C. (2021). Sensorimotor Activity and Network Connectivity to Dynamic and Static Emotional Faces in 7-Month-Old Infants. *Brain Sciences*, *11*(11), 1396. https://doi.org/10.3390/brainsci11111396

Rajhans, P., Jessen, S., Missana, M., & Grossmann, T. (2016). Putting the face in context: Body expressions impact facial emotion processing in human infants. *Developmental Cognitive Neuroscience*, *19*, 115–121. https://doi.org/10.1016/j.dcn.2016.01.004

Reichenbach, L., & Masters, J. C. (2021). *Children’s Use of Expressive and Contextual Cues in Judgments of Emotion*. 13.

Righart, R., & De Gelder, B. (2006). Context Influences Early Perceptual Analysis of Faces—An Electrophysiological Study. *Cerebral Cortex*, *16*(9), 1249–1257. https://doi.org/10.1093/cercor/bhj066

Roseberry, S., Richie, R., Hirsh-Pasek, K., Golinkoff, R. M., & Shipley, T. F. (2011). Babies Catch a Break: 7- to 9-Month-Olds Track Statistical Probabilities in Continuous Dynamic Events. *Psychological Science*, *22*(11), 1422–1424. https://doi.org/10.1177/0956797611422074

Rosenqvist, J., Lahti-Nuuttila, P., Laasonen, M., & Korkman, M. (2014). Preschoolers’ recognition of emotional expressions: Relationships with other neurocognitive capacities. *Child Neuropsychology*, *20*(3), 281–302. https://doi.org/10.1080/09297049.2013.778235

Rossion, B., & Caharel, S. (2011). ERP evidence for the speed of face categorization in the human brain: Disentangling the contribution of low-level visual cues from face perception. *Vision Research*, *51*(12), 1297–1311. https://doi.org/10.1016/j.visres.2011.04.003

Ruba, A. L., Johnson, K. M., Harris, L. T., & Wilbourn, M. P. (2017). Developmental changes in infants' categorization of anger and disgust facial expressions. *Developmental Psychology*, *53*(10), 1826–1832. https://doi.org/10.1037/dev0000381

Sacco, D. F., Wirth, J. H., Hugenberg, K., Chen, Z., & Williams, K. D. (2011a). The world in black and white: Ostracism enhances the categorical perception of social information. *Journal of Experimental Social Psychology*, *47*(4), 836–842. https://doi.org/10.1016/j.jesp.2011.03.001

Sacco, D. F., Wirth, J. H., Hugenberg, K., Chen, Z., & Williams, K. D. (2011b). The world in black and white: Ostracism enhances the categorical perception of social information. *Journal of Experimental Social Psychology*, *47*(4), 836–842. https://doi.org/10.1016/j.jesp.2011.03.001

Saffran, J. R. (2018). Statistical learning as a window into developmental disabilities. *Journal of Neurodevelopmental Disorders*, *10*(1), 35. https://doi.org/10.1186/s11689-018-9252-y

Saffran, J. R., Aslin, R. N., & Newport, E. L. (1996a). Statistical Learning by 8-Month-Old Infants. *Science*, *274*(5294), 1926–1928. https://doi.org/10.1126/science.274.5294.1926

Saffran, J. R., Aslin, R. N., & Newport, E. L. (1996b). Statistical Learning by 8-Month-Old Infants. *Science*, *274*(5294), 1926–1928. https://doi.org/10.1126/science.274.5294.1926

Saffran, J. R., Johnson, E. K., Aslin, R. N., & Newport, E. L. (1999). Statistical learning of tone sequences by human infants and adults. *Cognition*, *70*(1), 27–52. https://doi.org/10.1016/S0010-0277(98)00075-4

Saffran, J. R., & Kirkham, N. Z. (2018). Infant Statistical Learning. *Annual Review of Psychology*, *69*(1), 181–203. https://doi.org/10.1146/annurev-psych-122216-011805

Saffran, J. R., Pollak, S. D., Seibel, R. L., & Shkolnik, A. (2007). Dog is a dog is a dog: Infant rule learning is not specific to language. *Cognition*, *105*(3), 669–680. https://doi.org/10.1016/j.cognition.2006.11.004

Saylor, M. M., Baldwin, D. A., Baird, J. A., & LaBounty, J. (2007). Infants' On-line Segmentation of Dynamic Human Action. *Journal of Cognition and Development*, *8*(1), 113–128. https://doi.org/10.1080/15248370709336996

Schyns, P. G., Petro, L. S., & Smith, M. L. (2007). Dynamics of Visual Information Integration in the Brain for Categorizing Facial Expressions. *Current Biology*, *17*(18), 1580–1585. https://doi.org/10.1016/j.cub.2007.08.048

Smith, M. L., Cottrell, G. W., Gosselin, F., & Schyns, P. G. (2005). Transmitting and Decoding Facial Expressions. *Psychological Science*, *16*(3), 184–189. https://doi.org/10.1111/j.0956-7976.2005.00801.x

Song, R., Over, H., & Carpenter, M. (2015). Children draw more affiliative pictures following priming with third-party ostracism. *Developmental Psychology*, *51*(6), 831–840. https://doi.org/10.1037/a0039176

Stahl, A. E., Romberg, A. R., Roseberry, S., Golinkoff, R. M., & Hirsh-Pasek, K. (2014). Infants Segment Continuous Events Using Transitional Probabilities. *Child Development*, n/a-n/a. https://doi.org/10.1111/cdev.12247

Tager-Flusberg, H. (2010). The origins of social impairments in autism spectrum disorder: Studies of infants at risk. *Neural Networks*, *23*(8–9), 1072–1076. https://doi.org/10.1016/j.neunet.2010.07.008

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. https://doi.org/10.1111/cdev.12348

Teinonen, T., Fellman, V., Näätänen, R., Alku, P., & Huotilainen, M. (2009). Statistical language learning in neonates revealed by event-related brain potentials. *BMC Neuroscience*, *10*(1), 21. https://doi.org/10.1186/1471-2202-10-21

Thiele, M., Hepach, R., Michel, C., Gredebäck, G., & Haun, D. B. M. (2021). Social interaction targets enhance 13-month-old infants' associative learning. *Infancy*, *26*(3), 409–422. https://doi.org/10.1111/infa.12393

Tottenham, N., Tanaka, J. W., Leon, A. C., McCarry, T., Nurse, M., Hare, T. A., Marcus, D. J., Westerlund, A., Casey, B., & Nelson, C. (2009). The NimStim set of facial expressions: Judgments from untrained research participants. *Psychiatry Research*, *168*(3), 242–249. https://doi.org/10.1016/j.psychres.2008.05.006

Twenge, J. M., Baumeister, R. F., Tice, D. M., & Stucke, T. S. (2001). If you can't join them, beat them: Effects of social exclusion on aggressive behavior. *Journal of Personality and Social Psychology*, *81*(6), 1058–1069. https://doi.org/10.1037/0022-3514.81.6.1058

Vacaru, S. V., van Schaik, J. E., de Water, E., & Hunnius, S. (2020). Five-year-olds' facial mimicry following social ostracism is modulated by attachment security. *PLOS ONE*, *15*(12), e0240680. https://doi.org/10.1371/journal.pone.0240680

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. https://doi.org/10.1037/0033-2909.134.3.383

van Heijnsbergen, C. C. R. J., Meeren, H. K. M., Grèzes, J., & de Gelder, B. (2007). Rapid detection of fear in body expressions, an ERP study. *Brain Research*, *1186*, 233–241. https://doi.org/10.1016/j.brainres.2007.09.093

Vicari, S., Reilly, J. S., Pasqualetti, P., Vizzotto, A., & Caltagirone, C. (2000). Recognition of facial expressions of emotions in school-age children: The intersection of perceptual and semantic categories. *Acta Paediatrica*, *89*(7), 836–845. https://doi.org/10.1111/j.1651-2227.2000.tb00392.x

Vlach, H. A., & Johnson, S. P. (2013). Memory constraints on infants’ cross-situational statistical learning. *Cognition*, *127*(3), 375–382. https://doi.org/10.1016/j.cognition.2013.02.015

Vuilleumier, P., & Pourtois, G. (2007). Distributed and interactive brain mechanisms during emotion face perception: Evidence from functional neuroimaging. *Neuropsychologia*, *45*(1), 174–194. https://doi.org/10.1016/j.neuropsychologia.2006.06.003

Warburton, W. A., Williams, K. D., & Cairns, D. R. (2006a). When ostracism leads to aggression: The moderating effects of control deprivation. *Journal of Experimental Social Psychology*, *42*(2), 213–220. https://doi.org/10.1016/j.jesp.2005.03.005

Warburton, W. A., Williams, K. D., & Cairns, D. R. (2006b). When ostracism leads to aggression: The moderating effects of control deprivation. *Journal of Experimental Social Psychology*, *42*(2), 213–220. https://doi.org/10.1016/j.jesp.2005.03.005

Watson-Jones, R. E., Legare, C. H., Whitehouse, H., & Clegg, J. M. (2014). Task-specific effects of ostracism on imitative fidelity in early childhood. *Evolution and Human Behavior*, *35*(3), 204–210. https://doi.org/10.1016/j.evolhumbehav.2014.01.004

Watson-Jones, R. E., Whitehouse, H., & Legare, C. H. (2016). In-Group Ostracism Increases High-Fidelity Imitation in Early Childhood. *Psychological Science, 27*(1), 34–42. https://doi.org/10.1177/0956797615607205

Widen, S. C., & Russell, J. A. (2008). Children acquire emotion categories gradually. *Cognitive Development*, *23*(2), 291–312. https://doi.org/10.1016/j.cogdev.2008.01.002

Widen, S. C., & Russell, J. A. (2010). Differentiation in preschooler's categories of emotion. *Emotion*, *10*(5), 651–661. https://doi.org/10.1037/a0019005

Wieser, M. J., & Brosch, T. (2012). Faces in Context: A Review and Systematization of Contextual Influences on Affective Face Processing. *Frontiers in Psychology, 3*. https://doi.org/10.3389/fpsyg.2012.00471

Wieser, M. J., Gerdes, A. B. M., Büngel, I., Schwarz, K. A., Mühlberger, A., & Pauli, P. (2014). Not so harmless anymore: How context impacts the perception and electrocortical processing of neutral faces. *NeuroImage*, *92*, 74–82. https://doi.org/10.1016/j.neuroimage.2014.01.022

Williams, K. D. (2007). Ostracism. *Annual Review of Psychology*, *58*(1), 425–452. https://doi.org/10.1146/annurev.psych.58.110405.085641

Williams, K. D. (2009). Ostracism: A Temporal Need-Threat Model. In *Advances in Experimental Social Psychology* (Vol. 41, pp. 275–314). Elsevier. https://doi.org/10.1016/S0065-2601(08)00406-1

Williams, K. D., Cheung, C. K. T., & Choi, W. (2000). Cyberostracism: Effects of being ignored over the Internet. *Journal of Personality and Social Psychology*, *79*(5), 748–762. https://doi.org/10.1037/0022-3514.79.5.748

Williams, K. D., & Nida, S. A. (2011a). Ostracism: Consequences and Coping. *Current Directions in Psychological Science, 20*(2), 71–75. https://doi.org/10.1177/0963721411402480

Williams, K. D., & Nida, S. A. (2011b). Ostracism: Consequences and Coping. *Current Directions in Psychological Science*, *20*(2), 71–75. https://doi.org/10.1177/0963721411402480

Wölfer, R., & Scheithauer, H. (2013). Ostracism in childhood and adolescence: Emotional, cognitive, and behavioral effects of social exclusion. *Social Influence*, *8*(4), 217–236. https://doi.org/10.1080/15534510.2012.706233

Yan, X., Andrews, T. J., & Young, A. W. (2016). Cultural similarities and differences in perceiving and recognizing facial expressions of basic emotions. *Journal of Experimental Psychology: Human Perception and Performance*, *42*(3), 423–440. https://doi.org/10.1037/xhp0000114

Zadro, L., & Gonsalkorale, K. (2014). Sources of Ostracism: The Nature and Consequences of Excluding and Ignoring Others. *Current Directions in Psychological Science*, *23*(2), 93–97. https://doi.org/10.1177/0963721413520321

Zadro, L., Hawes, D. J., Iannuzzelli, R. E., Godwin, A., MacNevin, G., Griffiths, B., & Gonsalkorale, K. (2013). Ostracism and Children: A Guide to Effectively Using the Cyberball Paradigm With a Child Sample. *International Journal of Developmental Science*, *7*(1), 7–11. https://doi.org/10.3233/DEV-1312112

Chapter 2: Emotional actions exert an influence on infants' neural processing of emotional faces

Introduction

Being able to accurately detect and identify others' emotions is essential for successful interpersonal relationships. It allows us to infer others' internal states, predict their upcoming actions, and adjust our own behavior accordingly (Frith, 2009; Horstmann, 2003). In the last decades, researchers have considered facial expressions to be the main way of communicating emotions in humans, often neglecting other forms of emotional expression by using stimuli representing isolated faces to investigate emotion processing (Geangu et al., 2011; Hoehl et al., 2008; Hunnius et al., 2011b). Nonetheless, this does not constitute an accurate representation of real-life emotional communication, where facial expressions are usually embedded in a social context (Aviezer et al., 2017). Indeed, in everyday interactions, emotional faces are often accompanied by various other emotional cues such as vocal tones, body postures or body movements, which are likewise useful sources of emotional information.

More recently, several studies indicated that the ability to extract and discriminate the emotional content of different types of emotional cues is acquired early in development, as illustrated by infants' differential visual and neural responses to various emotional faces (Hunnius et al., 2011; Leppänen et al., 2007), body postures (Geangu & Vuong, 2020; Missana et al., 2014), and vocal tones (Grossmann, 2010). In addition to being able to extract emotional content from different modalities (e.g., visual and auditory) and forms of emotional expressions (e.g., body postures and faces) independently, infants seem to be capable of integrating the emotional information across modalities and forms. Indeed, several studies examining infants' looking times suggested that they could match emotional faces and body movements with the corresponding vocal tones (i.e., for happy and angry emotions; Heck et al., 2018; Palama et al., 2018; Zieber et al., 2014), and detect the correspondence between emotions from static body postures and faces (i.e., for happy, sad and angry emotions; Hock et al., 2017). This intermodal matching was also recently evidenced at the neural level in two studies examining event-related potentials (ERPs) previously shown to be modulated in response to different emotional facial expressions (Hoehl & Striano, 2008; Kobiella et al., 2008; Leppänen et al., 2007; Peltola et al., 2009), such as the P1, Nc, Pc, N290 and P400 components. In the first study, Grossman and colleagues (2006) examined the variations in amplitude of the Nc and Pc components in response to matching and mismatching emotional face-voice pairings in 7-month-olds (for angry and happy emotions). Results indicated an enhanced Pc in response to matching face-voice parings, and an enhanced Nc amplitude in response to mismatching face-voice pairings. Thus, it seems like infants detected the common emotion expressed by faces and voices in the matching condition, and allocated more attention when the two emotions were mismatched. In the same vein, Rajhans and colleagues (2016) used a priming paradigm in which 8-months-old infants first observed fearful or happy body postures, followed by matching or mismatching facial emotional expressions. Although they did not find any modulation of the P1, N290 and P400 components, a difference in Nc and Pc was observed in response to fearful and happy facial emotions, in the matching condition only. According to the authors, these results suggest that the observation of mismatching emotional body expressions impaired the subsequent neural discrimination of emotional faces, preventing infants to differentiate happy from fearful faces. Thus, both when present under the form of concomitant voice pairings and body posture primes, the social context modulated infants' allocation of attention and memory of emotional faces at the neural level. These findings suggest that infants possess neural mechanisms supporting the integration of emotional information across modalities (e.g., visual and auditory; Grossmann et al., 2006) and types of emotional expressions (e.g., faces, body postures; Rajhans et al., 2016).

While several recent studies started to explore infants' processing of emotions and their ability to integrate emotional information across modalities, most research has focused on static representations of emotions, such as photographs of faces or body postures. In fact, literature examining infants’ ability to extract emotional content from movement kinematics is extremely scarce. Yet, every day they witness adults performing actions whose kinematics noticeably reflect the agent’s emotional state, by their velocity, acceleration, and jerkiness (Pollick et al., 2001). A few studies suggested that infants and children are capable of picking up emotional information from body movements, as indicated by their differential neural response to dynamic point-light-displays of happy, angry and fearful body expressions (Ke et al., preprint 2021; Missana et al., 2015). However, only one study so far investigated infants’ sensitivity to emotional cues conveyed in the kinematic properties of an action. In this study, Addabbo and colleagues (2020) measured 11-month-olds’ facial electromyographic (EMG) activity while they watched video clips of an agent moving an object with either happy or angry kinematics. They found that infants matched their facial expressions to the different emotional kinematics they observed (i.e., increased zygomaticus activity in response to happy kinematics, and increased corrugator activity in response to angry kinematics).

While these results suggest that infants are able to extract the emotional content of the actions based on their kinematic properties, they do not provide any information on its potential integration to other sources of emotional information, such as emotional face expressions. Nonetheless, in everyday life, sources of external emotional information are multiple. Being able to extract the emotional content of these different sources (e.g., faces and kinematics) and to integrate them can provide important additional cues and facilitate the understanding of other’s internal states. Our study aimed at investigating whether infants are indeed capable of extracting emotional information from action kinematics, and whether they are capable of integrating the emotional content of action kinematics and facial expressions. In addition, by examining infants' ERP response, we aimed at providing a direct measure of the neural processes involved in this integration at the perceptual, attentional, and memory level.

To address this question, we used a priming paradigm in which 11- to 12-month-old infants were presented with prime videos of actions performed either with happy or angry kinematics, followed by target images of faces displaying happy or angry facial expressions. Priming designs have been shown to be effective on developmental populations (Stupica & Cassidy, 2014), and several recent studies examining intermodal matching in infancy have proven its efficacy (Geangu et al., 2021; Grossmann et al., 2006; Peykarjou et al., 2020; Rajhans et al., 2016). We chose to test children of 11- and 12-month-old based on Addabbo and colleagues' work (2021), which suggested that 11-month-olds are capable of extracting emotional information from action kinematics. Similarly to previous research on infants' emotional processing and intermodal matching using priming paradigms, we chose to examine three well-known ERP components: the P1, reflecting early-stage visual processing (Curtis & Cicchetti, 2013; Leppänen et al., 2007b), the Negative Central (Nc) component, reflecting allocation of attentional resources (De Haan et al., 2002), and the Positive component (Pc), indexing the recognition of a stimulus (Grossmann et al., 2006). We predicted that priming effects would be visible on the neural response to emotional faces. More particularly, we expected emotional action kinematics to modulate infants' allocation of attention (i.e., Nc component) and memory (i.e., Pc component) of emotional faces, similarly to what was observed in previous studies from Grossman and colleagues (2006) and Rajhans and colleagues (2016). We also expected to find priming effects at the level of infants' early visual processing (i.e., P1), similarly to what was found in studies exploring subliminal affective priming in adults (Li et al., 2008).

Methods

Participants

The sample consisted of 10 healthy 11- to 12-month-old infants (5 females; M = 358.3 days; SD = 19.21 days), born full-term (37–42 weeks of gestation) and with normal birthweight (> 2,500 g). As the pandemic considerably slowed down data collection, this sample is preliminary, and data collection is still ongoing. An additional 12 infants were tested but excluded from the final sample due to fussiness (N = 5), excessive artifacts (N = 6), or technical errors (N = 1). This attrition rate is within normal range for ERP studies on 12-month-old infants (Grossmann et al., 2007). A minimum of 10 artifact-free trials per condition (i.e., congruent versus incongruent) was required to proceed to further analysis. Participants were recruited via written invitation based on birth records of neighboring cities. Written informed consent was given by the parent or caretaker of the infants prior to testing. The protocol followed the ethical standards of the Declaration of Helsinki (BMJ 1991; 302:1194) and was approved by the ethical committee of the University of Milano-Bicocca (Protocol number: 421).

Stimuli

Stimuli consisted of priming videos of actions performed with angry or happy emotional kinematics, and of photographs of faces expressing anger or happiness. Emotions of anger and happiness were chosen for their very distinct kinematic properties (higher peak velocity, acceleration, and jerkiness for anger than happiness; Sawada et al., 2003), and based on previous research suggesting that infants reliably discriminate them when displayed by faces or body movements (Ke et al., preprint 2021; Leppänen et al., 2007; Quadrelli et al., 2019; Soken & Pick, 2021). Emotional kinematic videos were taken from the stimuli set used by Addabbo and colleagues (2020) and depicted a female actress picking up an object from one side of a table to move it into a box on the other side of that table (see Figure 1). The actress, whose face was not visible, was seated behind the table on which the object and the box were placed. The action was carried out by two different models selected based on high recognition rates (average recognition rate of 84% for happy kinematics, and 96% for angry kinematics; Addabbo et al., 2020), each model moving two different objects in the box. The direction of the movement (i.e., object moved from right to left, or left to right) was counterbalanced for both angry and happy emotional kinematics. The videos taken from Addabbo and colleagues' study were cut to have a shorter total duration of 1700 ms.

Following the presentation of the priming videos, colored photographs of female faces expressing happiness or anger were displayed. The photographs were taken from the validated BU-3DFE database (Yin et al., 2006), and three different female models were selected, based on high recognition rates (average recognition rate of 100% for happy faces, and 86% for angry faces). Similar to previous studies, the photographs were cropped using Adobe Photoshop software so that only the internal features of the face were visible within an oval shape (Rajhans et al., 2016).

Fig. 1. Example of frames from the priming videos depicting an actress picking up an object from one side of a table to move it into a box on the other side of that table.

Design

The design employed was similar to that of Rajhans and colleagues (2016). Infants were first primed with videos of actions performed with either happy or angry kinematics, followed by photographs of faces expressing either congruent (i.e., matching) or incongruent (i.e., mismatching) emotions (Figure 2). Thus, the congruent condition encompassed angry kinematics followed by angry faces, as well as happy kinematics followed by happy kinematics. Inversely, the incongruent condition encompassed angry kinematics followed by happy faces, as well as happy kinematics followed by angry faces. For each emotion, the action was carried out by two different models, and each model performed the movement in two different directions, leading to 4 possible action videos. As for the photographs of emotional faces, each emotion was expressed by 3 different models. All possible combinations of emotional actions and emotional faces were presented, leading to 12 combinations per sub-condition (e.g., 12 combinations of angry kinematics followed by angry faces). Thus, 24 combinations were presented for each of the congruent and the incongruent condition, for a total of 48 combinations. Each of these combinations was presented up to four times, for a maximum of 192 trials, or until the infant was too tired or fussy to continue.

Each trial started with the display of a white fixation cross on a black background for 500 ms, followed by the presentation of the prime video for 1700 ms. A fixation cross was then displayed for a random duration of 200 to 400 ms, followed by the presentation of the static emotional face for 1000 ms. The inter-trial interval consisted in a black screen, displayed for a random duration of 500 to 100 ms (Figure 2). All stimuli were presented in a random order, with the constraint that a same sub-condition could not be presented more than twice in a row.

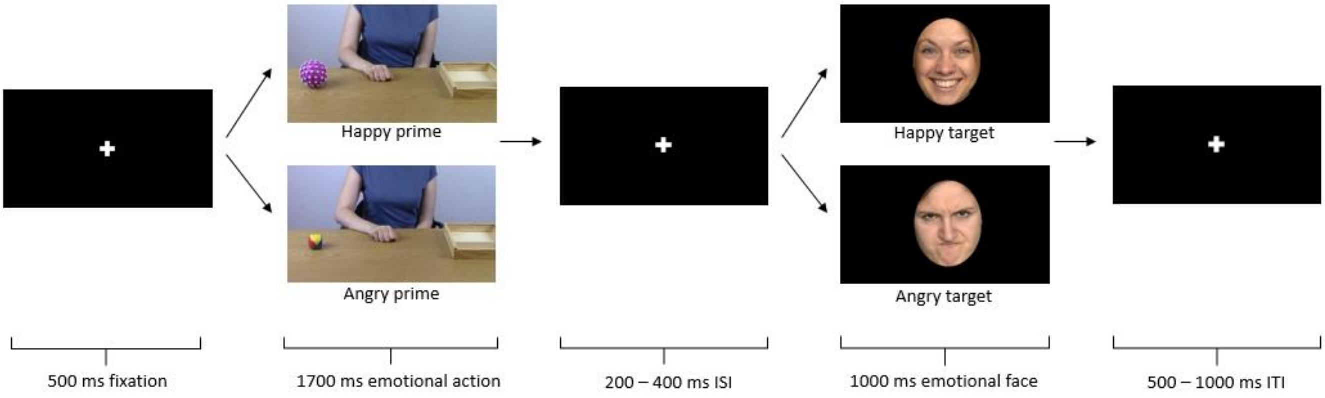

Fig. 2. Example of the priming design and stimuli used in the study. Infants are first primed with actions performed with happy or angry kinematics, and are then presented with target photographs of faces expressing either congruent or incongruent emotions.

Procedure and apparatus

Infants seated on their caregiver’s lap, in an electrically shielded and sound-proofed cabin. Stimuli were displayed on a 24-inch monitor positioned at approximately 60 cm from the infant’s eyes. They were displayed using the software E-Prime v2.0 (Psychology Software Tools Inc., Pittsburgh, PA). Prior to stimuli presentation, parents were instructed to avoid talking to the infant or pointing to the monitor, and remain as still as possible for the entire procedure. The infant’s face and body were recorded during the whole experiment using an infrared video camera hidden over the monitor, which fed into the data acquisition computer and TV monitor located outside the cabin. This allowed the experimenter to orient the infant’s attention back to the monitor by displaying an attention getter (i.e., a moving colored fixation point) whenever he or she was distracted, or to interrupt the study when he or she was getting too tired or fussy.

EEG acquisition and processing

We recorded the electroencephalograms (EEG) using a 128-electrode HydroCel Geodesic Sensor Net (Electrical Geodesic Inc., Eugene, OR). The data was referenced online to the vertex electrode (Cz) and amplified through an EGI NetAmps 300 amplifier at a sample rate of 500 Hz. An online band-pass filter of 0.1-100 Hz was applied. Prior to stimuli presentation, impedance values were inspected, so that any channel exceeding a threshold of 50 KΩ could be adjusted on the infant’s head. If still above threshold, the channel was interpolated during the following processing stage. Data processing was carried out on the NetStation software v4.6.4 (Eugene, OR). Continuous signals were bandpass filtered at 0.3-30 Hz and segmented into epochs comprising 100 ms of baseline and 1000 ms of the target stimulus presentation. Data were then re-referenced to the algebraic mean of all channels. Automatic artifact detection was first performed on segmented data to reject any signal exceeding ± 200 μV in a sliding window of 80 ms. Data were then visually inspected to eliminate any remaining artifact. Any trial containing more than 15% of the channels marked as bad was excluded from further analysis, and among the remaining trials, channels containing artifacts were replaced using spherical spline interpolation. An average of 18.3 trials were included in the ERP analysis for the congruent condition (M = 9.4 for angry prime and target, M = 8.9 for happy prime and target), and of 17.5 for the incongruent condition (M = 8.4 for angry prime followed by happy target, M = 9.1 for happy prime followed by angry target).

Inspection of the grand-average waveforms over fronto-central regions revealed a well-defined Nc attentional component and a well-defined Pc memory component. Two clusters of electrodes were selected, over the left (24, 28, 29, 34, 35, 36, 40, 41, 42, 47) and right central regions (93, 98, 103, 104, 109, 110, 111, 116, 117, 124). Based on visual inspection of the components' peaks and on previous studies examining infants' Nc and Pc components (Grossmann et al., 2007; Quadrelli et al., 2019; Rajhans et al., 2016), time windows of respectively 350-600 ms and a 600-750 ms were selected. A well-defined P1 early visual component was also observed over the occipital electrodes. Two clusters of electrodes in the left (64, 65, 69) and right (89, 90, 95) occipital-lateral region, and in the left (66, 70, 71, 74) and right (76, 82, 83, 84) occipital-medial regions were selected. In accordance with previous infant ERP studies (Leppänen et al., 2007; Quadrelli et al., 2019), a time window of 100-200 ms was chosen for the P1 component. For each of these three components, mean amplitudes (µV) values were measured and submitted to statistical analyses.

Data analysis

Statistical analyses were performed using the software Jamovi (version 1.6.15; http://jamovi.org). All statistical tests were conducted on a two-tailed .05 level of significance. Pairwise comparisons were performed using t-tests and the Fisher's least significant difference procedure (Howell, 2006). The Greenhouse-Geisser correction for non-sphericity was applied when appropriate, and effect sizes were estimated using the partial eta square measure (η_p^2). Mean amplitudes of the P1, Nc and Pc components were analyzed in separate 2*2*2 repeated measures Analyses of Variance (ANOVAs) with emotion (anger, happiness), condition (congruent, incongruent) and hemispheres (left, right) as within-subject factors. Data are reported as the mean and the standard deviation (SD).

Results

P1

The ANOVA performed on the P1 component at the occipital-lateral electrodes did not reveal any significant main effect of congruence, $F(1,9) = 2.60$, $p = 0.14$, $\eta^2_p = 0.023$, emotion, F(1,9) = 0.20, $p = 0.66$, $\eta^2_p = 0.001$ or hemisphere, $F(1,9) = 0.31$, $p = 0.59$, $\eta^2_p = 0.003$. However, a significant interaction was found between congruence and emotion, $F(1,9) = 15.06$, $p = 0.004$, $\eta^2_p = 0.059$. Post-hoc t-tests showed differences in P1 amplitudes both in response to angry faces primed with happy action kinematics, $t(9)= 3.59$, $p = 0.03$ and happy faces primed with happy action kinematics, $t(9)= 3.22$, $p = 0.05$, as compared to happy faces primed with angry kinematics. Indeed, P1 amplitudes in response to angry and happy faces primed with happy action kinematics ($M = 7.13$, $SD = 9.13$ and $M = 10.14$, $SD = 13.65$ respectively) were larger than P1 amplitudes in response to happy faces primed with angry action kinematics ($M = 0.58$, $SD = 13.25$; Figure 3). However, the ANOVA performed on the P1 component at occipital-medial electrodes did not reveal any congruency effects, $F(1,9) = 1.98$, $p = 0.19$, $\eta^2_p = 0.023$. In addition, there was no significant main effect of emotion, $F(1,9) = 2.23$, $p = 0.17$, $\eta^2_p = 0.003$, and no significant interaction between congruency and emotion, $F(1,9) = 2.44$, $p = 0.15$, $\eta^2_p = 0.024$.

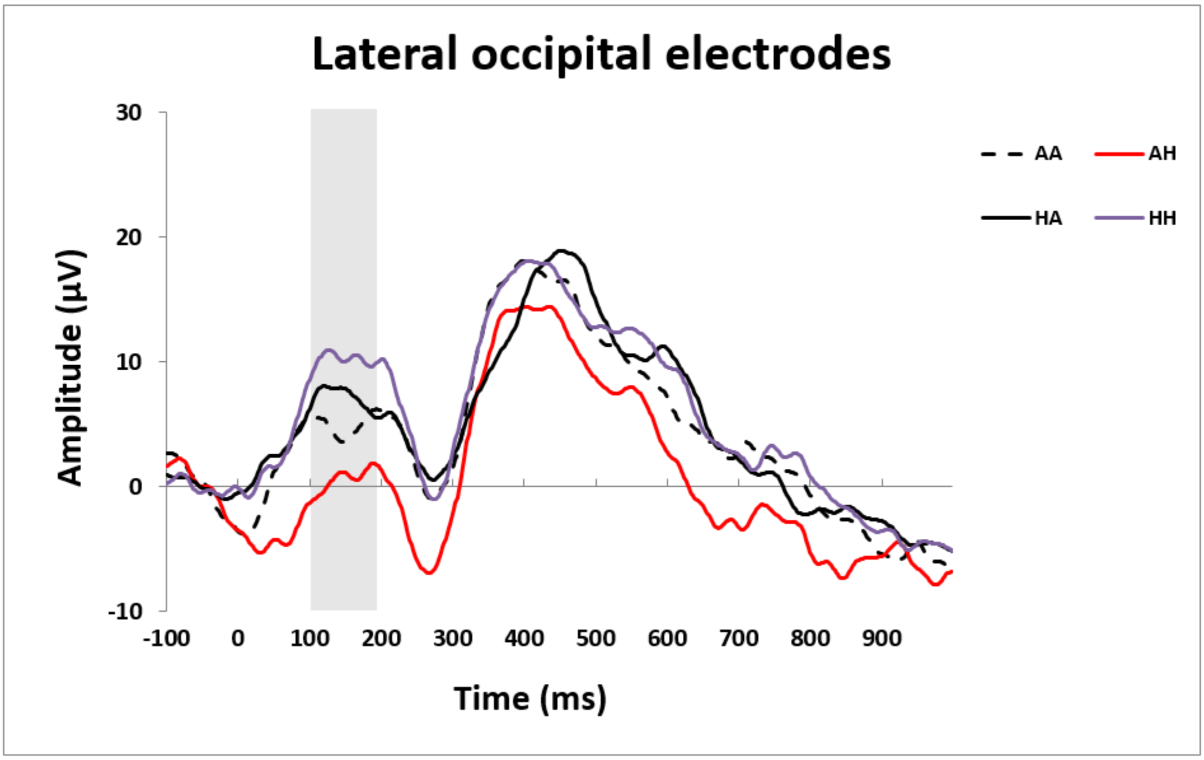

Fig. 3. Grand average waveforms depicting the P1 (100-200 ms) ERP component at occipital lateral electrodes in response to angry faces primed with angry kinematics (AA), angry faces primed with happy kinematics (HA), Happy faces primed with happy kinematics (HH), and happy faces primed with angry kinematics (AH).

Nc

The ANOVA performed on the Nc component did not reveal any congruency effects, $F(1,9) = 0.045$, $p = 0.84$, $\eta^2_p = 0.00$. In addition, there was no significant main effect of emotion, $F(1,9) = 0.56$, $p = 0.47$, $\eta^2_p = 0.003$, and no significant interaction between congruency and emotion, $F(1,9) = 1.29$, $p = 0.29$, $\eta^2_p = 0.007$.

Pc

The ANOVA performed on the Pc component did not reveal any congruency effects, $F(1,9) = 0.39$, $p = 0.55$, $\eta^2_p = 0.003$. In addition, there was no significant main effect of emotion, $F(1,9) =1.35$, $p = 0.28$, $\eta^2_p = 0.007$, and no significant interaction between congruency and emotion, $F(1,9) = 1.22$, $p = 0.30$, $\eta^2_p = 0.008$.

Discussion

The current study aimed at investigating infants' capacity to integrate emotional information across action kinematics and facial expressions and examined the neural mechanisms underlying this ability. Results revealed a modulation of the P1, an ERP component reflecting early-stage visual processing. In particular, the P1 component was larger in response to angry and happy faces primed with happy action kinematics than happy faces primed with angry action kinematics. Thus, it seems that happy action kinematics, by signaling the presence of a positive and pleasant stimulus, might have promoted the subsequent visual processing of emotional faces, irrespective of the facial emotion expressed. In adults, P1 responses to emotional target faces were enhanced when primed with fearful compared to happy subliminal facial expressions (Li et al., 2008). This result was interpreted as facilitation of early perceptual encoding of the target face by threatening priming stimuli. Differently, our results suggest that in infancy, positive information is more powerful in promoting the visual processing of emotional faces. Overall, our finding supports recent views proposing that the social context in which emotional expressions are embedded strongly influences their processing (Aviezer et al., 2017). Nonetheless, our sample size being very small (N = 10), these results are only preliminary and the sample size needs to be considerably increased in order to draw reliable conclusions. Contrary to our hypothesis, we did not observe any priming effect for the other ERP components. Specifically, we expected emotional action kinematics to influence infants' allocation of attention (i.e., Nc component) and memory (i.e., Pc component) of emotional faces, similarly to what was observed in previous studies (Grossmann et al., 2007; Rajhans et al., 2016). We had two hypotheses regarding the direction of this modulation. The first hypothesis derived from the findings of Grossman et al. (2006) and predicted that the observation of faces emotionally congruent with action kinematics would elicit a larger Pc, and the observation of faces emotionally incongruent with action kinematics would elicit a larger Nc. An enhanced Pc in the congruent condition would indicate that infants recognized and remembered that the emotion expressed on faces was the same as the emotion previously expressed in action kinematics. On the other hand, an enhanced Nc in incongruent condition would reflect an increased allocation of attention to facial emotions that did not match the action kinematics previously observed, evidencing that infants noticed the mismatch of emotions. The second hypothesis was formulated after Meeren et al. (2005) and Rajhans et al. (2016) and predicted that the amplitudes of the Pc and Nc components would differ between happy and angry faces in the congruent, but not in the incongruent condition. These variations in Pc and Nc would reflect differential attentional and memory responses, evidencing infants' ability to discriminate the two facial emotions in the congruent condition. However, the absence of difference would indicate that the observation of incongruent action kinematics impaired the subsequent neural discrimination of emotional faces, similarly to what was previously observed with body expressions in adults (Meeren et al., 2005) and infants (Rajhans et al., 2016). Although reflected by different neural modulations, both hypotheses implied that infants were able to extract, discriminate, and integrate emotions conveyed through action kinematics and faces.

Nevertheless, we did not observe such modulation of the Nc and Pc components. The absence of congruency effect on the ERP responses might reflect infants' incapacity to integrate emotions across action kinematics and facial expressions, despite their ability to extract the emotional information from both forms of emotional expression independently. Alternatively, even though the difference in the P1 component suggests that infants could discriminate angry and happy kinematics, they might not have been able to assimilate their emotional value and contrast it to the one expressed on emotional faces. Nonetheless, our sample size being very small (N = 10), and consequently, the statistical power very low, we cannot draw a firm conclusion about this absence of effect on the Nc and Pc components.

Our results constitute a first indication at the neural level that infants are capable of discriminating emotional information from kinematic properties, supporting the behavioral findings of Addabbo and colleagues (2020). In addition, our finding adds new insights to the current literature by showing that emotional information conveyed by action kinematics provides infants with contextual emotional cues that can influence and bias their attention at very early stages of visual processing. While these preliminary results are rather encouraging, they are very limited by the small sample size, and cannot be used to support or refute any hypothesis. Data collection is currently proceeding, and data will be analyzed again once we have a sufficiently large sample size. The analysis of the final results will be of great interest and could allow a better understanding of infants' capacity to extract and integrate emotional information from action kinematics and facial expressions and provide insights into the neural mechanisms underlying this ability.

This chapter, although based on preliminary results, suggests that emotional contextual cues presented under the form of priming action kinematics influence 12-months-olds' subsequent neural response, in particular their early visual processing of emotional faces in.

References

Abrams, D., Weick, M., Thomas, D., Colbe, H., & Franklin, K. M. (2011). On-line ostracism affects children differently from adolescents and adults: Ostracism: children, adolescents, adults. *British Journal of Developmental Psychology*, *29*(1), 110–123. https://doi.org/10.1348/026151010X494089

Ambadar, Z., Schooler, J. W., & Cohn, J. F. (2005). Deciphering the Enigmatic Face: The Importance of Facial Dynamics in Interpreting Subtle Facial Expressions. *Psychological Science*, *16*(5), 403–410. https://doi.org/10.1111/j.0956-7976.2005.01548.x

Aslin, R. N., Saffran, J. R., & Newport, E. L. (1998). Computation of Conditional Probability Statistics by 8-Month-Old Infants. *Psychological Science*, *9*(4), 321–324. https://doi.org/10.1111/1467-9280.00063

Augusti, E.-M., Melinder, A., & Gredebäck, G. (2010). Look who’s talking: Pre-verbal infants’ perception of face-to-face and back-to-back social interactions. *Frontiers in Psychology*, *1*. https://doi.org/10.3389/fpsyg.2010.00161

Aviezer, H., Ensenberg, N., & Hassin, R. R. (2017). The inherently contextualized nature of facial emotion perception. *Current Opinion in Psychology*, *17*, 47–54. https://doi.org/10.1016/j.copsyc.2017.06.006

Aviezer, H., Trope, Y., & Todorov, A. (2012). Body Cues, Not Facial Expressions, Discriminate Between Intense Positive and Negative Emotions. *Science*, *338*(6111), 1225–1229. https://doi.org/10.1126/science.1224313

Barrett, L. F., Mesquita, B., & Gendron, M. (2011). Context in Emotion Perception. *Current Directions in Psychological Science*, *20*(5), 286–290. https://doi.org/10.1177/0963721411422522

Batty, M., Meaux, E., Wittemeyer, K., Rogé, B., & Taylor, M. J. (2011). Early processing of emotional faces in children with autism: An event-related potential study. *Journal of Experimental Child Psychology, 109*(4), 430–444. https://doi.org/10.1016/j.jecp.2011.02.001

Baumeister, R. F., & Leary, M. R. (1995). The Need to Belong: Desire for Interpersonal Attachments as a Fundamental Human Motivation. *Psychological Bulletin, 117*(3), 34.

Baumeister, R. F., Twenge, J. M., & Nuss, C. K. (2002). Effects of social exclusion on cognitive processes: Anticipated aloneness reduces intelligent thought. *Journal of Personality and Social Psychology, 83*(4), 817–827. https://doi.org/10.1037/0022-3514.83.4.817

Bernstein, M. J., Young, S. G., Brown, C. M., Sacco, D. F., & Claypool, H. M. (2008). Adaptive Responses to Social Exclusion: Social Rejection Improves Detection of Real and Fake Smiles. *Psychological Science, 19*(10), 981–983. https://doi.org/10.1111/j.1467-9280.2008.02187.x

Bulf, H., Brenna, V., Valenza, E., Johnson, S. P., & Turati, C. (2015). Many faces, one rule: The role of perceptual expertise in infants' sequential rule learning. *Frontiers in Psychology, 6*. https://doi.org/10.3389/fpsyg.2015.01595

Bulf, H., Johnson, S. P., & Valenza, E. (2011). Visual statistical learning in the newborn infant. *Cognition*, *121*(1), 127–132. https://doi.org/10.1016/j.cognition.2011.06.010

Calder, A. J., Young, A. W., Perrett, D. I., Etcoff, N. L., & Rowland, D. (1996). Categorical Perception of Morphed Facial Expressions. *Visual Cognition*, *3*(2), 81–118. https://doi.org/10.1080/713756735

Camras, L. A., & Allison, K. (1985). Children's understanding of emotional facial expressions and verbal labels. *Journal of Nonverbal Behavior, 9*(2), 84–94. https://doi.org/10.1007/BF00987140

Carroll, J. M., & Russell, J. A. (1996). Do Facial Expressions Signal Specific Emotions? Judging Emotion From the Face in Context. *Journal of Personality and Social Psychology, 70*(2), 205.

Carter-Sowell, A. R., Chen, Z., & Williams, K. D. (2008). Ostracism increases social susceptibility. *Social Influence*, *3*(3), 143–153. https://doi.org/10.1080/15534510802204868

Cheung, E. O., Slotter, E. B., & Gardner, W. L. (2015). Are you feeling what I'm feeling? The role of facial mimicry in facilitating reconnection following social exclusion. *Motivation and Emotion*, *39*(4), 613–630. https://doi.org/10.1007/s11031-015-9479-9

Choudhury, S., Blakemore, S.-J., & Charman, T. (2006). Social cognitive development during adolescence. *Social Cognitive and Affective Neuroscience*, *1*(3), 165–174. https://doi.org/10.1093/scan/nsl024

Conte, S., Richards, J. E., Guy, M. W., Xie, W., & Roberts, J. E. (2020). Face-sensitive brain responses in the first year of life. *NeuroImage*, *211*, 116602. https://doi.org/10.1016/j.neuroimage.2020.116602

Csibra, G., Hernik, M., Mascaro, O., Tatone, D., & Lengyel, M. (2016). Statistical treatment of looking-time data. *Developmental Psychology*, *52*(4), 521–536. https://doi.org/10.1037/dev0000083

Curtis, W. J., & Cicchetti, D. (2013). Affective Facial Expression Processing in 15-Month-Old Infants Who Have Experienced Maltreatment: An Event-Related Potential Study. *Child Maltreatment*, *18*(3), 140–154. https://doi.org/10.1177/1077559513487944

Dawson, G., Webb, S. J., Carver, L., Panagiotides, H., & McPartland, J. (2004). Young children with autism show atypical brain responses to fearful versus neutral facial expressions of emotion. *Developmental Science, 7*(3), 340–359. https://doi.org/10.1111/j.1467-7687.2004.00352.x

De Haan, M., Johnson, M. H., & Halit, H. (2003). Development of face-sensitive event-related potentials during infancy: A review. *International Journal of Psychophysiology*, *51*(1), 45–58. https://doi.org/10.1016/S0167-8760(03)00152-1

de Haan, M., & Nelson, C. A. (1999). Brain Activity Differentiates Face and Object Processing in 6-Month-Old Infants. *Developmental Psychology*, *35*(4), 1113.

De Haan, M., Pascalis, O., & Johnson, M. H. (2002). Specialization of Neural Mechanisms Underlying Face Recognition in Human Infants. *Journal of Cognitive Neuroscience*, *14*(2), 199–209. https://doi.org/10.1162/089892902317236849

Dennis, T. A., Malone, M. M., & Chen, C.-C. (2009). Emotional Face Processing and Emotion Regulation in Children: An ERP Study. *Developmental Neuropsychology*, *34*(1), 85–102. https://doi.org/10.1080/87565640802564887

DeWall, C. N., Maner, J. K., & Rouby, D. A. (2009a). Social Exclusion and Early-Stage Interpersonal Perception: Selective Attention to Signs of Acceptance. *Journal of Personality and Social Psychology*, *96*(4), 729.

DeWall, C. N., Maner, J. K., & Rouby, D. A. (2009b). Social exclusion and early-stage interpersonal perception: Selective attention to signs of acceptance. *Journal of Personality and Social Psychology*, *96*(4), 729–741. https://doi.org/10.1037/a0014634

Di Lorenzo, R., van den Boomen, C., Kemner, C., & Junge, C. (2020). Charting development of ERP components on face-categorization: Results from a large longitudinal sample of infants. *Developmental Cognitive Neuroscience*, *45*, 100840. https://doi.org/10.1016/j.dcn.2020.100840

Dolan, R. J., Morris, J. S., & de Gelder, B. (2001). Crossmodal binding of fear in voice and face. *Proceedings of the National Academy of Sciences*, *98*(17), 10006–10010. https://doi.org/10.1073/pnas.171288598

D’Souza, J., & Gurin, M. (2016). The universal significance of Maslow’s concept of self-actualization. *The Humanistic Psychologist*, *44*(2), 210–214. https://doi.org/10.1037/hum0000027

Durand, K., Gallay, M., Seigneuric, A., Robichon, F., & Baudouin, J.-Y. (2007). The development of facial emotion recognition: The role of configural information. *Journal of Experimental Child Psychology*, *97*(1), 14–27. https://doi.org/10.1016/j.jecp.2006.12.001

Eisenberger, N. I., Lieberman, M. D., & Williams, K. D. (2003). *Does Rejection Hurt? An fMRI Study of Social Exclusion*. *302*, 3.

Ekman, P. (1992). An argument for basic emotions. *Cognition and Emotion*, *6*(3–4), 169–200. https://doi.org/10.1080/02699939208411068

Farroni, T., Menon, E., Rigato, S., & Johnson, M. H. (2007). The perception of facial expressions in newborns. *European Journal of Developmental Psychology*, *4*(1), 2–13. https://doi.org/10.1080/17405620601046832

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, *39*(2), 175–191. https://doi.org/10.3758/BF03193146

Fawcett, C., & Gredebäck, G. (2013). Infants use social context to bind actions into a collaborative sequence. *Developmental Science*, n/a-n/a. https://doi.org/10.1111/desc.12074

Gao, X., & Maurer, D. (2009). Influence of intensity on children’s sensitivity to happy, sad, and fearful facial expressions. *Journal of Experimental Child Psychology*, *102*(4), 503–521. https://doi.org/10.1016/j.jecp.2008.11.002

Gao, X., & Maurer, D. (2010). A happy story: Developmental changes in children’s sensitivity to facial expressions of varying intensities. *Journal of Experimental Child Psychology, 107*(2), 67–86. https://doi.org/10.1016/j.jecp.2010.05.003

Gardner, W. L., Pickett, C. L., & Brewer, M. B. (2000). Social Exclusion and Selective Memory: How the Need to belong Influences Memory for Social Events. *Personality and Social Psychology Bulletin*, *26*(4), 486–496. https://doi.org/10.1177/0146167200266007

Geangu, E., Hauf, P., Bhardwaj, R., & Bentz, W. (2011). Infant Pupil Diameter Changes in Response to Others’ Positive and Negative Emotions. *PLoS ONE*, *6*(11), e27132. https://doi.org/10.1371/journal.pone.0027132

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), R663–R664. https://doi.org/10.1016/j.cub.2016.05.072

Gebhart, A. L., Newport, E. L., & Aslin, R. N. (2009). Statistical learning of adjacent and nonadjacent dependencies among nonlinguistic sounds. *Psychonomic Bulletin & Review*, *16*(3), 486–490. https://doi.org/10.3758/PBR.16.3.486

Gendron, M., Mesquita, B., & Barrett, L. F. (2013). *Emotion Perception: Putting the Face in Context*. Oxford University Press. https://doi.org/10.1093/oxfordhb/9780195376746.013.0034

Gonsalkorale, K., & Williams, K. D. (2007). The KKK won’t let me play: Ostracism even by a despised outgroup hurts. *European Journal of Social Psychology, 37*(6), 1176–1186. https://doi.org/10.1002/ejsp.392

Grossmann, T., Striano, T., & Friederici, A. D. (2006). Crossmodal integration of emotional information from face and voice in the infant brain. *Developmental Science, 9*(3), 309–315. https://doi.org/10.1111/j.1467-7687.2006.00494.x

Grossmann, T., Striano, T., & Friederici, A. D. (2007). Developmental changes in infants' processing of happy and angry facial expressions: A neurobehavioral study. *Brain and Cognition*, *64*(1), 30–41. https://doi.org/10.1016/j.bandc.2006.10.002

Hannon, E. E., & Johnson, S. P. (2005). Infants use meter to categorize rhythms and melodies: Implications for musical structure learning. *Cognitive Psychology*, *50*(4), 354–377. https://doi.org/10.1016/j.cogpsych.2004.09.003

Hartgerink, C. H. J., van Beest, I., Wicherts, J. M., & Williams, K. D. (2015). The Ordinal Effects of Ostracism: A Meta-Analysis of 120 Cyberball Studies. *PLOS ONE*, *10*(5), e0127002. https://doi.org/10.1371/journal.pone.0127002

Hawes, D. J., Zadro, L., Fink, E., Richardson, R., O'Moore, K., Griffiths, B., Dadds, M. R., & Williams, K. D. (2012). The effects of peer ostracism on children's cognitive processes. *European Journal of Developmental Psychology*, *9*(5), 599–613. https://doi.org/10.1080/17405629.2011.638815

Hillyard, S. A., & Anllo-Vento, L. (1998). Event-related brain potentials in the study of visual selective attention. *Proceedings of the National Academy of Sciences*, *95*(3), 781–787. https://doi.org/10.1073/pnas.95.3.781

Hoehl, S., Palumbo, L., Heinisch, C., & Striano, T. (2008). *Infants' attention is biased by emotional expressions and eye gaze direction*. 4.

Hopkins, Z. L., & Branigan, H. P. (2020). Children show selectively increased language imitation after experiencing ostracism. *Developmental Psychology*, *56*(5), 897–911. https://doi.org/10.1037/dev0000915

Hunnius, S., de Wit, T. C. J., Vrins, S., & von Hofsten, C. (2011a). Facing threat: Infants' and adults' visual scanning of faces with neutral, happy, sad, angry, and fearful emotional expressions. *Cognition & Emotion*, *25*(2), 193–205. https://doi.org/10.1080/15298861003771189

Hunnius, S., de Wit, T. C. J., Vrins, S., & von Hofsten, C. (2011b). Facing threat: Infants' and adults' visual scanning of faces with neutral, happy, sad, angry, and fearful emotional expressions. *Cognition & Emotion*, *25*(2), 193–205. https://doi.org/10.1080/15298861003771189

Iidaka, T., Saito, D. N., Komeda, H., Mano, Y., Kanayama, N., Osumi, T., Ozaki, N., & Sadato, N. (2010). Transient Neural Activation in Human Amygdala Involved in Aversive Conditioning of Face and Voice. *Journal of Cognitive Neuroscience*, *22*(9), 2074–2085. https://doi.org/10.1162/jocn.2009.21347

Itier, R. J., & Taylor, M. J. (2002). Inversion and Contrast Polarity Reversal Affect both Encoding and Recognition Processes of Unfamiliar Faces: A Repetition Study Using ERPs. *NeuroImage*, *15*(2), 353–372. https://doi.org/10.1006/nimg.2001.0982

Izard, C. E. (1994). *Innate and Universal Facial Expressions: Evidence From Developmental and Cross-Cultural Research*. 288.

Jack, R. E., Garrod, O. G. B., Yu, H., Caldara, R., & Schyns, P. G. (2012). Facial expressions of emotion are not culturally universal. *Proceedings of the National Academy of Sciences*, *109*(19), 7241–7244. https://doi.org/10.1073/pnas.1200155109

Johnson, S. P., & Aslin, R. N. (1996). Perception of object unity in young infants: The roles of motion, depth, and orientation. *Cognitive Development*, *11*(2), 161–180. https://doi.org/10.1016/S0885-2014(96)90001-5

Kawamoto, T., Nittono, H., & Ura, M. (2014a). Social exclusion induces early-stage perceptual and behavioral changes in response to social cues. *Social Neuroscience*, *9*(2), 174–185. https://doi.org/10.1080/17470919.2014.883325

Kawamoto, T., Nittono, H., & Ura, M. (2014b). Social exclusion induces early-stage perceptual and behavioral changes in response to social cues. *Social Neuroscience*, *9*(2), 174–185. https://doi.org/10.1080/17470919.2014.883325

Kirkham, N. Z., Slemmer, J. A., & Johnson, S. P. (2002). Visual statistical learning in infancy: Evidence for a domain general learning mechanism. *Cognition*, *83*(2), B35–B42. https://doi.org/10.1016/S0010-0277(02)00004-5

Kirkham, N. Z., Slemmer, J. A., Richardson, D. C., & Johnson, S. P. (2007). Location, Location, Location: Development of Spatiotemporal Sequence Learning in Infancy. *Child Development*, *78*(5), 1559–1571. https://doi.org/10.1111/j.1467-8624.2007.01083.x

Kobiella, A., Grossmann, T., Reid, V. M., & Striano, T. (2008). The discrimination of angry and fearful facial expressions in 7-month-old infants: An event-related potential study. *Cognition and Emotion*, *22*(1), 134–146. https://doi.org/10.1080/02699930701394256

Koechlin, E. (1997). Numerical Transformations in Five-month-old Human Infants. *Mathematical Cognition*, *3*(2), 89–104. https://doi.org/10.1080/135467997387425

Kotsoni, E., de Haan, M., & Johnson, M. H. (2001). Categorical Perception of Facial Expressions by 7-Month-Old Infants. *Perception*, *30*(9), 1115–1125. https://doi.org/10.1068/p3155

Kuchuk, A., Vibbert, M., & Bornstein, M. H. (1986). The Perception of Smiling and Its Experiential Correlates in Three-Month-Old Infants. *Child Development*, 1054–1061.

Lakin, J. L., Chartrand, T. L., & Arkin, R. M. (2008). I Am Too Just Like You: Nonconscious Mimicry as an Automatic Behavioral Response to Social Exclusion. *Psychological Science*, *19*(8), 816–822. https://doi.org/10.1111/j.1467-9280.2008.02162.x

Leppänen, J. M., Moulson, M. C., Vogel-Farley, V. K., & Nelson, C. A. (2007a). An ERP Study of Emotional Face Processing in the Adult and Infant Brain. *Child Development*, *78*(1), 232–245. https://doi.org/10.1111/j.1467-8624.2007.00994.x

Leppänen, J. M., Moulson, M. C., Vogel-Farley, V. K., & Nelson, C. A. (2007b). An ERP Study of Emotional Face Processing in the Adult and Infant Brain. *Child Development*, *78*(1), 232–245. https://doi.org/10.1111/j.1467-8624.2007.00994.x

Leppänen, J. M., & Nelson, C. A. (2009). Tuning the developing brain to social signals of emotions. *Nature Reviews Neuroscience, 10*(1), 37–47. https://doi.org/10.1038/nrn2554

Li, W., Zinbarg, R. E., Boehm, S. G., & Paller, K. A. (2008). Neural and Behavioral Evidence for Affective Priming from Unconsciously Perceived Emotional Facial Expressions and the Influence of Trait Anxiety. *Journal of Cognitive Neuroscience*, *20*(1), 95–107.

Ludemann, P. M., & Nelson, C. A. (1988). *Categorical Representation of Facial Expressions by 7-Month-Old Infants*. 10.

MacDonald, G., & Leary, M. R. (2005). Why Does Social Exclusion Hurt? The Relationship Between Social and Physical Pain. *Psychological Bulletin*, *131*(2), 202–223. https://doi.org/10.1037/0033-2909.131.2.202

Marinović, V., & Träuble, B. (2018). Vicarious social exclusion and memory in young children. *Developmental Psychology*, *54*(11), 2067–2076. https://doi.org/10.1037/dev0000593

Marinović, V., Wahl, S., & Träuble, B. (2017). “Next to you”—Young children sit closer to a person following vicarious ostracism. *Journal of Experimental Child Psychology, 156,* 179–185. https://doi.org/10.1016/j.jecp.2016.11.011

Masuda, T., Ellsworth, P. C., Mesquita, B., Leu, J., Tanida, S., & Van de Veerdonk, E. (2008). Placing the face in context: Cultural differences in the perception of facial emotion. *Journal of Personality and Social Psychology, 94*(3), 365–381. https://doi.org/10.1037/0022-3514.94.3.365

Meeren, H. K. M., van Heijnsbergen, C. C. R. J., & de Gelder, B. (2005). Rapid perceptual integration of facial expression and emotional body language. *Proceedings of the National Academy of Sciences, 102*(45), 16518–16523. https://doi.org/10.1073/pnas.0507650102

Meier, I. M., van Honk, J., Bos, P. A., & Terburg, D. (2020). *Social touch increases dominant gaze in social confrontations* [Preprint]. PsyArXiv. https://doi.org/10.31234/osf.io/ubyv3

Meyer, M., Baldwin, D. A., & Sage, K. (2011). *Assessing Young Children’s Hierarchical Action Segmentation*. 7.

Monroy, C., Meyer, M., Gerson, S., & Hunnius, S. (2017). Statistical learning in social action contexts. *PLOS ONE, 12*(5), e0177261. https://doi.org/10.1371/journal.pone.0177261

Monroy, C., Meyer, M., Schröer, L., Gerson, S. A., & Hunnius, S. (2019). The infant motor system predicts actions based on visual statistical learning. *NeuroImage, 185,* 947–954. https://doi.org/10.1016/j.neuroimage.2017.12.016

Montague, D. P. F., & Walker-Andrews, A. S. (2001). Peekaboo: A new look at infants’ perception of emotion expressions. *Developmental Psychology, 37*(6), 826–838. https://doi.org/10.1037/0012-1649.37.6.826

Müller, V. I., Habel, U., Derntl, B., Schneider, F., Zilles, K., Turetsky, B. I., & Eickhoff, S. B. (2011). Incongruence effects in crossmodal emotional integration. *NeuroImage*, *54*(3), 2257–2266. https://doi.org/10.1016/j.neuroimage.2010.10.047

Mumenthaler, C., & Sander, D. (2012). Social appraisal influences recognition of emotions. *Journal of Personality and Social Psychology*, *102*(6), 1118–1135. https://doi.org/10.1037/a0026885

Nelson, C. A., & De Haan, M. (1996). Neural correlates of infants' visual responsiveness to facial expressions of emotion. *Developmental Psychobiology*, *29*(7), 577–595. https://doi.org/10.1002/(SICI)1098-2302(199611)29:7<577::AID-DEV3>3.0.CO;2-R

Niedenthal, P. M., Halberstadt, J. B., & Margolin, J. (2000). Emotional state and the detection of change in facial expression of emotion. *Eur. J. Soc. Psychol.*, 12.

Nielsen, M. (2006). Copying actions and copying outcomes: Social learning through the second year. *Developmental Psychology, 42*(3), 555–565. https://doi.org/10.1037/0012-1649.42.3.555

Oakes, L. M. (2017). Sample Size, Statistical Power, and False Conclusions in Infant Looking-Time Research. *Infancy*, *22*(4), 436–469. https://doi.org/10.1111/infa.12186

Over, H., & Carpenter, M. (2009a). Priming third-party ostracism increases affiliative imitation in children. *Developmental Science*, *12*(3), F1–F8. https://doi.org/10.1111/j.1467-7687.2008.00820.x

Over, H., & Carpenter, M. (2009b). Eighteen-Month-Old Infants Show Increased Helping Following Priming with Affiliation. *Psychological Science*, *20*(10), 1189–1193. https://doi.org/10.1111/j.1467-9280.2009.02419.x

Palama, A., Malsert, J., & Gentaz, E. (2018). Are 6-month-old human infants able to transfer emotional information (happy or angry) from voices to faces? An eye-tracking study. *PLOS ONE*, *13*(4), e0194579. https://doi.org/10.1371/journal.pone.0194579

Palermo, R., O’Connor, K. B., Davis, J. M., Irons, J., & McKone, E. (2013). New Tests to Measure Individual Differences in Matching and Labelling Facial Expressions of Emotion, and Their Association with Ability to Recognise Vocal Emotions and Facial Identity. *PLoS ONE*, *8*(6), e68126. https://doi.org/10.1371/journal.pone.0068126

Peltola, M. J., Leppänen, J. M., Palokangas, T., & Hietanen, J. K. (2008). Fearful faces modulate looking duration and attention disengagement in 7-month-old infants. *Developmental Science*, *11*(1), 60–68. https://doi.org/10.1111/j.1467-7687.2007.00659.x

Phelps, E. A., O’Connor, K. J., Cunningham, W. A., Funayama, E. S., Gatenby, J. C., Gore, J. C., & Banaji, M. R. (2000). Performance on Indirect Measures of Race Evaluation Predicts Amygdala Activation. *Journal of Cognitive Neuroscience*, *12*(5), 729–738.

Pickett, C. L., Gardner, W. L., & Knowles, M. (2004). Getting a Cue: The Need to Belong and Enhanced Sensitivity to Social Cues. *Personality and Social Psychology Bulletin*, *30*(9), 1095–1107. https://doi.org/10.1177/0146167203262085

Pollak, S. D., Messner, M., Kistler, D. J., & Cohn, J. F. (2009). Development of perceptual expertise in emotion recognition. *Cognition*, *110*(2), 242–247. https://doi.org/10.1016/j.cognition.2008.10.010

Pollak, S. D., & Sinha, P. (2002). Effects of early experience on children’s recognition of facial displays of emotion. *Developmental Psychology*, *38*(5), 784–791. https://doi.org/10.1037/0012-1649.38.5.784

Pourtois, G., Dan, E. S., Grandjean, D., Sander, D., & Vuilleumier, P. (2005). Enhanced extrastriate visual response to bandpass spatial frequency filtered fearful faces: Time course and topographic evoked-potentials mapping. *Human Brain Mapping*, *26*(1), 65–79. https://doi.org/10.1002/hbm.20130

Quadrelli, E., Conte, S., Macchi Cassia, V., & Turati, C. (2019). Emotion in motion: Facial dynamics affect infants' neural processing of emotions. *Developmental Psychobiology, 61*(6), 843–858. https://doi.org/10.1002/dev.21860

Quadrelli, E., Monacò, S., Turati, C., & Bulf, H. (2020). Social context influences infants' ability to extract statistical information from a sequence of gestures. *Infant Behavior and Development*, *61*, 101506. https://doi.org/10.1016/j.infbeh.2020.101506

Quadrelli, E., Roberti, E., Polver, S., Bulf, H., & Turati, C. (2021). Sensorimotor Activity and Network Connectivity to Dynamic and Static Emotional Faces in 7-Month-Old Infants. *Brain Sciences, 11*(11), 1396. https://doi.org/10.3390/brainsci11111396

Rajhans, P., Jessen, S., Missana, M., & Grossmann, T. (2016). Putting the face in context: Body expressions impact facial emotion processing in human infants. *Developmental Cognitive Neuroscience*, *19*, 115–121. https://doi.org/10.1016/j.dcn.2016.01.004

Reichenbach, L., & Masters, J. C. (2021). *Children's Use of Expressive and Contextual Cues in Judgments of Emotion*. 13.

Righart, R., & De Gelder, B. (2006). Context Influences Early Perceptual Analysis of Faces—An Electrophysiological Study. *Cerebral Cortex*, *16*(9), 1249–1257. https://doi.org/10.1093/cercor/bhj066

Roseberry, S., Richie, R., Hirsh-Pasek, K., Golinkoff, R. M., & Shipley, T. F. (2011). Babies Catch a Break: 7- to 9-Month-Olds Track Statistical Probabilities in Continuous Dynamic Events. *Psychological Science, 22*(11), 1422–1424. https://doi.org/10.1177/0956797611422074

Rosenqvist, J., Lahti-Nuuttila, P., Laasonen, M., & Korkman, M. (2014). Preschoolers' recognition of emotional expressions: Relationships with other neurocognitive capacities. *Child Neuropsychology*, *20*(3), 281–302. https://doi.org/10.1080/09297049.2013.778235

Rossion, B., & Caharel, S. (2011). ERP evidence for the speed of face categorization in the human brain: Disentangling the contribution of low-level visual cues from face perception. *Vision Research*, *51*(12), 1297–1311. https://doi.org/10.1016/j.visres.2011.04.003

Ruba, A. L., Johnson, K. M., Harris, L. T., & Wilbourn, M. P. (2017). Developmental changes in infants' categorization of anger and disgust facial expressions. *Developmental Psychology*, *53*(10), 1826–1832. https://doi.org/10.1037/dev0000381

Sacco, D. F., Wirth, J. H., Hugenberg, K., Chen, Z., & Williams, K. D. (2011a). The world in black and white: Ostracism enhances the categorical perception of social information. *Journal of Experimental Social Psychology*, *47*(4), 836–842. https://doi.org/10.1016/j.jesp.2011.03.001

Sacco, D. F., Wirth, J. H., Hugenberg, K., Chen, Z., & Williams, K. D. (2011b). The world in black and white: Ostracism enhances the categorical perception of social information. *Journal of Experimental Social Psychology*, *47*(4), 836–842. https://doi.org/10.1016/j.jesp.2011.03.001

Saffran, J. R. (2018). Statistical learning as a window into developmental disabilities. *Journal of Neurodevelopmental Disorders*, *10*(1), 35. https://doi.org/10.1186/s11689-018-9252-y

Saffran, J. R., Aslin, R. N., & Newport, E. L. (1996a). Statistical Learning by 8-Month-Old Infants. *Science*, *274*(5294), 1926–1928. https://doi.org/10.1126/science.274.5294.1926

Saffran, J. R., Aslin, R. N., & Newport, E. L. (1996b). Statistical Learning by 8-Month-Old Infants. *Science*, *274*(5294), 1926–1928. https://doi.org/10.1126/science.274.5294.1926

Saffran, J. R., Johnson, E. K., Aslin, R. N., & Newport, E. L. (1999). Statistical learning of tone sequences by human infants and adults. *Cognition*, *70*(1), 27–52. https://doi.org/10.1016/S0010-0277(98)00075-4

Saffran, J. R., & Kirkham, N. Z. (2018). Infant Statistical Learning. *Annual Review of Psychology*, *69*(1), 181–203. https://doi.org/10.1146/annurev-psych-122216-011805

Saffran, J. R., Pollak, S. D., Seibel, R. L., & Shkolnik, A. (2007). Dog is a dog is a dog: Infant rule learning is not specific to language. *Cognition*, *105*(3), 669–680. https://doi.org/10.1016/j.cognition.2006.11.004

Saylor, M. M., Baldwin, D. A., Baird, J. A., & LaBounty, J. (2007). Infants' On-line Segmentation of Dynamic Human Action. *Journal of Cognition and Development*, *8*(1), 113–128. https://doi.org/10.1080/15248370709336996

Schyns, P. G., Petro, L. S., & Smith, M. L. (2007). Dynamics of Visual Information Integration in the Brain for Categorizing Facial Expressions. *Current Biology*, *17*(18), 1580–1585. https://doi.org/10.1016/j.cub.2007.08.048

Smith, M. L., Cottrell, G. W., Gosselin, F., & Schyns, P. G. (2005). Transmitting and Decoding Facial Expressions. *Psychological Science*, *16*(3), 184–189. https://doi.org/10.1111/j.0956-7976.2005.00801.x

Song, R., Over, H., & Carpenter, M. (2015). Children draw more affiliative pictures following priming with third-party ostracism. *Developmental Psychology*, *51*(6), 831–840. https://doi.org/10.1037/a0039176

Stahl, A. E., Romberg, A. R., Roseberry, S., Golinkoff, R. M., & Hirsh-Pasek, K. (2014). Infants Segment Continuous Events Using Transitional Probabilities. *Child Development*, n/a-n/a. https://doi.org/10.1111/cdev.12247

Tager-Flusberg, H. (2010). The origins of social impairments in autism spectrum disorder: Studies of infants at risk. *Neural Networks*, *23*(8–9), 1072–1076. https://doi.org/10.1016/j.neunet.2010.07.008

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. https://doi.org/10.1111/cdev.12348

Teinonen, T., Fellman, V., Näätänen, R., Alku, P., & Huotilainen, M. (2009). Statistical language learning in neonates revealed by event-related brain potentials. *BMC Neuroscience*, *10*(1), 21. https://doi.org/10.1186/1471-2202-10-21

Thiele, M., Hepach, R., Michel, C., Gredebäck, G., & Haun, D. B. M. (2021). Social interaction targets enhance 13-month-old infants' associative learning. *Infancy*, *26*(3), 409–422. https://doi.org/10.1111/infa.12393

Tottenham, N., Tanaka, J. W., Leon, A. C., McCarry, T., Nurse, M., Hare, T. A., Marcus, D. J., Westerlund, A., Casey, B., & Nelson, C. (2009). The NimStim set of facial expressions: Judgments from untrained research participants. *Psychiatry Research*, *168*(3), 242–249. https://doi.org/10.1016/j.psychres.2008.05.006

Twenge, J. M., Baumeister, R. F., Tice, D. M., & Stucke, T. S. (2001). If you can't join them, beat them: Effects of social exclusion on aggressive behavior. *Journal of Personality and Social Psychology*, *81*(6), 1058–1069. https://doi.org/10.1037/0022-3514.81.6.1058

Vacaru, S. V., van Schaik, J. E., de Water, E., & Hunnius, S. (2020). Five-year-olds' facial mimicry following social ostracism is modulated by attachment security. *PLOS ONE*, *15*(12), e0240680. https://doi.org/10.1371/journal.pone.0240680

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. https://doi.org/10.1037/0033-2909.134.3.383

van Heijnsbergen, C. C. R. J., Meeren, H. K. M., Grèzes, J., & de Gelder, B. (2007). Rapid detection of fear in body expressions, an ERP study. *Brain Research*, *1186*, 233–241. https://doi.org/10.1016/j.brainres.2007.09.093

Vicari, S., Reilly, J. S., Pasqualetti, P., Vizzotto, A., & Caltagirone, C. (2000). Recognition of facial expressions of emotions in school-age children: The intersection of perceptual and semantic categories. *Acta Paediatrica*, *89*(7), 836–845. https://doi.org/10.1111/j.1651-2227.2000.tb00392.x

Vlach, H. A., & Johnson, S. P. (2013). Memory constraints on infants' cross-situational statistical learning. *Cognition*, *127*(3), 375–382. https://doi.org/10.1016/j.cognition.2013.02.015

Vuilleumier, P., & Pourtois, G. (2007). Distributed and interactive brain mechanisms during emotion face perception: Evidence from functional neuroimaging. *Neuropsychologia*, *45*(1), 174–194. https://doi.org/10.1016/j.neuropsychologia.2006.06.003

Warburton, W. A., Williams, K. D., & Cairns, D. R. (2006a). When ostracism leads to aggression: The moderating effects of control deprivation. *Journal of Experimental Social Psychology*, *42*(2), 213–220. https://doi.org/10.1016/j.jesp.2005.03.005

Warburton, W. A., Williams, K. D., & Cairns, D. R. (2006b). When ostracism leads to aggression: The moderating effects of control deprivation. *Journal of Experimental Social Psychology*, *42*(2), 213–220. https://doi.org/10.1016/j.jesp.2005.03.005

Watson-Jones, R. E., Legare, C. H., Whitehouse, H., & Clegg, J. M. (2014). Task-specific effects of ostracism on imitative fidelity in early childhood. *Evolution and Human Behavior*, *35*(3), 204–210. https://doi.org/10.1016/j.evolhumbehav.2014.01.004

Watson-Jones, R. E., Whitehouse, H., & Legare, C. H. (2016). In-Group Ostracism Increases High-Fidelity Imitation in Early Childhood. *Psychological Science, 27*(1), 34–42. https://doi.org/10.1177/0956797615607205

Widen, S. C., & Russell, J. A. (2008). Children acquire emotion categories gradually. *Cognitive Development*, *23*(2), 291–312. https://doi.org/10.1016/j.cogdev.2008.01.002

Widen, S. C., & Russell, J. A. (2010). Differentiation in preschooler's categories of emotion. *Emotion*, *10*(5), 651–661. https://doi.org/10.1037/a0019005

Wieser, M. J., & Brosch, T. (2012). Faces in Context: A Review and Systematization of Contextual Influences on Affective Face Processing. *Frontiers in Psychology, 3*. https://doi.org/10.3389/fpsyg.2012.00471

Wieser, M. J., Gerdes, A. B. M., Büngel, I., Schwarz, K. A., Mühlberger, A., & Pauli, P. (2014). Not so harmless anymore: How context impacts the perception and electrocortical processing of neutral faces. *NeuroImage*, *92*, 74–82. https://doi.org/10.1016/j.neuroimage.2014.01.022

Williams, K. D. (2007). Ostracism. *Annual Review of Psychology*, *58*(1), 425–452. https://doi.org/10.1146/annurev.psych.58.110405.085641

Williams, K. D. (2009). Ostracism: A Temporal Need-Threat Model. In *Advances in Experimental Social Psychology* (Vol. 41, pp. 275–314). Elsevier. https://doi.org/10.1016/S0065-2601(08)00406-1

Williams, K. D., Cheung, C. K. T., & Choi, W. (2000). Cyberostracism: Effects of being ignored over the Internet. *Journal of Personality and Social Psychology*, *79*(5), 748–762. https://doi.org/10.1037/0022-3514.79.5.748

Williams, K. D., & Nida, S. A. (2011a). Ostracism: Consequences and Coping. *Current Directions in Psychological Science*, *20*(2), 71–75. https://doi.org/10.1177/0963721411402480

Williams, K. D., & Nida, S. A. (2011b). Ostracism: Consequences and Coping. *Current Directions in Psychological Science*, *20*(2), 71–75. https://doi.org/10.1177/0963721411402480

Wölfer, R., & Scheithauer, H. (2013). Ostracism in childhood and adolescence: Emotional, cognitive, and behavioral effects of social exclusion. *Social Influence*, *8*(4), 217–236. https://doi.org/10.1080/15534510.2012.706233

Yan, X., Andrews, T. J., & Young, A. W. (2016). Cultural similarities and differences in perceiving and recognizing facial expressions of basic emotions. *Journal of Experimental Psychology: Human Perception and Performance*, *42*(3), 423–440. https://doi.org/10.1037/xhp0000114

Zadro, L., & Gonsalkorale, K. (2014). Sources of Ostracism: The Nature and Consequences of Excluding and Ignoring Others. *Current Directions in Psychological Science*, *23*(2), 93–97. https://doi.org/10.1177/0963721413520321

Zadro, L., Hawes, D. J., Iannuzzelli, R. E., Godwin, A., MacNevin, G., Griffiths, B., & Gonsalkorale, K. (2013). Ostracism and Children: A Guide to Effectively Using the Cyberball Paradigm With a Child Sample. *International Journal of Developmental Science*, *7*(1), 7–11. https://doi.org/10.3233/DEV-1312112

PART II

The influence of social context on the processing of emotional faces

Chapter 3: Social exclusion influences infants' neural processing of emotional faces

Introduction

Forming and maintaining successful social connections is essential for human beings. Most of their complex social behaviors are motivated by the need to belong, which lies amongst the most fundamental human motivation (Baumeister & Leary, 1995; D'Souza & Gurin, 2016; Maslow 1968), and bears an evolutionary function for survival and reproduction (Baumeister & Leary, 1995). Nonetheless, situations in which individuals do not belong arise very frequently, across different contexts and developmental stages (Zadro & Gonsalkorale, 2014), unleashing a variety of negative psychological repercussions. In particular, it is known that ostracism, the act of being ignored and excluded by another individual or group (Williams, 2007), threatens belonging needs and compromises adults' and children's sense of meaningful existence, control and self-esteem (Abrams et al., 2011; for a review see Williams & Nida, 2011). It decreases individuals' mood, and elicits negative feelings such as anger, sadness, pain or distress (Gonsalkorale & Williams, 2007; Williams, 2009; Wölfer & Scheithauer, 2013). Interestingly, ostracism has even been shown to elicit activity in the dorsal anterior cingulate cortex in adults, the same brain region involved in physical pain, highlighting the presence of common neural bases for social and physical pain (Eisenberger et al., 2003; MacDonald & Leary, 2005). Thus, similarly to physical pain, the psychological pain elicited by ostracism might serve to signal a danger to the individual, under the form of a social threat, in order to avoid further exposure to ostracism.

Research suggests that ostracism could trigger two potential yet antagonistic behavioral responses in individuals, depending on their level of control and on the likelihoods of being re-included in the group (Williams, 2009). If ostracized individuals possess enough sense of control to consider re-inclusion as possible, they will aim at fulfilling belonging needs through prosocial behaviors. For instance, they will be more likely to conform on a task (Williams et al., 2000), more compliant to others' requests (Carter-Sowell et al., 2008), and will imitate others more (Cheung et al., 2015; Kawamoto et al., 2014b). On the contrary, if ostracized individuals possess a low sense of control, they will regard re-inclusion as unlikely, which will trigger anti-social behaviors such as aggression, aimed at re-establishing control rather than social connections (Twenge et al., 2001; Warburton et al., 2006a). Moreover, previous research has shown that ostracism elicits considerable cognitive changes in individuals. Indeed, when confronted with social threat, humans tend to concentrate cognitive resources towards the processing of social cues, at the expense of other non-social stimuli (Pickett et al., 2004). Ostracized individuals are thus noticeably more attuned to socially relevant stimuli, which constitutes a major asset for re-inclusion, while undergoing a decrease in general (non-social) cognitive performances. For instance, ostracism was shown to increase adults' and children's memory of social events (Gardner et al., 2000; Marinović & Träuble, 2018), but decrease effortful logic (Baumeister et al., 2002) and memory of non-social items (Hawes et al., 2012).

In one of the first studies to investigate ostracism in adults, Williams and Sommer (1997) implemented a face-to-face ball-tossing paradigm, in which participants were led to throw a ball with two confederates, while waiting for the experimenter to come back. Included participants were thrown the ball one third of the time during the entire game, while ostracized participants were only thrown the ball a few times at the beginning and were then ignored by the two confederates for the rest of the game. The observed effect was so strong that an online version of the game called Cyberball (Williams et al., 2000) was implemented a few years later, which proved to be consistently efficient in inducing feelings of ostracism irrespective of the structural aspects of the game (i.e., number of throws, duration, etc.) and of the target population (i.e., nationality, gender, age; see the meta-analysis by Hartgerink et al., 2015). In particular, a shorter version of the adult Cyberball was shown to be equally effective in children populations as young as 5-years-old (Abrams et al., 2011; Zadro et al., 2013).

Since then, the online Cyberball has been widely used in developmental research and has contributed to the great progress in understanding the effects of ostracism in children. Recent research showed that similarly to adults, ostracized 5- to 12-years-old children engaged in more prosocial behaviors, such as action (Hopkins & Branigan, 2020) or language (Watson-Jones et al., 2016) imitation. In line with Pickett and colleagues' theory (2004), ostracism also enhanced children's selective memory for social events (Wölfer & Scheithauer, 2013), and led to a decrease in cognitive performance on non-social tasks in girls, but not boys (Hawes et al., 2012). Interestingly, children as young as 5-years-old who had merely been primed with videos depicting ostracism displayed more affiliative behaviors, by subsequently sitting closer to a stranger (Watson-Jones et al., 2014), drawing characters closer to each other (Song et al., 2015), or showing a greater imitative fidelity of others' actions (Over & Carpenter, 2009a; Watson-Jones et al., 2014). Thus, it seems like even the most subtle cue of ostracism induces considerable behavioral and cognitive changes very early on in development. Furthermore, the effects of ostracism seem rather similar across developmental stages, with an increase in prosocial and affiliative behaviors and an attunement to social stimuli at the expense of non-social cues for both adults and children.

Recently, researchers have started to investigate the effects of ostracism on the processing of a fundamental social cue: emotional faces. Given the importance of a reliable decoding of emotional faces in interpersonal interactions, one could assume that it is modulated by experiences of ostracism. Indeed, research using the Cyberball paradigm on adults showed that ostracized individuals were overall more accurate at decoding and categorizing emotions (Cheung et al., 2015; Sacco et al., 2011b). In the same vein, studies investigating the effects of social rejection on adults showed that rejected participants were better at identifying facial emotions (Pickett et al., 2004), and at discriminating “real” from “fake” smiles (Bernstein et al., 2008). Moreover, DeWall and colleagues (2009) found that rejection also modulated early attentional processing of emotional faces, with rejected participants displaying selective attention to happy faces, when presented concurrently with angry and disgusted faces. Therefore, the effects of ostracism may also vary according to the emotion expressed on the face.

Although great progress has been made in understanding the effects of ostracism on individuals’ behavior and cognition, to date, very little is known about its potential influence at the neurophysiological level. The examination of the neural mechanisms might be of relevance to investigate the developmental roots of the ability to process social stimuli, and its potential modulation by social exclusion. To our knowledge, only one study has investigated the effects of ostracism on adults’ neural responses to emotional cues. In this study, Kawamoto and colleagues (2014) manipulated ostracism using the Cyberball paradigm, and recorded participants’ event-related potentials (ERPs) in response to happy, disgusted, and neutral faces. In particular, they examined changes in amplitude of the P1 component, reflecting early visual attention, and of the N170 component, reflecting structural encoding of faces. A larger P1 was found in response to disgusted faces as compared to neutral faces in ostracized participants, while such difference was absent in included participants. From these results, the authors concluded that ostracism modulated allocation of attention to the different emotional faces. As for the N170, no difference in amplitude was observed between ostracized and included participants, but participants higher in need threat showed larger N170 amplitudes to all faces. These results suggested that the structural encoding of emotional faces was related to need threat rather than ostracism per se, and that altogether, the changes in neural processing of emotional faces might reflect an early regulation of individuals’ belonging status.

Although Kawamoto and colleagues' study (2014) constitutes a first indication that ostracism may modulate the neural processing of emotional faces, more research is needed to fully characterize its effects. To date, no study has investigated whether these changes also occur in response to other emotional faces, and whether they are already present during development. Since pre-verbal infants rely particularly on non-linguistic cues such as emotional faces during social interactions, it would be particularly relevant to study these effects in infant population. Moreover, it is known that, due to the high early plasticity of the human brain, the first 3 years of life represent a unique window of opportunity for the individual to develop typical cognitive and socio-emotional competences. It is therefore essential to understand the processes that might interfere with early typical development. Although social exclusion might represent a possible threat to the foundations of the developing social mind, it has never been investigated during infancy, and more specifically in children younger than 5-years-old.

The current study aimed at filling this gap by examining the effects of ostracism on the neural processing of emotions in infants. Specifically, we examined whether a face-to-face version of the Cyberball paradigm, similar to that originally implemented by Williams and Sommer (1997), modulated 13- to 14-month-old infants' event-related potential (ERP) components in response to the observation of videos of female faces expressing anger, fear and happiness. In particular, we examined potential changes in the latencies and amplitudes of the following ERPs: the P1, indexing early visual processing, the Nc component, reflecting allocation of attentional resources, the N290, thought to mediate the structural encoding of the physical properties of faces, and the P400, reflecting the extraction of the communicative and affective content of faces (De Haan et al., 2002, 2003; Tager-Flusberg, 2010). There has been a considerable number of studies investigating variations in latencies and amplitudes of these components in response to the static display of different emotional faces. Previous studies suggest that from 7 months of age, infants display a negative bias towards fear when contrasted with happy and neutral emotional expressions, as illustrated by larger Nc amplitudes in response to fearful as compared to happy faces (Nelson & De Haan, 1996) and larger P400 amplitudes for fearful as compared happy and neutral faces (Leppänen et al., 2007b). However, findings on infants' neural response to anger are rather mixed. Thus, it is not clear yet whether the bias observed for fearful faces also generalizes to other negative emotions, although some studies suggest that an anger bias might develop between 7 and 12 months of age (Grossmann et al., 2007; Quadrelli et al., 2019). Research examining variations in the P1 component in infancy is more limited. Previous studies suggest that it is particularly sensitive to faces at all ages (Conte et al., 2020; de Haan & Nelson, 1999; Di Lorenzo et al., 2020; Itier & Taylor, 2002; Rossion & Caharel, 2011), and that it is modulated by emotional expressions both in adults (Kawamoto et al., 2014b; Pourtois et al., 2005; van Heijnsbergen et al., 2007) and young children (Batty et al., 2011; Dawson et al., 2004; Dennis et al., 2009). Nonetheless, whether this modulation is also present in infants is still debated, as findings are rather mixed (Curtis & Cicchetti, 2013; Leppänen et al., 2007b). Similarly, although the N290 is now an established face-sensitive component in infancy, no consistent pattern of activation has been observed in response to the different emotional faces (Kobiella et al., 2008; Leppänen et al., 2007b; Quadrelli et al., 2019). Thus, although a few discrepancies remain, research has uncovered some consistent differences in activation in response to various emotional expressions. Moreover, recent studies (Quadrelli et al., 2019) suggested that presenting stimuli in a dynamic way might reinforce infants' neural processing of emotional faces, potentially constituting a more accurate representation of real-life mechanisms, as emotions as usually dynamic in everyday infants' experience. This motivated our choice to present stimuli in a dynamic manner, and to examine the variations in P1, Nc, P400 and N290 components in response to videos of faces expressing angry, fearful, and happy emotions.

Consistent with previous studies on the effect of ostracism and rejection on adults' decoding of emotional faces (Bernstein et al., 2008; Cheung et al., 2015; Sacco et al., 2011b), we hypothesized that ostracized participants would show heightened neural processing of all emotional faces. Indeed, allocating more resources to perceptual and attentional processes (i.e., enhanced P1 and Nc amplitude) and to the extraction of affective content (i.e., enhanced P400) of emotional faces would allow infants to process more efficiently signals of danger or threat (i.e., fear and anger), avoiding further ostracism situations, and signals of acceptance (i.e., happiness), fostering re-inclusion.

Methods

Participants

Twenty-eight healthy 13- to 14-months-old infants (15 females; M = 14 months; SD = 15 days; min age = 13 months; max age = 14 months and 25 days) were included in the final analysis. Data collection was considerably slowed down by the pandemic and is still ongoing, therefore this sample is preliminary. Participants were all born full-term (37–42 weeks of gestation) and had normal birth weight (> 2,500 g). They were randomly assigned to the *inclusion* condition (N = 14) or to the *ostracism* condition (N = 14). Thirty-four additional participants were tested but excluded from the final sample due to fussiness (N = 3 in the inclusion condition, N = 3 in the exclusion condition), experimental error (N = 1 in the inclusion condition, N = 1 in the exclusion condition) or excessive artifacts (N = 15 in the inclusion condition, N = 11 in the exclusion condition). This dropout rate is within normal range for infant ERP studies (Grossmann et al., 2007). A minimum of 10 artifact-free trials per emotion was required to proceed to further analysis. Participants were recruited from birth records of neighboring cities via written invitation and written informed consent was given by the parent or caretaker of the infants before testing began. The protocol followed the ethical standards of the Declaration of Helsinki (BMJ 1991; 302:1194) and was approved by the ethical committee of the xxx *(omitted for blind purposes)* (Protocol number: 421).

Design and procedure

The study was composed of two parts: a training phase, in which the infants participated in a social interaction (i.e., face-to-face Cyberball), and a test phase, in which EEG was recorded while infants observed videos of female faces expressing different emotions.

Face-to-face Cyberball

The training phase took place at a table at the center of the laboratory and consisted in a face-to-face Cyberball (Williams et al., 2000) between two experimenters and the infant, sitting on his parent's lap on the other side of the table. Infants were randomly assigned either to the *inclusion* or to the *ostracism* condition. In the *inclusion* condition, infants received the ball a third of the time (i.e., 6 times out of a total of 18 throws), so each player participated to the game equitably. In the *ostracism* condition, infants received the ball only twice at the beginning of the game, and were then ignored by the two experimenters, who kept playing together until they reached 18 throws.

The entire training phase was recorded through a Sony video camera and was coded later on to quantify the infants' behavior in response to inclusion or ostracism and assess the degree to which the infant seemed affected by the experimental manipulation. We chose to code the behaviors that were most frequently expressed by infants and that reflected their reaction to inclusion or exclusion (behaviors coded are listed in Table 1).

Behaviors coded
Body posture towards the other players
Sitting back or physically withdrawing from the game
Happy vocalization or laugh
Angry vocalization or cry
Smiles
Eye contact with parent or turning to parent to seek support
Look at the ball
Look at the players
Throws the ball without help from the parent
Hands or arms asking for the ball
Movement of hands or arms (e.g., hits table) to catch the players' attention

Table 1; Description of the different behaviors expressed by infants during the training phase that were coded to quantify and compare the impact of the inclusion and ostracism manipulations on infants' behaviors.

The videos were cut from the first movement initiating the first throw, to the last reception of the ball, and were divided into two parts. The first part, the baseline, was identical for both the *inclusion* and the *ostracism* conditions, and consisted in the first 6 throws, during which infants received the ball twice. The second part however, consisted in the inclusion or ostracism manipulation, and differed between the two conditions. Infants in the *inclusion* condition receiving the ball 4 times out of 12 throws (i.e., equitably, a third of the time), while infants in the *ostracism* conditions never received the ball and observed the two experimenters play together for the remaining 12 tosses. Both parts were segmented into 2-seconds windows. Each behavior was coded for each time window, which was assigned a score of 1 whenever a behavior was present, and of 0 if it was absent. The scores of the different behaviors were then summed up and normalized by dividing the final score by the number of time windows, separately for both the baseline and the inclusion/ostracism parts. In this way, we could have an average score for each behavior for both the baseline part and the inclusion or ostracism manipulation part. Finally, a delta score was calculated, by subtracting the average score over the baseline to that of the inclusion/ostracism part. Positive delta scores indicated more display of the behavior during the inclusion/ostracism part as compared to the baseline, while negative delta scores indicated less display of the behavior during the inclusion/ostracism part as compared to the baseline. This allowed us to ensure that infants' behaviors did not differ between conditions during the baseline part, and to quantify and compare the impact of the inclusion and ostracism manipulations on infants' behaviors.

Testing phase

At the end of the training phase, the infants were carried to a sound-proofed, electrically shielded cabin at the corner of the laboratory to participate in the EEG test phase. They were seated on their parent's lap, at approximately 60 cm from the 24-inch monitor on which the stimuli were displayed. Stimuli consisted of colored videos of two female Caucasian actresses facing forward and displaying facial expressions of fear, anger, and happiness. We chose to present fearful and angry emotions for their relevance in situations of social threat such as ostracism, fear signaling a potential threat, and anger indicating an impending aggression. On the other hand, happiness was chosen as a contrasting positive emotion in order to compare included and ostracized participants' response to different emotional valences. Each video lasted for a total of 1500 ms, beginning with the actress displaying a neutral face for 200 ms, followed by the unfolding of the emotional expression (i.e., neutral to 100% intensity) during the next 520 ms, and the actress holding the expression at its peak for the last 780 ms (Figure 1). Stimuli were chosen to be dynamic and contained whole faces (i.e., not cropped) in order to be as naturalistic as possible and increase the ecological validity of the study. The videos were recorded in our laboratory and edited using the Adobe Premiere Pro CC 2019 and Kinovea softwares. Luminance and motion were controlled and did not differ between emotion categories, Kruskal-Wallis H test for luminance, $\chi^2(2) = 1.14$; $p = 0.56$; $\varepsilon^2 = 0.23$, Kruskal-Wallis H test for motion $\chi^2(2) = 0.29$; $p = 0.87$; $\varepsilon^2 = 0.06$. The stimuli were selected based on the ratings of 18 adults (11 females), who completed a survey in which they identified the emotion expressed in each video and the intensity of each emotion (ranging from 1: very low to 9: very high). Expressions of happiness, anger and fear were correctly identified by respectively 97%, 89% and 81% of the raters. These percentages significantly differed from chance level, Binomial tests, all ps < 0.001, and the proportion of subjects who correctly identified the emotional expression did not differ between emotions, $\chi^2(2) = 5.40$, $p > .06$. The stimuli were presented at a viewing distance of 60 cm, with a visual angle of 15.3° vertically and 10.5° horizontally. They were displayed on the monitor using the E-Prime software v2.0 (Psychology Software Tools Inc., Pittsburgh, PA). Parents were instructed to avoid any interaction with the infant and remain as still as possible throughout the entire experimental procedure. An infrared video camera hidden over the monitor recorded the infants' face and body during the whole experiment and fed into the data acquisition computer and a TV monitor, both located outside of the testing cabin. In this way, the experimenter could see the live image of the infant and display an attention getter (a moving fixation point) to orient the infant' attention back to the monitor whenever he was distracted or interrupt the study when he was getting too fussy. The stimuli were presented in a random order, with the constraint that stimuli of a same category of emotion could not be presented more than twice in a row. Each stimulus lasted 1500 ms, with inter-stimulus intervals varying randomly between 900 and 1100 ms. The experimental session was concluded when the infant watched the maximum number of trials (N = 170) or was too tired or fussy to continue.

Fig. 1. Example of stimuli presented in the testing phase. Stimuli consisted of colored videos of two female actresses displaying facial expressions of fear, anger, and happiness. Each video lasted for a total of 1500 ms, beginning with the actress displaying a neutral face for 200 ms, followed by the unfolding of the emotional expression (i.e., neutral to 100% intensity) during the next 520 ms, and the actress holding the expression at its peak for the last 780 ms.

EEG acquisition and pre-processing

Electroencephalograms (EEG) were recorded continuously using a 128-electrode HydroCel Geodesic Sensor Net (Electrical Geodesic Inc., Eugene, OR) and referenced to the vertex electrode (Cz). Data was amplified through an EGI NetAmps 300 amplifier with a sample rate of 500 Hz and an online band-pass filter of 0.1-100 Hz was applied. Impedance values were inspected online prior to stimuli presentation to ensure that they were below 50 KΩ. A 0.3-30 Hz bandpass filter was applied offline to the continuous signals using NetStation v4.6.4 (Eugene, OR).

Continuous EEG signals were subsequently segmented into epochs ranging from 100 ms before stimulus onset to 1500 ms after stimulus onset. Automatic artifact detection was first implemented on the segmented data so that any channel with a signal exceeding ± 200 μV in a sliding window of 80 ms was rejected. Visual inspection of the data was then completed to eliminate any remaining artifacts. Trials containing more than 15% of the channels ($N \geq 18$) marked as bad were excluded from further analysis. For the remaining trials, channels containing artifacts were replaced using spherical spline interpolation. An average of 16.7, 17.3 and 17.1 trials across participants were considered for the ERP analysis for the expressions of fear, anger, and happiness respectively. Data was then re-referenced to the algebraic mean of all the channels. Well-defined P1, N290 and P400 components were observed over the medial occipital electrodes during visual examination of the grand-average waveforms. Electrodes from two clusters in the left (65, 66 and 70) and right (83, 84 and 90) occipital-temporal regions were averaged, and time-windows of respectively 130-230 ms, 250-350 ms and 380-540 ms were chosen for the analysis of the P1, N290 and P400 components, similarly to previous infant ERP studies (e.g., Leppänen et al., 2007; Quadrelli et al., 2019). Inspection of the grand-average waveforms also revealed a well-defined Nc attentional component over the fronto-central region and guided the selection of the channels of interest. Two additional clusters of electrodes were selected, over the left (29, 30, 35, 36, and 41) and right central regions (103, 104, 105, 110, and 111). A 380-530 ms time-window was chosen based on visual inspection of the component's peak, in accordance with previous reports of the Nc component (e.g., Quadrelli et al., 2019; Taylor-Colls & Pasco Fearon, 2015). The peak latency (ms) and mean amplitude (μV) values were measured for each of the three components and submitted to statistical analyses.

Statistical analysis

For the behavioral coding, the delta scores of each behavior were analyzed using independent samples t-tests, with condition as between subject factor. For the ERP data, mean amplitudes and peak latencies of the N290, P400 and Nc components were analyzed in a

3*2*2 repeated measures Analysis of Variance (ANOVA) with emotion (fear, anger, happiness) and hemispheres (left and right) as within-subject factors, and condition (inclusion, ostracism) as between subject factor. Significant main effects or interactions were explored by conducting planned comparisons. Independent samples t-tests were performed to investigate the effect of condition on all three emotions separately, and paired sample t-tests were used to examine differences in the neural processing of the different emotions within each condition separately. These comparisons were planned a priori, based on our hypothesis that ostracism may affect the neural processing of emotional faces, and that its effect might vary in function of the emotion processed. All statistical analyses were performed using the software Jamovi (version 1.6.15; http://jamovi.org). The Greenhouse-Geisser correction for non-sphericity was used to adjust the degrees of freedom when needed. All statistical tests were conducted on a two-tailed .05 level of significance, and pairwise comparisons were performed by applying t-tests and the Fisher's least significant difference procedure (Howell, 1987). Effect sizes were estimated using the partial eta square measure (η_p^2) and the data are reported as the mean and the standard deviation (SD).

Results

Behavioral coding

The independent t-tests conducted on delta scores for each behavior revealed a significant difference in the "Body posture towards the other players" behavior between the two conditions, *t* (25) = -2.62, *p* = 0.015, *d* = -1.01. In particular, delta scores were higher for the inclusion (*M* = 0.03, *SD* = 0.06) than the ostracism condition (*M* = -0.05, *SD* = 0.11), suggesting that included participants displayed a body posture towards the other players more frequently than excluded participants during the live Cyberball phase.

P1 component

Latency. The ANOVA performed on the P1 peak latency values revealed a significant interaction between emotion and condition, F (2,23) = 1.82; p = 0.033, η_p^2= 0.13. Planned comparisons showed a faster P1 latency in response to happy faces in the *ostracism* (M = 162 ms, SD = 10.2) as compared to the *inclusion* condition (M = 175 ms, SD = 13.7), t (26) = −2.80, p = 0.009, d = -1.06 (Figure 2). In addition, differences in P1 latencies between anger and happiness, t (13) = −2.33, p = 0.037, d = -0.62, and fear and happiness t (13) = −4.04, p = 0.001, d = -1.08 were observed in the *inclusion* condition, with both anger (M = 167 ms, SD = 19) and fear (M = 167 ms, SD = 12.6) having faster latencies than happiness (M = 175 ms, SD = 13.7) (Figure 3). However, no significant difference in P1 latency was observed in the *ostracism* condition (anger: M = 166 ms, SD = 11.8, fear: M = 162 ms, SD = 13.1, happiness: M = 162 ms, SD = 10.2; all ps > 0.22).

Amplitude. The ANOVA performed on the P1 amplitude values did not yield any significant main effect or interaction (all ps > 0.49).

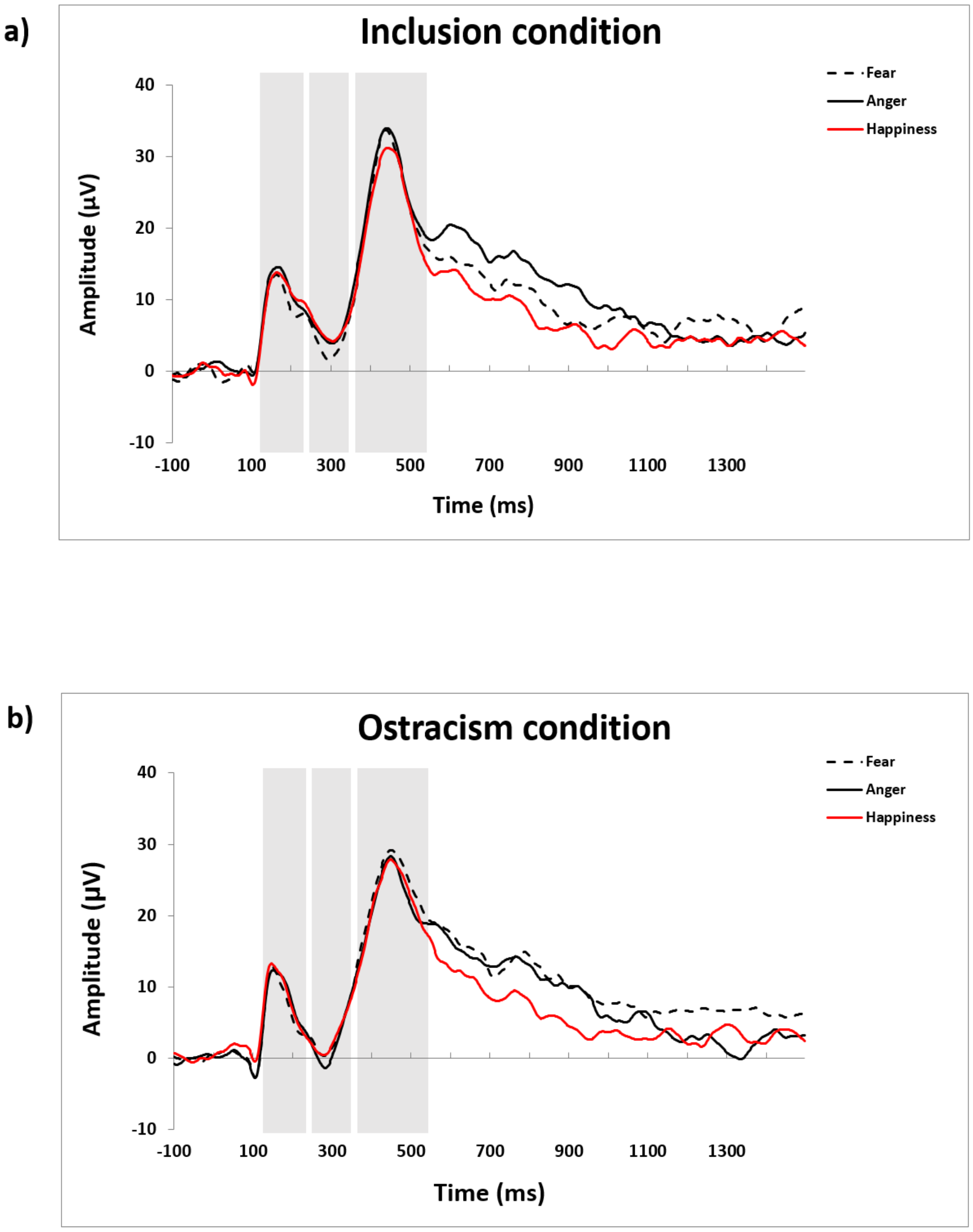

Fig. 3. Grand average waveforms depicting the P1 (130-230 ms), N290 (250-350 ms) and P400 (380-540 ms) ERP components at medial occipital electrodes in response to fearful (black dotted line), angry (black line) and happy (red line) faces for the a) inclusion condition and b) ostracism condition.

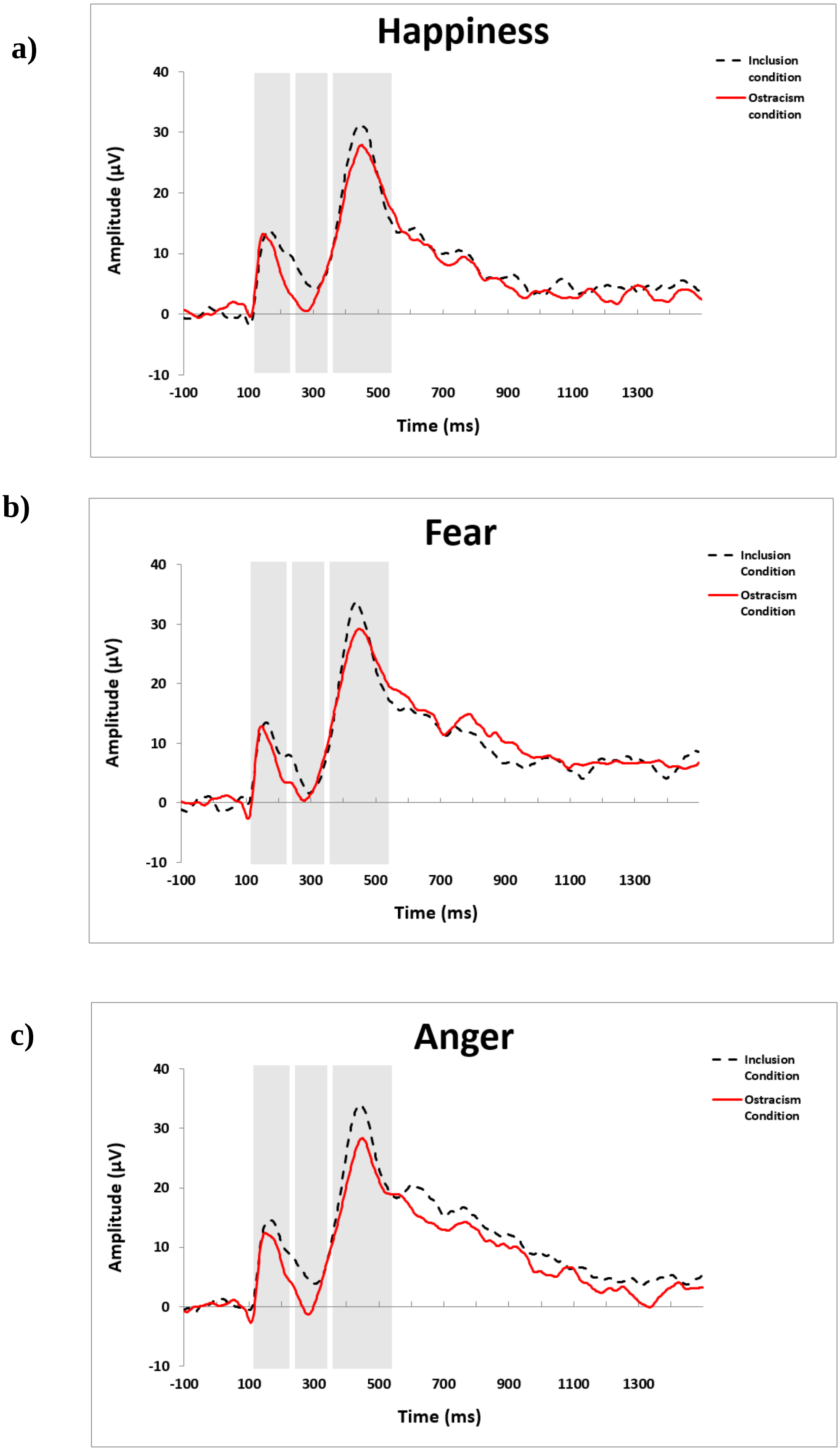

Fig. 2. Grand average waveforms depicting the P1 (130-230 ms), N290 (250-350 ms) and P400 (380-540 ms) ERP components at medial occipital electrodes in response to (a) happy, (b) fearful and (c) angry faces for the inclusion (black dotted line) and ostracism (red line) conditions.

N290, P400, Nc components

The ANOVAs performed on peak latency and amplitude values of the N290, P400 and Nc did not reveal any significant main effect or interaction (all *p*s > 0.22). Thus, conditions and emotions did not seem to modulate these components.

Discussion

Since data collection is not complete yet, the results exposed in this discussion as well as the conclusions drawn are preliminary. They might considerably differ once the final sample size will be reached. The primary aim of our study was to investigate the effects of ostracism on the neural processing of facial emotional expressions in 13- to 14-months-old infants. To do so, infants first participated in a face-to-face ball-tossing game in which they were either included or ostracized, and their electrocortical activity was subsequently measured in response to dynamic facial expressions of fear, anger and happiness. The preliminary results suggest that the ostracism manipulation modulated infants' neural processing of facial emotions, and that this modulation varied according to the emotion processed. These results are not entirely surprising, given recent models attributing distinct neural processing to the different facial emotions (Hunnius et al., 2011; Leppänen et al., 2007; Quadrelli et al., 2019), and are in line with previous work on adults (Kawamoto et al., 2014b).

Similarly to Kawamoto and colleagues (2014), variations were found in the P1 component, which is thought to reflect early-stage processing of the stimuli at the perceptual level (De Haan et al., 2003). Nonetheless, the changes induced by ostracism in the current study showed opposite patterns, and affected P1 latency rather than its amplitude. These differences might have been driven by the use of distinct facial emotions (i.e., happiness, disgust and neutral in Kawamoto et al., 2014; happiness, fear and anger in the current study), or might reflect an actual difference in psychophysiological reaction to ostracism between adulthood and infancy. In the current study, faster P1 latencies were observed for both fear and anger as compared to happiness in the *inclusion* condition. Negatively-valenced emotions (i.e., fear and anger) might have been processed faster than the positively-valenced emotion (i.e., happiness) because of their evolutionary relevance in signaling impending danger or threat. It is possible that the manipulation of inclusion, by signaling safety and lowering anxiety in infants, promoted the exploration of negative emotions such as fear and anger, similarly to what was observed in adults in response to social touch (Meier et al., 2020). To our knowledge, only one study showed heightened sensitivity of the P1 for negative (i.e., angry) as compared to positive (i.e., happy) emotional faces in infants, but this sensitivity was indicated by enhanced P1 amplitudes rather than faster latencies (Curtis & Cicchetti, 2013). Nevertheless, a negative bias was previously identified in the attentional Nc and the face-sensitive P400 components in infants between 7 and 12 months of age, which showed enhanced amplitudes in response to fearful and angry emotions (Grossmann et al., 2007; Leppänen et al., 2007b; Nelson & De Haan, 1996; Quadrelli et al., 2019). Therefore, even though it is observed in a different component in the current study, the presence of a negativity bias in infants’ processing of emotional faces is consistent with previous research. Thus, the pattern of neural activity observed in response to angry, fearful and happy faces following inclusion is quite similar from what is commonly observed in infancy.

However, this pattern of activity was not observed in the *ostracism* condition. Indeed, no difference in P1 was observed in response to the different emotions in ostracized children. Thus, ostracism might have cancelled the difference in speed of the early visual processing previously found between negatively- and positively-valenced emotions. The absence of difference in the ostracism condition might be interpreted as evidence of an equally fast processing of anger, fear and happiness at early perceptual level. Together with results obtained in the inclusion condition, these findings show an accelerated visual processing of happy faces in ostracized as compared to included participants. Indeed, faster P1 latencies were found in response to happy faces in the *ostracism* as compared to the *inclusion* condition. These faster latencies might reflect an accelerated processing of signals of acceptance, which could be beneficial for ostracized infants to quickly detect potential social connections that could enable re-inclusion. Similar findings were found through behavioral measures of attention in excluded adults (DeWall et al., 2009b), who were faster to identify, slower to disengage, and fixated more happy faces when presented concurrently with angry and disgusted faces compared with included participants. However, similarly to what was observed in adults, no change in processing of angry or fearful faces was induced by ostracism in the current study.

In sum, while included participants showed a rather common pattern of activation, with negative emotional faces being processed faster than positive ones, this higher sensitivity toward negative emotional signals was not observed in ostracized participant. Therefore, ostracism might have interfered with infants' processing of negative emotional signals. Moreover, ostracism seemed to have speeded up the early visual processing of happy faces. Importantly, these variations in the visual processing of the different emotions could not be due to systematic differences in low-level features of the stimuli, as the exact same videos were used in the *inclusion* and *ostracism* conditions, and the motion and luminance of the stimuli were controlled to ensure that they did not significantly vary between emotions. Yet, whether these variations in early visual processing reflect differences in the visuo-spatial orienting of attention (Hillyard & Anllo-Vento, 1998; Kawamoto et al., 2014b), or in the extraction of emotional information (Batty et al., 2011; Vuilleumier & Pourtois, 2007) is still unknown, and more research is needed to fully characterize the P1 component in infancy. Indeed, literature examining infants' P1 component in response to facial emotions is extremely limited, and the few studies investigating it used static images instead of dynamic videos of facial emotional expressions such as those used in the current study (Curtis &

Cicchetti, 2013; Leppänen et al., 2007). Surprisingly, ostracism did not seem to induce variations in the Nc and P400 components. It is possible that ostracism might actually elicit changes in the neural processing of emotional faces at very early stages only, as reflected by variations in the P1 component, leaving unaffected the later stages of processing. The use of dynamic stimuli, which were previously shown to influence adults' and infants' processing of facial emotions (Ambadar et al., 2005; Quadrelli et al., 2019, 2021), might have promoted such an early-stage processing of emotional faces. Nonetheless, these data are still preliminary, as data collection is not complete yet, and potential differences in P400 and Nc might be observed once the final sample will be reached.

In addition to investigate the modulation of ostracism on infants' neural processing of emotional faces, we also examined its influence on infants' behavior. Towards this aim, we recorded the face-to-face ball tossing game, and quantified the appearance of a list of behaviors that were frequently expressed by infants and likely reflected their reaction to social inclusion or exclusion (see Table 1). Infants showed a difference between conditions in the "Body posture towards the other players" behavior, with included participants displaying it more frequently than excluded participants. This difference reflects more involvement in the ball-tossing game for included as compared to ostracized participants, which suggest that the manipulation successfully induced feelings of social inclusion and exclusion in infants. Although it is surprising to note the absence of difference between the two conditions for all the other behaviors, more differences might emerge once we obtain a larger sample size. This sample size could be considerably larger, as it may include participants who were excluded from the ERP analysis for insufficient amount of EEG data, but successfully participated in the face-to-face Cyberball phase.

In conclusion, the current study suggest that ostracism influences infants both at the behavioral and at the neural level. In particular, ostracism seem to modulate infants' involvement in social interactions, as well as their subsequent neural processing of facial emotions. However, more research is needed to fully understand infants' behavioral and neurophysiological response to social inclusion and exclusion. For instance, future work could investigate the role of temperament in infants' reaction to inclusion and ostracism, as well as its influence on their neural processing of emotional faces.

The preliminary results of this study suggest that the social context in which 13-months-old infants are involved, in particular whether they are socially included or excluded, can modulate their subsequent neural processing of emotional faces. Specifically, contextual effects seem to be visible at the level of early attentional processes. The next chapter will investigate whether similar social context also affects children's recognition of facial expressions.

References

Abrams, D., Weick, M., Thomas, D., Colbe, H., & Franklin, K. M. (2011). On-line ostracism affects children differently from adolescents and adults: Ostracism: children, adolescents, adults. *British Journal of Developmental Psychology*, *29*(1), 110–123. https://doi.org/10.1348/026151010X494089

Ambadar, Z., Schooler, J. W., & Cohn, J. F. (2005). Deciphering the Enigmatic Face: The Importance of Facial Dynamics in Interpreting Subtle Facial Expressions. *Psychological Science*, *16*(5), 403–410. https://doi.org/10.1111/j.0956-7976.2005.01548.x

Aslin, R. N., Saffran, J. R., & Newport, E. L. (1998). Computation of Conditional Probability Statistics by 8-Month-Old Infants. *Psychological Science*, *9*(4), 321–324. https://doi.org/10.1111/1467-9280.00063

Augusti, E.-M., Melinder, A., & Gredebäck, G. (2010). Look who's talking: Pre-verbal infants' perception of face-to-face and back-to-back social interactions. *Frontiers in Psychology*, *1*. https://doi.org/10.3389/fpsyg.2010.00161

Aviezer, H., Ensenberg, N., & Hassin, R. R. (2017). The inherently contextualized nature of facial emotion perception. *Current Opinion in Psychology*, *17*, 47–54. https://doi.org/10.1016/j.copsyc.2017.06.006

Aviezer, H., Trope, Y., & Todorov, A. (2012). Body Cues, Not Facial Expressions, Discriminate Between Intense Positive and Negative Emotions. *Science*, *338*(6111), 1225–1229. https://doi.org/10.1126/science.1224313

Barrett, L. F., Mesquita, B., & Gendron, M. (2011). Context in Emotion Perception. *Current Directions in Psychological Science*, *20*(5), 286–290. https://doi.org/10.1177/0963721411422522

Batty, M., Meaux, E., Wittemeyer, K., Rogé, B., & Taylor, M. J. (2011). Early processing of emotional faces in children with autism: An event-related potential study. *Journal of Experimental Child Psychology, 109*(4), 430–444. https://doi.org/10.1016/j.jecp.2011.02.001

Baumeister, R. F., & Leary, M. R. (1995). The Need to Belong: Desire for Interpersonal Attachments as a Fundamental Human Motivation. *Psychological Bulletin, 117*(3), 34.

Baumeister, R. F., Twenge, J. M., & Nuss, C. K. (2002). Effects of social exclusion on cognitive processes: Anticipated aloneness reduces intelligent thought. *Journal of Personality and Social Psychology, 83*(4), 817–827. https://doi.org/10.1037/0022-3514.83.4.817

Bernstein, M. J., Young, S. G., Brown, C. M., Sacco, D. F., & Claypool, H. M. (2008). Adaptive Responses to Social Exclusion: Social Rejection Improves Detection of Real and Fake Smiles. *Psychological Science, 19*(10), 981–983. https://doi.org/10.1111/j.1467-9280.2008.02187.x

Bulf, H., Brenna, V., Valenza, E., Johnson, S. P., & Turati, C. (2015). Many faces, one rule: The role of perceptual expertise in infants’ sequential rule learning. *Frontiers in Psychology, 6*. https://doi.org/10.3389/fpsyg.2015.01595

Bulf, H., Johnson, S. P., & Valenza, E. (2011). Visual statistical learning in the newborn infant. *Cognition*, *121*(1), 127–132. https://doi.org/10.1016/j.cognition.2011.06.010

Calder, A. J., Young, A. W., Perrett, D. I., Etcoff, N. L., & Rowland, D. (1996). Categorical Perception of Morphed Facial Expressions. *Visual Cognition*, *3*(2), 81–118. https://doi.org/10.1080/713756735

Camras, L. A., & Allison, K. (1985). Children’s understanding of emotional facial expressions and verbal labels. *Journal of Nonverbal Behavior, 9*(2), 84–94. https://doi.org/10.1007/BF00987140

Carroll, J. M., & Russell, J. A. (1996). Do Facial Expressions Signal Specific Emotions? Judging Emotion From the Face in Context. *Journal of Personality and Social Psychology, 70*(2), 205.

Carter-Sowell, A. R., Chen, Z., & Williams, K. D. (2008). Ostracism increases social susceptibility. *Social Influence*, *3*(3), 143–153. https://doi.org/10.1080/15534510802204868

Cheung, E. O., Slotter, E. B., & Gardner, W. L. (2015). Are you feeling what I'm feeling? The role of facial mimicry in facilitating reconnection following social exclusion. *Motivation and Emotion*, *39*(4), 613–630. https://doi.org/10.1007/s11031-015-9479-9

Choudhury, S., Blakemore, S.-J., & Charman, T. (2006). Social cognitive development during adolescence. *Social Cognitive and Affective Neuroscience*, *1*(3), 165–174. https://doi.org/10.1093/scan/nsl024

Conte, S., Richards, J. E., Guy, M. W., Xie, W., & Roberts, J. E. (2020). Face-sensitive brain responses in the first year of life. *NeuroImage*, *211*, 116602. https://doi.org/10.1016/j.neuroimage.2020.116602

Csibra, G., Hernik, M., Mascaro, O., Tatone, D., & Lengyel, M. (2016). Statistical treatment of looking-time data. *Developmental Psychology*, *52*(4), 521–536. https://doi.org/10.1037/dev0000083

Curtis, W. J., & Cicchetti, D. (2013). Affective Facial Expression Processing in 15-Month-Old Infants Who Have Experienced Maltreatment: An Event-Related Potential Study. *Child Maltreatment*, *18*(3), 140–154. https://doi.org/10.1177/1077559513487944

Dawson, G., Webb, S. J., Carver, L., Panagiotides, H., & McPartland, J. (2004). Young children with autism show atypical brain responses to fearful versus neutral facial expressions of emotion. *Developmental Science, 7*(3), 340–359. https://doi.org/10.1111/j.1467-7687.2004.00352.x

De Haan, M., Johnson, M. H., & Halit, H. (2003). Development of face-sensitive event-related potentials during infancy: A review. *International Journal of Psychophysiology*, *51*(1), 45–58. https://doi.org/10.1016/S0167-8760(03)00152-1

de Haan, M., & Nelson, C. A. (1999). Brain Activity Differentiates Face and Object Processing in 6-Month-Old Infants. *Developmental Psychology*, *35*(4), 1113.

De Haan, M., Pascalis, O., & Johnson, M. H. (2002). Specialization of Neural Mechanisms Underlying Face Recognition in Human Infants. *Journal of Cognitive Neuroscience*, *14*(2), 199–209. https://doi.org/10.1162/089892902317236849

Dennis, T. A., Malone, M. M., & Chen, C.-C. (2009). Emotional Face Processing and Emotion Regulation in Children: An ERP Study. *Developmental Neuropsychology*, *34*(1), 85–102. https://doi.org/10.1080/87565640802564887

DeWall, C. N., Maner, J. K., & Rouby, D. A. (2009a). Social Exclusion and Early-Stage Interpersonal Perception: Selective Attention to Signs of Acceptance. *Journal of Personality and Social Psychology*, *96*(4), 729.

DeWall, C. N., Maner, J. K., & Rouby, D. A. (2009b). Social exclusion and early-stage interpersonal perception: Selective attention to signs of acceptance. *Journal of Personality and Social Psychology*, *96*(4), 729–741. https://doi.org/10.1037/a0014634

Di Lorenzo, R., van den Boomen, C., Kemner, C., & Junge, C. (2020). Charting development of ERP components on face-categorization: Results from a large longitudinal sample of infants. *Developmental Cognitive Neuroscience*, *45*, 100840. https://doi.org/10.1016/j.dcn.2020.100840

Dolan, R. J., Morris, J. S., & de Gelder, B. (2001). Crossmodal binding of fear in voice and face. *Proceedings of the National Academy of Sciences*, *98*(17), 10006–10010. https://doi.org/10.1073/pnas.171288598

D’Souza, J., & Gurin, M. (2016). The universal significance of Maslow’s concept of self-actualization. *The Humanistic Psychologist*, *44*(2), 210–214. https://doi.org/10.1037/hum0000027

Durand, K., Gallay, M., Seigneuric, A., Robichon, F., & Baudouin, J.-Y. (2007). The development of facial emotion recognition: The role of configural information. *Journal of Experimental Child Psychology*, *97*(1), 14–27. https://doi.org/10.1016/j.jecp.2006.12.001

Eisenberger, N. I., Lieberman, M. D., & Williams, K. D. (2003). *Does Rejection Hurt? An fMRI Study of Social Exclusion*. *302*, 3.

Ekman, P. (1992). An argument for basic emotions. *Cognition and Emotion*, *6*(3–4), 169–200. https://doi.org/10.1080/02699939208411068

Farroni, T., Menon, E., Rigato, S., & Johnson, M. H. (2007). The perception of facial expressions in newborns. *European Journal of Developmental Psychology*, *4*(1), 2–13. https://doi.org/10.1080/17405620601046832

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, *39*(2), 175–191. https://doi.org/10.3758/BF03193146

Fawcett, C., & Gredebäck, G. (2013). Infants use social context to bind actions into a collaborative sequence. *Developmental Science*, n/a-n/a. https://doi.org/10.1111/desc.12074

Gao, X., & Maurer, D. (2009). Influence of intensity on children’s sensitivity to happy, sad, and fearful facial expressions. *Journal of Experimental Child Psychology*, *102*(4), 503–521. https://doi.org/10.1016/j.jecp.2008.11.002

Gao, X., & Maurer, D. (2010). A happy story: Developmental changes in children's sensitivity to facial expressions of varying intensities. *Journal of Experimental Child Psychology, 107*(2), 67–86. https://doi.org/10.1016/j.jecp.2010.05.003

Gardner, W. L., Pickett, C. L., & Brewer, M. B. (2000). Social Exclusion and Selective Memory: How the Need to belong Influences Memory for Social Events. *Personality and Social Psychology Bulletin*, *26*(4), 486–496. https://doi.org/10.1177/0146167200266007

Geangu, E., Hauf, P., Bhardwaj, R., & Bentz, W. (2011). Infant Pupil Diameter Changes in Response to Others' Positive and Negative Emotions. *PLoS ONE*, *6*(11), e27132. https://doi.org/10.1371/journal.pone.0027132

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), R663–R664. https://doi.org/10.1016/j.cub.2016.05.072

Gebhart, A. L., Newport, E. L., & Aslin, R. N. (2009). Statistical learning of adjacent and nonadjacent dependencies among nonlinguistic sounds. *Psychonomic Bulletin & Review*, *16*(3), 486–490. https://doi.org/10.3758/PBR.16.3.486

Gendron, M., Mesquita, B., & Barrett, L. F. (2013). *Emotion Perception: Putting the Face in Context*. Oxford University Press. https://doi.org/10.1093/oxfordhb/9780195376746.013.0034

Gonsalkorale, K., & Williams, K. D. (2007). The KKK won't let me play: Ostracism even by a despised outgroup hurts. *European Journal of Social Psychology, 37*(6), 1176–1186. https://doi.org/10.1002/ejsp.392

Grossmann, T., Striano, T., & Friederici, A. D. (2006). Crossmodal integration of emotional information from face and voice in the infant brain. *Developmental Science, 9*(3), 309–315. https://doi.org/10.1111/j.1467-7687.2006.00494.x

Grossmann, T., Striano, T., & Friederici, A. D. (2007). Developmental changes in infants' processing of happy and angry facial expressions: A neurobehavioral study. *Brain and Cognition*, *64*(1), 30–41. https://doi.org/10.1016/j.bandc.2006.10.002

Hannon, E. E., & Johnson, S. P. (2005). Infants use meter to categorize rhythms and melodies: Implications for musical structure learning. *Cognitive Psychology*, *50*(4), 354–377. https://doi.org/10.1016/j.cogpsych.2004.09.003

Hartgerink, C. H. J., van Beest, I., Wicherts, J. M., & Williams, K. D. (2015). The Ordinal Effects of Ostracism: A Meta-Analysis of 120 Cyberball Studies. *PLOS ONE*, *10*(5), e0127002. https://doi.org/10.1371/journal.pone.0127002

Hawes, D. J., Zadro, L., Fink, E., Richardson, R., O'Moore, K., Griffiths, B., Dadds, M. R., & Williams, K. D. (2012). The effects of peer ostracism on children's cognitive processes. *European Journal of Developmental Psychology*, *9*(5), 599–613. https://doi.org/10.1080/17405629.2011.638815

Hillyard, S. A., & Anllo-Vento, L. (1998). Event-related brain potentials in the study of visual selective attention. *Proceedings of the National Academy of Sciences*, *95*(3), 781–787. https://doi.org/10.1073/pnas.95.3.781

Hoehl, S., Palumbo, L., Heinisch, C., & Striano, T. (2008). *Infants' attention is biased by emotional expressions and eye gaze direction*. 4.

Hopkins, Z. L., & Branigan, H. P. (2020). Children show selectively increased language imitation after experiencing ostracism. *Developmental Psychology*, *56*(5), 897–911. https://doi.org/10.1037/dev0000915

Hunnius, S., de Wit, T. C. J., Vrins, S., & von Hofsten, C. (2011a). Facing threat: Infants' and adults' visual scanning of faces with neutral, happy, sad, angry, and fearful emotional expressions. *Cognition & Emotion*, *25*(2), 193–205. https://doi.org/10.1080/15298861003771189

Hunnius, S., de Wit, T. C. J., Vrins, S., & von Hofsten, C. (2011b). Facing threat: Infants' and adults' visual scanning of faces with neutral, happy, sad, angry, and fearful emotional expressions. *Cognition & Emotion*, *25*(2), 193–205. https://doi.org/10.1080/15298861003771189

Iidaka, T., Saito, D. N., Komeda, H., Mano, Y., Kanayama, N., Osumi, T., Ozaki, N., & Sadato, N. (2010). Transient Neural Activation in Human Amygdala Involved in Aversive Conditioning of Face and Voice. *Journal of Cognitive Neuroscience*, *22*(9), 2074–2085. https://doi.org/10.1162/jocn.2009.21347

Itier, R. J., & Taylor, M. J. (2002). Inversion and Contrast Polarity Reversal Affect both Encoding and Recognition Processes of Unfamiliar Faces: A Repetition Study Using ERPs. *NeuroImage*, *15*(2), 353–372. https://doi.org/10.1006/nimg.2001.0982

Izard, C. E. (1994). *Innate and Universal Facial Expressions: Evidence From Developmental and Cross-Cultural Research*. 288.

Jack, R. E., Garrod, O. G. B., Yu, H., Caldara, R., & Schyns, P. G. (2012). Facial expressions of emotion are not culturally universal. *Proceedings of the National Academy of Sciences*, *109*(19), 7241–7244. https://doi.org/10.1073/pnas.1200155109

Johnson, S. P., & Aslin, R. N. (1996). Perception of object unity in young infants: The roles of motion, depth, and orientation. *Cognitive Development*, *11*(2), 161–180. https://doi.org/10.1016/S0885-2014(96)90001-5

Kawamoto, T., Nittono, H., & Ura, M. (2014a). Social exclusion induces early-stage perceptual and behavioral changes in response to social cues. *Social Neuroscience*, *9*(2), 174–185. https://doi.org/10.1080/17470919.2014.883325

Kawamoto, T., Nittono, H., & Ura, M. (2014b). Social exclusion induces early-stage perceptual and behavioral changes in response to social cues. *Social Neuroscience*, *9*(2), 174–185. https://doi.org/10.1080/17470919.2014.883325

Kirkham, N. Z., Slemmer, J. A., & Johnson, S. P. (2002). Visual statistical learning in infancy: Evidence for a domain general learning mechanism. *Cognition*, *83*(2), B35–B42. https://doi.org/10.1016/S0010-0277(02)00004-5

Kirkham, N. Z., Slemmer, J. A., Richardson, D. C., & Johnson, S. P. (2007). Location, Location, Location: Development of Spatiotemporal Sequence Learning in Infancy. *Child Development*, *78*(5), 1559–1571. https://doi.org/10.1111/j.1467-8624.2007.01083.x

Kobiella, A., Grossmann, T., Reid, V. M., & Striano, T. (2008). The discrimination of angry and fearful facial expressions in 7-month-old infants: An event-related potential study. *Cognition and Emotion*, *22*(1), 134–146. https://doi.org/10.1080/02699930701394256

Koechlin, E. (1997). Numerical Transformations in Five-month-old Human Infants. *Mathematical Cognition*, *3*(2), 89–104. https://doi.org/10.1080/135467997387425

Kotsoni, E., de Haan, M., & Johnson, M. H. (2001). Categorical Perception of Facial Expressions by 7-Month-Old Infants. *Perception*, *30*(9), 1115–1125. https://doi.org/10.1068/p3155

Kuchuk, A., Vibbert, M., & Bornstein, M. H. (1986). The Perception of Smiling and Its Experiential Correlates in Three-Month-Old Infants. *Child Development*, 1054–1061.

Lakin, J. L., Chartrand, T. L., & Arkin, R. M. (2008). I Am Too Just Like You: Nonconscious Mimicry as an Automatic Behavioral Response to Social Exclusion. *Psychological Science*, *19*(8), 816–822. https://doi.org/10.1111/j.1467-9280.2008.02162.x

Leppänen, J. M., Moulson, M. C., Vogel-Farley, V. K., & Nelson, C. A. (2007a). An ERP Study of Emotional Face Processing in the Adult and Infant Brain. *Child Development*, *78*(1), 232–245. https://doi.org/10.1111/j.1467-8624.2007.00994.x

Leppänen, J. M., Moulson, M. C., Vogel-Farley, V. K., & Nelson, C. A. (2007b). An ERP Study of Emotional Face Processing in the Adult and Infant Brain. *Child Development*, *78*(1), 232–245. https://doi.org/10.1111/j.1467-8624.2007.00994.x

Leppänen, J. M., & Nelson, C. A. (2009). Tuning the developing brain to social signals of emotions. *Nature Reviews Neuroscience, 10*(1), 37–47. https://doi.org/10.1038/nrn2554

Li, W., Zinbarg, R. E., Boehm, S. G., & Paller, K. A. (2008). Neural and Behavioral Evidence for Affective Priming from Unconsciously Perceived Emotional Facial Expressions and the Influence of Trait Anxiety. *Journal of Cognitive Neuroscience, 20*(1), 95–107.

Ludemann, P. M., & Nelson, C. A. (1988). *Categorical Representation of Facial Expressions by 7-Month-Old Infants*. 10.

MacDonald, G., & Leary, M. R. (2005). Why Does Social Exclusion Hurt? The Relationship Between Social and Physical Pain. *Psychological Bulletin*, *131*(2), 202–223. https://doi.org/10.1037/0033-2909.131.2.202

Marinović, V., & Träuble, B. (2018). Vicarious social exclusion and memory in young children. *Developmental Psychology*, *54*(11), 2067–2076. https://doi.org/10.1037/dev0000593

Marinović, V., Wahl, S., & Träuble, B. (2017). “Next to you”—Young children sit closer to a person following vicarious ostracism. *Journal of Experimental Child Psychology, 156,* 179–185. https://doi.org/10.1016/j.jecp.2016.11.011

Masuda, T., Ellsworth, P. C., Mesquita, B., Leu, J., Tanida, S., & Van de Veerdonk, E. (2008). Placing the face in context: Cultural differences in the perception of facial emotion. *Journal of Personality and Social Psychology, 94*(3), 365–381. https://doi.org/10.1037/0022-3514.94.3.365

Meeren, H. K. M., van Heijnsbergen, C. C. R. J., & de Gelder, B. (2005). Rapid perceptual integration of facial expression and emotional body language. *Proceedings of the National Academy of Sciences, 102*(45), 16518–16523. https://doi.org/10.1073/pnas.0507650102

Meier, I. M., van Honk, J., Bos, P. A., & Terburg, D. (2020). *Social touch increases dominant gaze in social confrontations* [Preprint]. PsyArXiv. https://doi.org/10.31234/osf.io/ubyv3

Meyer, M., Baldwin, D. A., & Sage, K. (2011). *Assessing Young Children’s Hierarchical Action Segmentation*. 7.

Monroy, C., Meyer, M., Gerson, S., & Hunnius, S. (2017). Statistical learning in social action contexts. *PLOS ONE, 12*(5), e0177261. https://doi.org/10.1371/journal.pone.0177261

Monroy, C., Meyer, M., Schröer, L., Gerson, S. A., & Hunnius, S. (2019). The infant motor system predicts actions based on visual statistical learning. *NeuroImage, 185,* 947–954. https://doi.org/10.1016/j.neuroimage.2017.12.016

Montague, D. P. F., & Walker-Andrews, A. S. (2001). Peekaboo: A new look at infants’ perception of emotion expressions. *Developmental Psychology, 37*(6), 826–838. https://doi.org/10.1037/0012-1649.37.6.826

Müller, V. I., Habel, U., Derntl, B., Schneider, F., Zilles, K., Turetsky, B. I., & Eickhoff, S. B. (2011). Incongruence effects in crossmodal emotional integration. *NeuroImage*, *54*(3), 2257–2266. https://doi.org/10.1016/j.neuroimage.2010.10.047

Mumenthaler, C., & Sander, D. (2012). Social appraisal influences recognition of emotions. *Journal of Personality and Social Psychology*, *102*(6), 1118–1135. https://doi.org/10.1037/a0026885

Nelson, C. A., & De Haan, M. (1996). Neural correlates of infants' visual responsiveness to facial expressions of emotion. *Developmental Psychobiology*, *29*(7), 577–595. https://doi.org/10.1002/(SICI)1098-2302(199611)29:7<577::AID-DEV3>3.0.CO;2-R

Niedenthal, P. M., Halberstadt, J. B., & Margolin, J. (2000). Emotional state and the detection of change in facial expression of emotion. *Eur. J. Soc. Psychol.*, 12.

Nielsen, M. (2006). Copying actions and copying outcomes: Social learning through the second year. *Developmental Psychology, 42*(3), 555–565. https://doi.org/10.1037/0012-1649.42.3.555

Oakes, L. M. (2017). Sample Size, Statistical Power, and False Conclusions in Infant Looking-Time Research. *Infancy*, *22*(4), 436–469. https://doi.org/10.1111/infa.12186

Over, H., & Carpenter, M. (2009a). Priming third-party ostracism increases affiliative imitation in children. *Developmental Science*, *12*(3), F1–F8. https://doi.org/10.1111/j.1467-7687.2008.00820.x

Over, H., & Carpenter, M. (2009b). Eighteen-Month-Old Infants Show Increased Helping Following Priming with Affiliation. *Psychological Science*, *20*(10), 1189–1193. https://doi.org/10.1111/j.1467-9280.2009.02419.x

Palama, A., Malsert, J., & Gentaz, E. (2018). Are 6-month-old human infants able to transfer emotional information (happy or angry) from voices to faces? An eye-tracking study. *PLOS ONE*, *13*(4), e0194579. https://doi.org/10.1371/journal.pone.0194579

Palermo, R., O’Connor, K. B., Davis, J. M., Irons, J., & McKone, E. (2013). New Tests to Measure Individual Differences in Matching and Labelling Facial Expressions of Emotion, and Their Association with Ability to Recognise Vocal Emotions and Facial Identity. *PLoS ONE*, *8*(6), e68126. https://doi.org/10.1371/journal.pone.0068126

Peltola, M. J., Leppänen, J. M., Palokangas, T., & Hietanen, J. K. (2008). Fearful faces modulate looking duration and attention disengagement in 7-month-old infants. *Developmental Science*, *11*(1), 60–68. https://doi.org/10.1111/j.1467-7687.2007.00659.x

Phelps, E. A., O’Connor, K. J., Cunningham, W. A., Funayama, E. S., Gatenby, J. C., Gore, J. C., & Banaji, M. R. (2000). Performance on Indirect Measures of Race Evaluation Predicts Amygdala Activation. *Journal of Cognitive Neuroscience*, *12*(5), 729–738.

Pickett, C. L., Gardner, W. L., & Knowles, M. (2004). Getting a Cue: The Need to Belong and Enhanced Sensitivity to Social Cues. *Personality and Social Psychology Bulletin*, *30*(9), 1095–1107. https://doi.org/10.1177/0146167203262085

Pollak, S. D., Messner, M., Kistler, D. J., & Cohn, J. F. (2009). Development of perceptual expertise in emotion recognition. *Cognition*, *110*(2), 242–247. https://doi.org/10.1016/j.cognition.2008.10.010

Pollak, S. D., & Sinha, P. (2002). Effects of early experience on children’s recognition of facial displays of emotion. *Developmental Psychology*, *38*(5), 784–791. https://doi.org/10.1037/0012-1649.38.5.784

Pourtois, G., Dan, E. S., Grandjean, D., Sander, D., & Vuilleumier, P. (2005). Enhanced extrastriate visual response to bandpass spatial frequency filtered fearful faces: Time course and topographic evoked-potentials mapping. *Human Brain Mapping*, *26*(1), 65–79. https://doi.org/10.1002/hbm.20130

Quadrelli, E., Conte, S., Macchi Cassia, V., & Turati, C. (2019). Emotion in motion: Facial dynamics affect infants' neural processing of emotions. *Developmental Psychobiology, 61*(6), 843–858. https://doi.org/10.1002/dev.21860

Quadrelli, E., Monacò, S., Turati, C., & Bulf, H. (2020). Social context influences infants' ability to extract statistical information from a sequence of gestures. *Infant Behavior and Development*, *61*, 101506. https://doi.org/10.1016/j.infbeh.2020.101506

Quadrelli, E., Roberti, E., Polver, S., Bulf, H., & Turati, C. (2021). Sensorimotor Activity and Network Connectivity to Dynamic and Static Emotional Faces in 7-Month-Old Infants. *Brain Sciences*, *11*(11), 1396. https://doi.org/10.3390/brainsci11111396

Rajhans, P., Jessen, S., Missana, M., & Grossmann, T. (2016). Putting the face in context: Body expressions impact facial emotion processing in human infants. *Developmental Cognitive Neuroscience*, *19*, 115–121. https://doi.org/10.1016/j.dcn.2016.01.004

Reichenbach, L., & Masters, J. C. (2021). *Children's Use of Expressive and Contextual Cues in Judgments of Emotion*. 13.

Righart, R., & De Gelder, B. (2006). Context Influences Early Perceptual Analysis of Faces—An Electrophysiological Study. *Cerebral Cortex*, *16*(9), 1249–1257. https://doi.org/10.1093/cercor/bhj066

Roseberry, S., Richie, R., Hirsh-Pasek, K., Golinkoff, R. M., & Shipley, T. F. (2011). Babies Catch a Break: 7- to 9-Month-Olds Track Statistical Probabilities in Continuous Dynamic Events. *Psychological Science*, *22*(11), 1422–1424. https://doi.org/10.1177/0956797611422074

Rosenqvist, J., Lahti-Nuuttila, P., Laasonen, M., & Korkman, M. (2014). Preschoolers' recognition of emotional expressions: Relationships with other neurocognitive capacities. *Child Neuropsychology*, *20*(3), 281–302. https://doi.org/10.1080/09297049.2013.778235

Rossion, B., & Caharel, S. (2011). ERP evidence for the speed of face categorization in the human brain: Disentangling the contribution of low-level visual cues from face perception. *Vision Research*, *51*(12), 1297–1311. https://doi.org/10.1016/j.visres.2011.04.003

Ruba, A. L., Johnson, K. M., Harris, L. T., & Wilbourn, M. P. (2017). Developmental changes in infants' categorization of anger and disgust facial expressions. *Developmental Psychology*, *53*(10), 1826–1832. https://doi.org/10.1037/dev0000381

Sacco, D. F., Wirth, J. H., Hugenberg, K., Chen, Z., & Williams, K. D. (2011a). The world in black and white: Ostracism enhances the categorical perception of social information. *Journal of Experimental Social Psychology*, *47*(4), 836–842. https://doi.org/10.1016/j.jesp.2011.03.001

Sacco, D. F., Wirth, J. H., Hugenberg, K., Chen, Z., & Williams, K. D. (2011b). The world in black and white: Ostracism enhances the categorical perception of social information. *Journal of Experimental Social Psychology*, *47*(4), 836–842. https://doi.org/10.1016/j.jesp.2011.03.001

Saffran, J. R. (2018). Statistical learning as a window into developmental disabilities. *Journal of Neurodevelopmental Disorders*, *10*(1), 35. https://doi.org/10.1186/s11689-018-9252-y

Saffran, J. R., Aslin, R. N., & Newport, E. L. (1996a). Statistical Learning by 8-Month-Old Infants. *Science*, *274*(5294), 1926–1928. https://doi.org/10.1126/science.274.5294.1926

Saffran, J. R., Aslin, R. N., & Newport, E. L. (1996b). Statistical Learning by 8-Month-Old Infants. *Science*, *274*(5294), 1926–1928. https://doi.org/10.1126/science.274.5294.1926

Saffran, J. R., Johnson, E. K., Aslin, R. N., & Newport, E. L. (1999). Statistical learning of tone sequences by human infants and adults. *Cognition*, *70*(1), 27–52. https://doi.org/10.1016/S0010-0277(98)00075-4

Saffran, J. R., & Kirkham, N. Z. (2018). Infant Statistical Learning. *Annual Review of Psychology*, *69*(1), 181–203. https://doi.org/10.1146/annurev-psych-122216-011805

Saffran, J. R., Pollak, S. D., Seibel, R. L., & Shkolnik, A. (2007). Dog is a dog is a dog: Infant rule learning is not specific to language. *Cognition*, *105*(3), 669–680. https://doi.org/10.1016/j.cognition.2006.11.004

Saylor, M. M., Baldwin, D. A., Baird, J. A., & LaBounty, J. (2007). Infants' On-line Segmentation of Dynamic Human Action. *Journal of Cognition and Development*, *8*(1), 113–128. https://doi.org/10.1080/15248370709336996

Schyns, P. G., Petro, L. S., & Smith, M. L. (2007). Dynamics of Visual Information Integration in the Brain for Categorizing Facial Expressions. *Current Biology*, *17*(18), 1580–1585. https://doi.org/10.1016/j.cub.2007.08.048

Smith, M. L., Cottrell, G. W., Gosselin, F., & Schyns, P. G. (2005). Transmitting and Decoding Facial Expressions. *Psychological Science*, *16*(3), 184–189. https://doi.org/10.1111/j.0956-7976.2005.00801.x

Song, R., Over, H., & Carpenter, M. (2015). Children draw more affiliative pictures following priming with third-party ostracism. *Developmental Psychology*, *51*(6), 831–840. https://doi.org/10.1037/a0039176

Stahl, A. E., Romberg, A. R., Roseberry, S., Golinkoff, R. M., & Hirsh-Pasek, K. (2014). Infants Segment Continuous Events Using Transitional Probabilities. *Child Development*, n/a-n/a. https://doi.org/10.1111/cdev.12247

Tager-Flusberg, H. (2010). The origins of social impairments in autism spectrum disorder: Studies of infants at risk. *Neural Networks*, *23*(8–9), 1072–1076. https://doi.org/10.1016/j.neunet.2010.07.008

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. https://doi.org/10.1111/cdev.12348

Teinonen, T., Fellman, V., Näätänen, R., Alku, P., & Huotilainen, M. (2009). Statistical language learning in neonates revealed by event-related brain potentials. *BMC Neuroscience*, *10*(1), 21. https://doi.org/10.1186/1471-2202-10-21

Thiele, M., Hepach, R., Michel, C., Gredebäck, G., & Haun, D. B. M. (2021). Social interaction targets enhance 13-month-old infants' associative learning. *Infancy*, *26*(3), 409–422. https://doi.org/10.1111/infa.12393

Tottenham, N., Tanaka, J. W., Leon, A. C., McCarry, T., Nurse, M., Hare, T. A., Marcus, D. J., Westerlund, A., Casey, B., & Nelson, C. (2009). The NimStim set of facial expressions: Judgments from untrained research participants. *Psychiatry Research*, *168*(3), 242–249. https://doi.org/10.1016/j.psychres.2008.05.006

Twenge, J. M., Baumeister, R. F., Tice, D. M., & Stucke, T. S. (2001). If you can't join them, beat them: Effects of social exclusion on aggressive behavior. *Journal of Personality and Social Psychology*, *81*(6), 1058–1069. https://doi.org/10.1037/0022-3514.81.6.1058

Vacaru, S. V., van Schaik, J. E., de Water, E., & Hunnius, S. (2020). Five-year-olds' facial mimicry following social ostracism is modulated by attachment security. *PLOS ONE*, *15*(12), e0240680. https://doi.org/10.1371/journal.pone.0240680

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. https://doi.org/10.1037/0033-2909.134.3.383

van Heijnsbergen, C. C. R. J., Meeren, H. K. M., Grèzes, J., & de Gelder, B. (2007). Rapid detection of fear in body expressions, an ERP study. *Brain Research*, *1186*, 233–241. https://doi.org/10.1016/j.brainres.2007.09.093

Vicari, S., Reilly, J. S., Pasqualetti, P., Vizzotto, A., & Caltagirone, C. (2000). Recognition of facial expressions of emotions in school-age children: The intersection of perceptual and semantic categories. *Acta Paediatrica*, *89*(7), 836–845. https://doi.org/10.1111/j.1651-2227.2000.tb00392.x

Vlach, H. A., & Johnson, S. P. (2013). Memory constraints on infants' cross-situational statistical learning. *Cognition*, *127*(3), 375–382. https://doi.org/10.1016/j.cognition.2013.02.015

Vuilleumier, P., & Pourtois, G. (2007). Distributed and interactive brain mechanisms during emotion face perception: Evidence from functional neuroimaging. *Neuropsychologia*, *45*(1), 174–194. https://doi.org/10.1016/j.neuropsychologia.2006.06.003

Warburton, W. A., Williams, K. D., & Cairns, D. R. (2006a). When ostracism leads to aggression: The moderating effects of control deprivation. *Journal of Experimental Social Psychology*, *42*(2), 213–220. https://doi.org/10.1016/j.jesp.2005.03.005

Warburton, W. A., Williams, K. D., & Cairns, D. R. (2006b). When ostracism leads to aggression: The moderating effects of control deprivation. *Journal of Experimental Social Psychology*, *42*(2), 213–220. https://doi.org/10.1016/j.jesp.2005.03.005

Watson-Jones, R. E., Legare, C. H., Whitehouse, H., & Clegg, J. M. (2014). Task-specific effects of ostracism on imitative fidelity in early childhood. *Evolution and Human Behavior*, *35*(3), 204–210. https://doi.org/10.1016/j.evolhumbehav.2014.01.004

Watson-Jones, R. E., Whitehouse, H., & Legare, C. H. (2016). In-Group Ostracism Increases High-Fidelity Imitation in Early Childhood. *Psychological Science, 27*(1), 34–42. https://doi.org/10.1177/0956797615607205

Widen, S. C., & Russell, J. A. (2008). Children acquire emotion categories gradually. *Cognitive Development*, *23*(2), 291–312. https://doi.org/10.1016/j.cogdev.2008.01.002

Widen, S. C., & Russell, J. A. (2010). Differentiation in preschooler's categories of emotion. *Emotion*, *10*(5), 651–661. https://doi.org/10.1037/a0019005

Wieser, M. J., & Brosch, T. (2012). Faces in Context: A Review and Systematization of Contextual Influences on Affective Face Processing. *Frontiers in Psychology, 3*. https://doi.org/10.3389/fpsyg.2012.00471

Wieser, M. J., Gerdes, A. B. M., Büngel, I., Schwarz, K. A., Mühlberger, A., & Pauli, P. (2014). Not so harmless anymore: How context impacts the perception and electrocortical processing of neutral faces. *NeuroImage*, *92*, 74–82. https://doi.org/10.1016/j.neuroimage.2014.01.022

Williams, K. D. (2007). Ostracism. *Annual Review of Psychology*, *58*(1), 425–452. https://doi.org/10.1146/annurev.psych.58.110405.085641

Williams, K. D. (2009). Ostracism: A Temporal Need-Threat Model. In *Advances in Experimental Social Psychology* (Vol. 41, pp. 275–314). Elsevier. https://doi.org/10.1016/S0065-2601(08)00406-1

Williams, K. D., Cheung, C. K. T., & Choi, W. (2000). Cyberostracism: Effects of being ignored over the Internet. *Journal of Personality and Social Psychology*, *79*(5), 748–762. https://doi.org/10.1037/0022-3514.79.5.748

Williams, K. D., & Nida, S. A. (2011a). Ostracism: Consequences and Coping. *Current Directions in Psychological Science*, *20*(2), 71–75. https://doi.org/10.1177/0963721411402480

Williams, K. D., & Nida, S. A. (2011b). Ostracism: Consequences and Coping. *Current Directions in Psychological Science*, *20*(2), 71–75. https://doi.org/10.1177/0963721411402480

Wölfer, R., & Scheithauer, H. (2013). Ostracism in childhood and adolescence: Emotional, cognitive, and behavioral effects of social exclusion. *Social Influence*, *8*(4), 217–236. https://doi.org/10.1080/15534510.2012.706233

Yan, X., Andrews, T. J., & Young, A. W. (2016). Cultural similarities and differences in perceiving and recognizing facial expressions of basic emotions. *Journal of Experimental Psychology: Human Perception and Performance*, *42*(3), 423–440. https://doi.org/10.1037/xhp0000114

Zadro, L., & Gonsalkorale, K. (2014). Sources of Ostracism: The Nature and Consequences of Excluding and Ignoring Others. *Current Directions in Psychological Science*, *23*(2), 93–97. https://doi.org/10.1177/0963721413520321

Zadro, L., Hawes, D. J., Iannuzzelli, R. E., Godwin, A., MacNevin, G., Griffiths, B., & Gonsalkorale, K. (2013). Ostracism and Children: A Guide to Effectively Using the Cyberball Paradigm With a Child Sample. *International Journal of Developmental Science*, *7*(1), 7–11. https://doi.org/10.3233/DEV-1312112

Chapter 4: Social exclusion influences children's recognition of emotional faces

Introduction

Human beings display a variety of remarkably complex social behaviors. They heavily rely on social interactions to survive and thrive in their environment, and put great effort into establishing and maintaining social relationships with their peers. Indeed, the need to belong was characterized as one of the most fundamental human motives (Baumeister & Leary, 1995; Maslow, 1968), prompting individuals to be part of a group and to avoid being left out. All forms of social exclusion, as for example ostracism (i.e., being ignored and excluded) or rejection (i.e., being explicitly communicated that we are not wanted), threaten primary needs such as belonging, control, self-esteem and sense of meaningful existence in adults (Hartgerink et al., 2015; for a review see Williams & Nida, 2011) as well as in children (Abrams et al., 2011). They lower the mood, increase sadness and anger, and lead to pain or distress (Gonsalkorale & Williams, 2007; Williams, 2009; Wölfer & Scheithauer, 2013). Interestingly, the psychological pain induced by social exclusion seems to be similar to physical pain at the neuroanatomical level, as demonstrated by recent research on adults showing activation in the dorsal anterior cingulate cortex when experiencing exclusion, the same region of the brain that is activated when experiencing physical pain (Eisenberger et al., 2003; MacDonald & Leary, 2005). This suggests that the negative affect and pain elicited by social exclusion might serve as a warning, in the same way that physical pain signals a danger to the body, alerting individuals of a social threat that could compromise their place in the group. This allows the individual to adjust its behavior accordingly in order to avoid further social exclusion.

According to Williams (2007), social exclusion can lead either to prosocial or antisocial behaviors, depending on the likelihood of being re-included in the group and on the psychological need that is most threatened. If re-inclusion is perceived as likely, belonging and self-esteem needs will trigger prosocial behaviors, aiming at fortifying relationships and being re-accepted in the group. For instance, after being ostracized through an online ball-tossing game (Cyberball; Williams et al., 2000), participants were shown to be more compliant to others' requests (Carter-Sowell et al., 2008; Kawamoto et al., 2014a; Lakin et al., 2008; Vacaru et al., 2020), and mimicked more others' facial emotions than included participants (Cheung et al., 2015; Kawamoto et al., 2014a; Lakin et al., 2008; Vacaru et al., 2020). On the contrary, if re-inclusion is perceived as unlikely, the response will be driven by the need of control and meaningful existence, which will elicit anti-social behaviors meant to re-establish a sense of control for the individual, rather than facilitate its re-inclusion (Williams & Nida, 2011b). For example, ostracized and rejected participants displayed more aggressive behaviors (i.e., allocated more hot sauce or played aversive noise to a stranger) when experiencing a loss of control as compared to included participants and ostracized participants with higher levels of control (Twenge et al., 2001; Warburton et al., 2006b).

In addition to influencing behavior, social exclusion also induces noticeable attentional and cognitive changes. According to Pickett and Gardner (2005), individuals possess a social monitoring system which, when detecting threats to their belonging need, directs attentional and cognitive resources towards social cues. In this way, they are better equipped to selectively detect socially relevant information that will subsequently facilitate the re-establishment of social connections and their re-inclusion. Numerous research using different forms of social exclusion which threaten the individual's sense of belonging (e.g., rejection messages, ostracism via an online ball-tossing game, or priming videos depicting third-party exclusion) support the social monitoring model. For instance, excluded adults allocated more attention and were more accurate in identifying emotional vocal tones than included ones (Pickett et al., 2004), and displayed selective memory for explicit social events (Gardner et al., 2000; Wölfer & Scheithauer, 2013). However, this allocation of attentional and cognitive resources towards socially-relevant cues seem to be detrimental for other non-social cognitive tasks, as demonstrated by adults' decrease in general cognitive performances such as effortful logic and reasoning after social exclusion (Baumeister et al., 2002).

A growing body of research suggests that social exclusion also induces considerable behavioral and cognitive changes at early stages of development. For example, at 5 years of age, excluded children displayed more affiliative behaviors such as increased imitation of others' actions or language choices as compared to included ones (Hopkins & Branigan, 2020; Watson-Jones et al., 2016). Besides, the effects of social exclusion are so robust that merely witnessing someone else being excluded prompted children to sit closer to a stranger (Marinović et al., 2017), draw more affiliative pictures (Song et al., 2015) and imitate more accurately others' action (Over & Carpenter, 2009b; Watson-Jones et al., 2014). Similarly to adults, social exclusion also seemed to drive children's attentional and cognitive resources towards social cues, while having detrimental effects on non-social tasks. For instance, 5-years-old children who witnessed third-party exclusion or were excluded themselves showed selective memory for social events and items (Marinović et al., 2017; Marinović & Träuble, 2018), while 8- to 12-years-old girls (but not boys) displayed lower cognitive performances on non-social tasks (Hawes et al., 2012). Altogether, these findings suggest that humans' acute sensitivity to social exclusion appears early on in development, and that an efficient detection and understanding of social cues are essential to form and maintain social connections at all ages.

Taken together, the literature emphasizes the importance of belonging to a group, and suggests that an efficient detection and understanding of social cues are essential to form and maintain social connections. Given that faces are among the most informative social cues in the human environment, being able to accurately decode others' facial expressions is a considerable asset. Reading others' facial expressions allows individuals to reason about others' internal dispositions and infer their emotional state, which in turn facilitates successful social interactions. Thus, social exclusion might possibly modulate emotion recognition abilities, for instance by allocating more cognitive resources to emotion decoding to reconnect with others and facilitate re-inclusion after social exclusion. Indeed, research on adults showed that social exclusion improved the decoding of static and dynamic facial expressions of happiness, anger, fear, sadness and disgust (Cheung et al., 2015; Pickett et al., 2004). In addition, excluded participants were better at categorizing angry versus happy facial expressions (Sacco et al., 2011b) and at discriminating "fake" versus "real" smiles (Bernstein et al., 2008) than included ones. However, when looking at more automatic processes, social exclusion differently affected adults' processing of diverse emotional expressions, increasing selective attention to happy faces only, when presented concurrently with angry and disgusted faces (DeWall et al., 2009b).

Extensive research on the development of emotion recognition abilities has demonstrated that children's recognition of emotional faces gradually improves over the years, with a large increase in accuracy between 3- and 7-years-old (Camras & Allison, 1985; Durand et al., 2007; Vicari et al., 2000), to become adult-like around 7 years of age. In addition, research showed that children recognize positive emotions at younger age (Widen & Russell, 2008) and they are more accurate in recognizing positive emotions than negative ones (Gao & Maurer, 2009, 2010), which might influence their social interactions by limiting their understanding of others' emotional states, particularly for negative expressions. However, no study so far has examined whether being socially excluded affected emotion recognition abilities throughout development.

The current study aimed at investigating whether social exclusion modulates emotion recognition abilities in 5-, 7-, and 10-years-old children, and whether this modulation varies across development. To do so, ostracism was induced using the well-established Cyberball paradigm (Williams et al., 2000), an online ball-tossing game in which children were either included (i.e., frequently received the ball during the entire game), or ostracized (i.e., received the ball only twice at the beginning of the game, and then never again). Already widely used in adults, recent research suggests that the Cyberball is equally efficient at inducing ostracism in children from 5 years of age (Abrams et al., 2011; Hawes et al., 2012; Marinović & Träuble, 2018; Over & Carpenter, 2009b; Watson-Jones et al., 2014). Following the Cyberball game, children participated in an emotion recognition task, in which they were asked to identify the emotions displayed on female faces expressing either anger, fear, happiness, or displaying a neutral face.

Based on numerous evidence of its robust effect in modulating individuals’ behavior and cognition, we expected ostracism to induce considerable changes in children’s emotion recognition abilities. Furthermore, since the most recent models on the development of emotion recognition abilities agree in attributing distinct visual and neural processing methods in response to different emotions (Hunnius et al., 2011b; Leppänen et al., 2007b; Quadrelli et al., 2019), we hypothesized that ostracism’ effects may differ depending on the emotion observed. Finally, we presumed that age might modulate children’s response to ostracism, and in turn their recognition of emotions.

Methods

Participants

A total of 123 children was included in the final sample, from whom forty 5-year-olds (21 females; M_{age} = 5.36 years, SD_{age} = 0.33 years), forty-one 7-year-olds (26 females; M_{age} = 7.44 years, SD_{age} = 0.239 years), and forty-two10-year-olds (21 females; M_{age} = 10.5 years, SD_{age} = 0.233 years). In each age group, approximately half of the participants were randomly assigned to the *inclusion* condition (N= 19, N= 18, and N= 23 for the 5-, 7- and 10-year-olds respectively), and the other half to the *ostracism* condition (N= 21, N= 23, and N= 19 for the

5-, 7- and 10-year-olds respectively). Four additional participants were tested but excluded from the final sample due to accuracy values exceeding ± 2.5 standard deviations (N= 1), atypical motor development (N= 1), or because the child refused to take part in the task (N= 2). Based on the existing literature using comparable procedures (Gao & Maurer, 2009, 2010; Wölfer & Scheithauer, 2013) and on an a priori power analysis conducted using the G*Power software (Faul et al., 2007), a sample size of 125 participants was estimated in order to have 80% probability to detect a significant interaction ($\alpha = .05$) with a medium effect size ($r = .25$) in a mixed model, following Cohen's guidelines (Cohen, 1977). Participants were recruited via written invitation based on birth records of neighboring cities. Informed consent was given by both the parents and the children prior to the participation in the study. The procedure followed the ethical standards of the Declaration of Helsinki (BMJ 1991; 302: 1194) and was approved by the Ethical Committee of the University of Milano-Bicocca (Protocol number: 556).

Procedure

The entire study took place online, so each family participated from home on their own computer. Once they accepted to participate in the study, families were sent a document via email containing a detailed description of the procedure, the instructions to complete the task, and a link to access it. The task was carried out on Qualtrics software (Qualtrics, Provo, UT), and was composed of three parts: a training phase, in which children were briefly familiarized with the game and learnt to play the online catch and throw game (Cyberball; Williams et al., 2000), the actual Cyberball phase, in which children participated in the actual Cyberball game consisting in the inclusion or ostracism manipulation, and a test phase, in which they were asked to identify the different emotions expressed on photographs of female faces (Figure 1). Parents were instructed to encourage the child to continue the task if necessary, yet they were asked to sit back and never help the child, who had to complete the task by him or herself. Once parents gave their consent for the participation of their child to the study, they passed on the computer to the child.

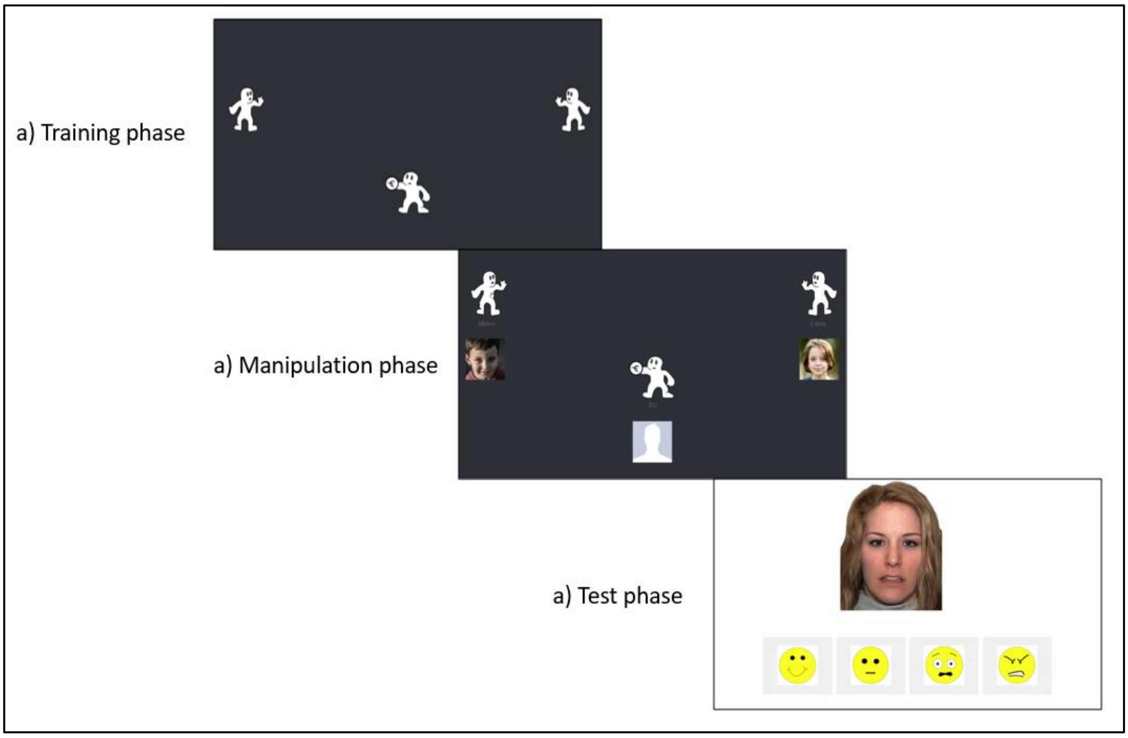

Fig. 1. Illustration of the three phases of the study. In the training phase (a), children were briefly familiarized with the on-line Cyberball game. In the Cyberball phase (b), children participated in the actual Cyberball consisting of the inclusion or ostracism manipulation; to make it more credible that two other children were playing online, two photos representing them were displayed below their avatars during the game. In the emotion recognition test phase (c), children were asked to identify the different emotions expressed on photographs of female faces by clicking on the corresponding schematic face.

Cyberball paradigm

Before starting the Cyberball training phase, children were given detailed video instructions on how to play the game. They were told that they would play a ball tossing game with two other children, Laura and Marco, playing from home too. In reality, the entire game was computer-programmed. They were instructed that when they had the ball, they could throw it to the player of their choice by clicking with the mouse on his or her image, and that when the other players had the ball, they could also decide who to throw it to. Finally, they were explained that the game was not a competition, but a game of imagination, and were asked to imagine being at the park, throwing the ball with Laura and Marco.

The training phase consisted in a very brief version of the Cyberball. Children were explained that this part was merely a training to learn how to play the game. The ball was placed in the hands of the avatar representing the child, who could decide to throw it to one of the other two avatars by clicking on it (Figure 1). The overall training phase lasted five throws, from which two were performed by the child.

Children were then instructed that the real game with the two other children was about to start. To make it more realistic, a message indicating “connection with the other players” was shown before the game started, and two photos representing Laura and Marco were displayed below their avatars during the game. The children were randomly assigned to the condition of social inclusion or ostracism. In both cases, the Cyberball game was programmed to last 18 throws (around 1 minute overall). Children assigned to the *inclusion* condition received the ball a third of the time (i.e., 6 times out of a total of 18 throws), so each player participated to the game equitably. Children assigned to the *ostracism* condition, however, received the ball only twice at the beginning of the game, and were then ignored by the other two players, who kept passing the ball to each other until they reached 18 throws.

This Cyberball paradigm was adapted to children, and based on past research showing that its average effect was large and generalizable across structural (number of throws, duration of ostracism, etc.) and sampling (age, gender, nationality) aspects (for details, see the meta-analysis by Hartgerink et al., 2015). Although most previous studies investigated the effects of Cyberball on adults, a few recent studies confirmed the robustness of the ostracism manipulation on children ranging from 5 to 10 years of age (Abrams et al., 2011; Hawes et al., 2012; Marinović & Träuble, 2018; Over & Carpenter, 2009b; Watson-Jones et al., 2014).

Emotion recognition task

Following the Cyberball game, children participated in the test phase, in which they were asked to identify different emotional expressions on photographs of female faces. They were first explained that they would see photographs of either Flavia or Valentina, who sometimes felt happy, sometimes angry, sometimes scared, and sometimes did not feel anything. Then, the experimenter asked the child to help him understand how the two friends felt. The photographs were presented one by one at the center of the screen, and below were displayed the 4 potential answers in the form of schematic faces expressing happy, angry, fearful or neutral emotions (Figure 2). The children were asked to identify the emotion (or absence of emotion) expressed on Valentina's or Flavia's face, by clicking on the matching schematic face below the photograph. In order to make sure that each child knew which emotion was depicted on the different schematic faces, each emotion was named and associated with the corresponding schematic face during the instruction video before the start of the task. The schematic faces were identical to those used in Gao and Maurer's studies (2009, 2010), and the order of presentation of the photographs and the relative positions of the schematic faces below each photograph were randomly set.

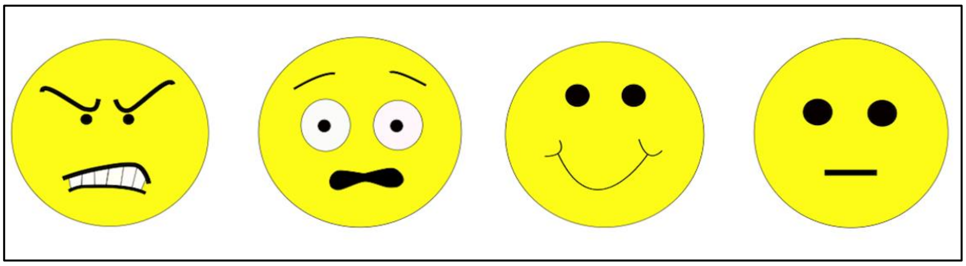

Fig. 2. Schematic faces used in the test phase. From left to right: angry, fearful, happy, and neutral.

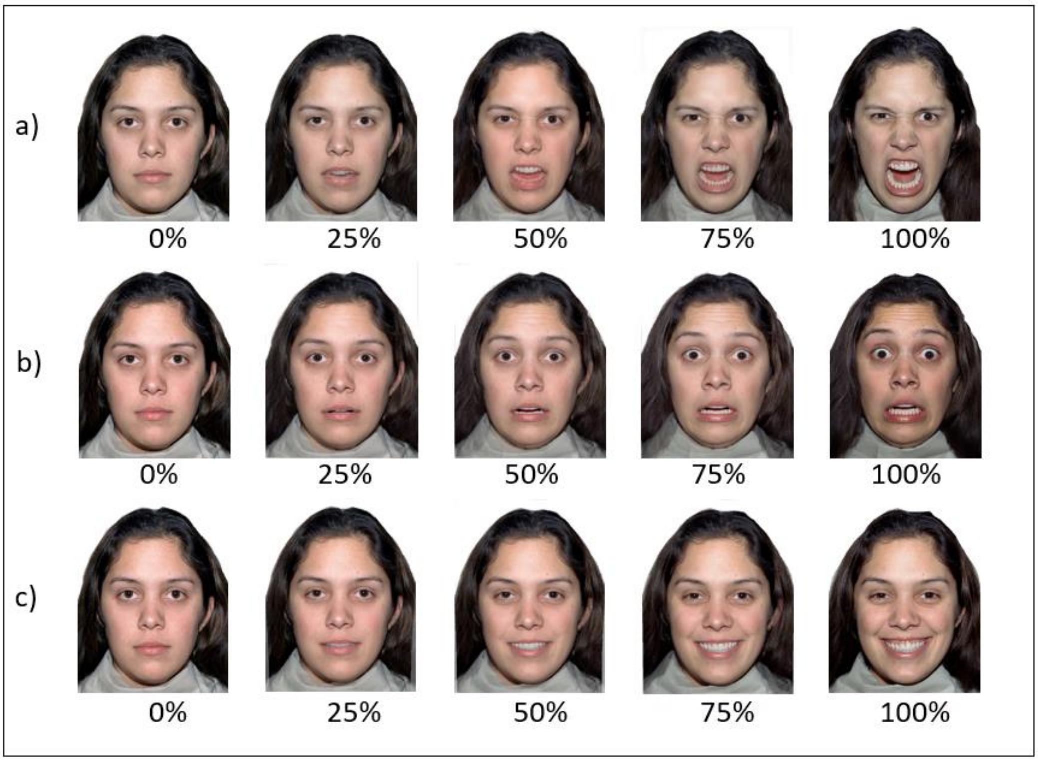

Fig. 3. Examples of stimuli used in the test phase for angry (a), fearful (b), and happy (c) facial expressions at the five intensity levels (0%, 25%, 50%, 75%, and 100%).

Stimuli

The stimuli were extracted from a study by Gao and Maurer (Gao & Maurer, 2009) and were composed of a total of 30 photographs posed by two female models expressing either happiness, anger, fear or neutral expressions. The emotions presented were chosen to match the emotions that children could feel while being included (i.e., happiness) or ostracized (i.e., anger and fear), hypothesizing that feeling an emotion might further facilitate its subsequent recognition, as previously seen in adults (Niedenthal et al., 2000). We also chose to present expressions of fear, as it serves the crucial evolutionary function of signaling a potential danger, which might be relevant when exposed to a social threat such as exclusion. Stimuli were selected from the NimStim Set of Facial Expressions (Tottenham et al., 2009, models 3 and 10), based on adults' high accuracy and intensity ratings for the expressions of anger (M_{acc} = 95%, M_{int} =6.1 on a 7-point scale), fear (M_{acc} = 81.5%, M_{int} =5.9 on a 7-point scale) and happiness (M_{acc} = 99.5%, M_{int} =5.9 on a 7-point scale; (Palermo et al., 2013; Tottenham et al., 2009). They were colored photographs with a resolution of 506 x 650 pixels. Contrary to most studies using only peak intensities, we chose to display photographs of emotional expressions at varying levels of intensity. Indeed, recognizing subtle expressions of emotions might be a great asset for successful social interactions, particularly when attempting to re-connect with others after being excluded. In addition, in the eventuality of children performing perfectly at highest intensities of emotion, differences in emotion recognition abilities might be visible only at lower intensities. Thus, we decided to use Gao and Maurer's stimuli (2009, 2010), who morphed photographs of highly intense facial emotional expressions with photographs of neutral faces of the same models to create different levels of intensity. In this way, they created 20 levels of intensity with 5% increments, ranging from 5 to 100% (for details, see Gao & Maurer, 2009). However, we decided to present only female faces to children, and since our study was held online and comprised two different phases (i.e., Cyberball game and facial recognition task), we kept only a subset of these stimuli and reduce the number of intensity levels to 5 (i.e., intensity of 0%, 25%, 50%, 75% and 100%; Figure 3). Thus, each model expressed three different emotions at five different levels of intensities, resulting in a total of 30 photographs (2 models x 3 emotions x 5 intensities).

Analysis

Following Gao and Maurer (2009, 2010), statistical analyses were performed on two different dependent variables. Indeed, having various levels of intensities meant that children could make two different types of errors. The first type of error was to fail to detect any emotion on a low-intensity emotional face, mistaking it for a neutral face. This type of error was measured by calculating the thresholds at which children detect an emotion on a face, identifying it as non-neutral. The second type of error was the misidentification of an emotion, that is, mistaking one emotion for another. This type of error was calculated by measuring the percentage of misidentification for all faces that were recognized as non-neutral (i.e. above threshold).

Threshold

The thresholds represented the level of intensity at which children identified an expression as non-neutral, that is, children's sensitivity to this emotion. To calculate it, responses were divided into two categories: the neutral responses, when children did not detect any emotion at all (e.g., happiness identified as neutral), and the non-neutral responses, when children detected an emotion, whether it was correct (e.g., happiness identified as happiness) or mistaken (e.g., happiness identified as fear or anger). After Gao and Maurer (2009; 2010), the responses of each participant to each emotion were then fitted with a cumulative Gaussian function to obtain a probability of identification of 0.5. That is, the threshold represented the intensity at which 50% of the time children identified the emotional face as neutral, and 50% of the time they identified it as expressive. The thresholds were calculated for each participant by averaging the thresholds obtained across the two models for each expression. Thus, a low threshold meant that the child successfully identified a face expressing an emotion at low level of intensity as non-neutral. In sum, the child showed a high sensitivity for this emotion.

Misidentification rate

The misidentification rates represented the frequency of erroneous identifications of emotions among the faces that were recognized as non-neutral. Taking into account only the data above threshold, it was calculated by dividing the frequency of misidentification by the total number of responses above threshold. The misidentification rates were calculated for each participant by averaging the rates obtained across the two models for each expression.

Statistical analysis

The same statistical analysis was performed for both thresholds and misidentification rates. Since preliminary analysis indicated no effect of model on the results, all analyses were performed on values averaged across both models. We first conducted a linear mixed model analysis, with age group (5-, 7-, and 10-year-olds), condition (*inclusion*, *ostracism*), and emotion (happiness, anger, and fear) as fixed effects, and intercept as random effect. As the main aim of our study was to investigate the effect of ostracism on emotion recognition in the different age groups, rather than conducting a direct comparison between them, we decided to test the effect of condition and its potential interaction with emotion, separately for each age group. Thus, we performed linear mixed model analyses in each age group independently, with condition (*inclusion*, *ostracism*) and emotion (happiness, anger, and fear) as fixed effects, and intercept as random effect. For each age group with a significant main effect or interaction, planned comparisons were conducted using independent samples t-tests, to examine the effect of condition for each emotion separately. For each age group, we also performed planned comparisons using paired sample t-tests, to investigate differences in recognition of the different emotions within each condition separately. All these comparisons were planned a priori, based on our hypothesis that ostracism may differently affect the recognition of the three emotions. All statistical analyses were performed with Jamovi 1.6.15 (http;//jamovi.org), using a two-tailed 0.05 level of significance.

Results

Threshold

The linear mixed model performed on thresholds revealed a significant main effect of age group, $F(2, 117) = 7.73$, $p < .001$, and a significant main effect of emotion, $F(2, 234) = 14.50$, $p < .001$. Indeed, there was a difference in threshold between 5-year-old children and both 7-year-old *t*(117) = 3.19, *p* = 0.002, and 10-year-old children *t*(117) = 3.60, *p* < 0.001, with 5-year-olds showing higher thresholds than the two other age groups (5-year-olds: *M* = 36.2 , *SD* = 11.9; 7-year-olds: *M* = 31.4, *SD* = 10.9; 10-year-olds: *M* = 30.8, *SD* = 11.6). In addition, there was a significant difference between the threshold for anger and the threshold for fear *t*(234) = 5.36, *p* < 0.001, and happiness *t*(234) = 2.27, *p* = 0.024, and between the threshold for fear and the threshold for happiness *t*(234) = -3.90, *p* = 0.002, with the threshold for anger being higher than both the thresholds for fear and happiness, and the threshold for happiness being higher than the threshold for fear (threshold anger: *M* = 37.3 , *SD* = 8.96; threshold happiness: *M* = 32.6, *SD* = 11.6; threshold fear: *M* = 28.5, *SD* = 13.1). In sum, 5-year-old children were less sensitive to subtle expressions of emotions than 7- and 10-year-olds, and children were overall less sensitive to low intensity expressions of anger as compared to fear and happiness, and less sensitive to low intensity expressions of happiness as compared to fear. In order to further examine the effects of emotion and condition in the different age groups, additional analyses were performed by means of three separate 2 (condition) by 3 (emotion) linear mixed model analysis for each age group.

5-year-old children

The linear mixed model performed on 5-year-olds' thresholds revealed a marginally significant interaction between emotion and condition, *F*(2, 76) = 2.89, *p* = 0.061. No main effect of emotion or condition was observed (all *p*s > .19). Planned comparisons showed a marginally significant difference in threshold for angry expressions between included and ostracized participants, *t*(38) = 1.97 , *p* = 0.056, with children in the *ostracism* condition having a slightly higher threshold for anger (*M* = 41.4 , *SD* = 9.39) than participants in the *inclusion* condition (*M* = 35.7, *SD* = 8.85; Figure 4). In addition, a significant difference in threshold was found between anger and fear, *t*(20) = -2.83 , *p* = 0.010, as well as anger and happiness, *t*(20) = -2.54 , *p* = 0.019, in the ostracism condition, with ostracized children showing higher threshold for anger (*M* = 41.4, *SD* = 9.39) than for fear (*M* = 31.5 , *SD* = 13.47) and happiness (*M* = 35.2 , *SD* = 13.66). In sum, 5-year-old children who were ostracized were less sensitive to subtle angry expressions than to subtle happy and fearful expressions. In addition, they were marginally less sensitive to subtle angry expressions than included children.

7-year-old children

The linear mixed model performed on 7-year-olds' thresholds revealed a significant main effect of emotion, *F*(2, 117) = 5.20, *p* = 0.007. Planned comparisons showed a significant difference between the threshold for fear and the threshold for anger, *t*(40) = -2.92, *p* = 0.006, and happiness, *t*(40) = -2.34, *p* = 0.024. Indeed, 7-year-olds had a lower threshold for fear (*M* = 27.01, *SD* = 13.57) than for anger (*M* = 34.21 , *SD* = 7.55) and happiness (*M* = 32.93 , *SD* = 9.58; Figure 4), showing that they were more sensitive to subtle expressions of fear than anger and happiness. However, no main effect or interaction involving condition was detected (all *p*s > 0.89).

10-year-old children

The linear mixed model performed on 10-year-olds' thresholds also revealed a significant main effect of emotion, *F*(2, 120) = 10.64, *p* < 0.001. Planned comparisons showed a significant difference between the threshold for fear and the threshold for anger, *t*(41) = -4.66, *p* < 0.001, and happiness, *t*(41) = -2.29, *p* = 0.027, as well as a significant difference between the threshold for happiness and the threshold for anger, *t*(41) = -2.20, *p* = 0.033. Indeed, children had a lower threshold for fear (*M* = 25.17, *SD* = 11.21) than for anger (*M* = 36.31, *SD* = 11.43) and happiness (*M* = 30.95, *SD* = 9.66; Figure 4), and a lower threshold for happiness than anger. In sum, 10-year-olds were more sensitive to subtle expressions of fear than anger and happiness, and more sensitive to subtle expressions of happiness as compared to anger. However, no main effect or interaction involving condition was found (all *p*s > 0.49).

Misidentification rate

The linear mixed model performed on misidentification rates did not reveal any main effect or interaction (all ps > 0.15). Similarly, the analyses performed on each age group separately did not yield any significant main effect or interaction (all *p*s > 0.097).

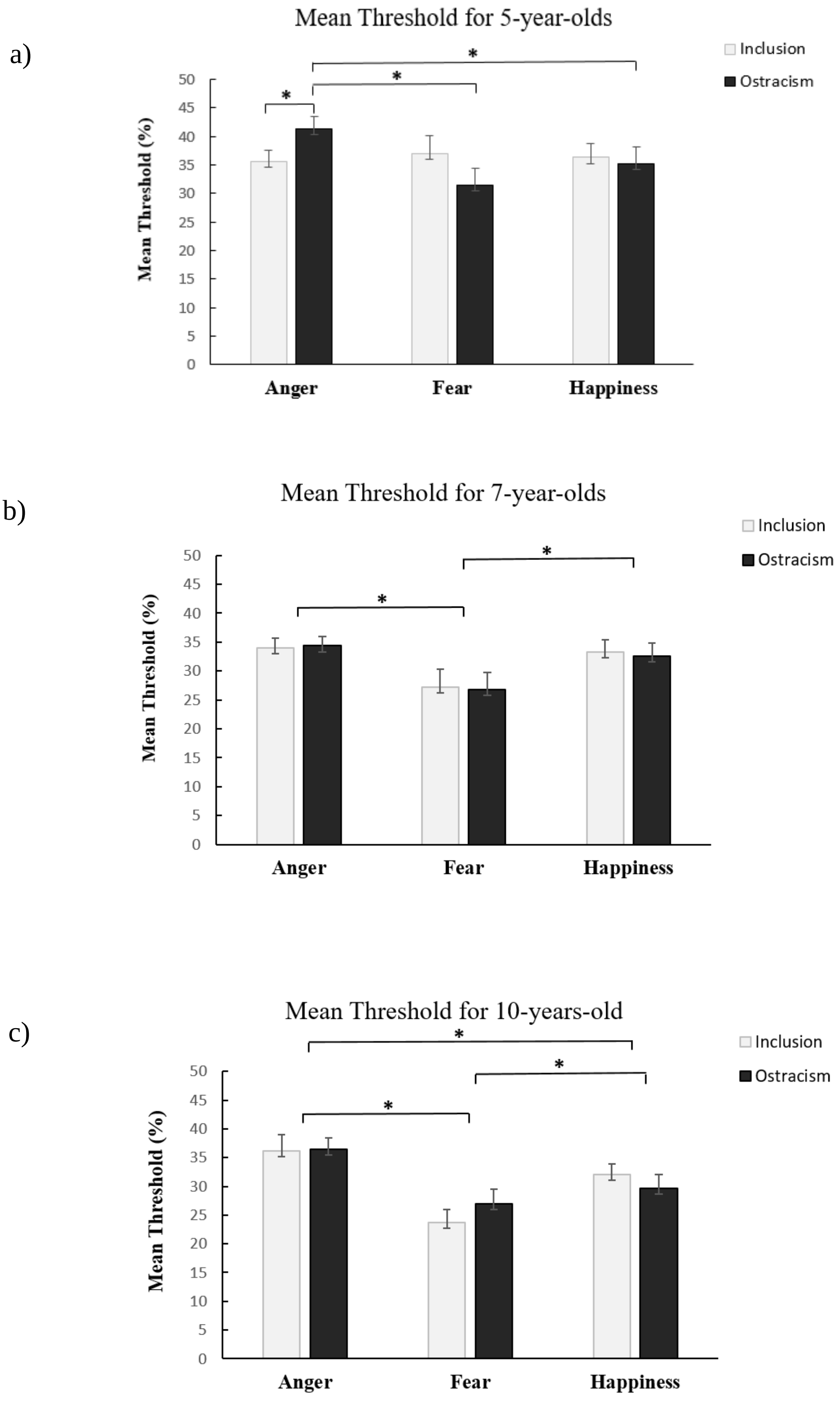

Fig.4. Mean threshold (±SE) for anger, fear and happiness for a) 5-, b) 7- and c) 10-year-olds. 5-year-olds (a) showed a marginally significant interaction between emotion and condition (p = 0.061), with children in the *ostracism* condition having a slightly higher threshold for anger (p = 0. 0.056) than included children, and ostracized children having higher threshold for anger than for fear (p = 0.010) and happiness (p = 0.019). 7-year-olds (b) showed a significant main effect of emotion (p = 0.007), with a significantly lower threshold for fear than for anger (p = 0.006) and happiness (p = 0.024). 10-year-olds (c) also showed a significant main effect of emotion $p < 0.001$, with a significantly lower threshold for fear than for anger ($p < 0.001$) and happiness (p = 0.027), and a significantly lower threshold for happiness than for anger (p = 0.033). * Significant.

Discussion

Most past research examining the consequences of social exclusion on children has focused on its impact at the behavioral level, but very little is known about its influence on children's cognitive capacities. Besides, no study so far has investigated whether children's cognitive response to social exclusion varied across development. The current study aimed at investigating whether ostracism modulates emotion recognition abilities in children, and whether this modulation varies between 5 and 10 years of age. To do so, 5-, 7-, and 10-years-old children participated in an online Cyberball game during which they were either included or ostracized, and then completed a facial emotion recognition task.

Consistent with previous research showing that Cyberball-induced ostracism can affect diverse aspects of children's cognition (Hawes et al., 2012; Marinović et al., 2017; Marinović & Träuble, 2018), our results showed that ostracism elicited marginal changes in children's recognition of emotional facial expressions. More precisely, the present data revealed that the changes in emotion recognition abilities differed in function of children's age and of the emotion considered. Indeed, only 5-year-olds' abilities seemed to be affected by ostracism, while no effect was observed for 7- and 10-year-olds. At 5 years of age, children who were ostracized showed a marginally higher threshold of recognition of angry faces as compared to included children. In addition, ostracized 5-year-olds had a significantly higher threshold of recognition of anger as compared to fear and happiness, which was not the case for included children. Therefore, ostracized children seemed to be less sensitive to angry expressions than included ones, and less sensitive to anger than to fear and happiness. This suggests that ostracism induced an aversive reaction to angry faces in 5-year-olds, which were recognized only when expressed at higher intensities. Children might have felt threatened by social exclusion and experienced unpleasant and aversive feelings towards ostracism, which caused them to avoid further confrontation with aversive and threatening stimuli such as angry faces. However, this avoidant reaction to anger was only observed in 5-years-old children, but not in 7- and 10-year-olds. This might be due to the fact that 5-year-olds were less exposed to ostracism during their life, which might have elicited stronger negative feelings and perception of threat when facing ostracism than older children.

Nonetheless, the effects of ostracism observed in 5-year-olds were only marginal. Although there is a possibility that ostracism only have a minimal impact on children’s recognition of emotions, several other factors could explain this weak effect. The use of only five degrees of intensities, which was aimed at minimizing children’s memory and attentional demands, might have prevented us from observing more subtle differences in emotion recognition, such as differences occurring between 0 and 25 percent of intensity. In addition, the emotions we chose to present to children, as well as the choice of answers they had might have influenced the results. Indeed, we might have observed stronger effects of ostracism by examining emotions other than happiness, fear and anger, or by presenting a different or more various set of answers in the forced-choice procedure. Stronger effects might also have been observed if we had chosen to present more naturalistic dynamic stimuli rather than static images, as previously observed in adults (Ambadar et al., 2005).

Although no effect of ostracism was observed in 7- and 10-years-old children, their recognition abilities nevertheless varied as a function of emotions. Indeed, both age groups were overall significantly more sensitive to subtle expressions of fear than anger and happiness. This might be due to the evolutionary function of signaling a potential danger in the environment, which makes fearful faces particularly relevant irrespective of the surrounding social context, and their recognition prioritized over other emotional expressions. The high saliency of fearful expressions was also highlighted through the analysis of emotion recognition abilities combining all three age groups, which showed that children were overall more sensitive to fear than happiness and anger. In addition, 10-year-olds were more sensitive to subtle expressions of happiness than anger. This might reflect children's higher amount of exposure to happy faces, which may have promoted their recognition, as suggested in previous studies (Pollak et al., 2009; Pollak & Sinha, 2002). These findings are in line with recent research showing that recognition abilities develop more slowly for anger than for fear and happiness, with children only reaching adult-like sensitivity to angry faces after 10 years of age (Gao & Maurer, 2010). This was further supported by the examination of recognition abilities merging all three age groups, which showed that children were overall less sensitive to low intensity expressions of anger as compared to fear and happiness.

Besides depending on the type of emotion observed, recognition abilities also varied with children's age, with 5-year-olds being overall less sensitive to subtle expressions of emotions than 7- and 10-year-olds. This is in agreement with previous research showing that children's accuracy at recognizing emotions, though gradually improving with age, undergoes a sharp increase between 3- and 7-years-old (Camras & Allison, 1985; Durand et al., 2007; Vicari et al., 2000). This might reflect increasing cognitive abilities, such as attention, understanding of social situations, or perspective taking (Choudhury et al., 2006; Rosenqvist et al., 2014), which facilitated the recognition of emotional expressions in older children.

Overall, our results are partially in line with previous research demonstrating that ostracism affects children's cognitive capacities. In agreement with the hypothesis that being socially excluded would modulate subsequent emotion recognition, ostracism led to a marginally decreased sensitivity to angry faces in 5-year-olds, suggesting that facing a social threat induced an aversion for threatening expressions such as anger in younger children. Interestingly, this modulation of recognition capacities was solely observed for angry expressions, and only in the youngest age group. Thus, it seems that the influence of ostracism on emotion recognition skills was not generalized for all emotions and ages, but rather varied as a function of the processed emotion, and of the developmental stage of the ostracized individual. In addition, our findings are contrary to the social monitoring system model, which proposes that the detection of a social threat should direct cognitive resources towards social cues (Pickett et al., 2004). According to this model, and given that emotional faces are inherently social, excluded individuals should show a general improvement in emotion recognition (i.e., for all emotions), similarly to what was observed in adults (Cheung et al., 2015; Pickett et al., 2004). Instead, 5-year-olds showed an aversion for angry faces, and 7- and 10-year-olds did not show any modulation in recognition abilities. Thus, it seems like the effects of ostracism on children substantially differed from those observed in adults. Children might have been differently affected at the psychological level by social exclusion, perhaps because of their overall lower understanding of social interactions, or they might not have been capable of implementing a strategy to re-connect with others like adults. Alternatively, the design of our study might have prevented us from observing an improvement in emotion recognition abilities in children. In particular, the use of only five degrees of intensities (i.e., 0%, 25%, 50%, 75%, and 100%) might have impeded the observation of more subtle differences in emotion recognition, such as differences occurring between 0 and 25 percent of intensity. In addition, the fact that our study was held online, which entailed substantial differences in testing conditions across participants (e.g., size of the screen, familiarity with the use of the computer, environmental distractions), as well as a lack of control of these conditions, might have masked potential differences in children’s emotion recognition.

In conclusion, to fully understand the effects of social exclusion, future research should investigate its physiological and psychological consequences at different developmental stages. This could allow us to link specific psychophysiological alterations with their resulting cognitive and behavioral changes in the different age groups, and better apprehend the developmental patterns in the strategies adopted to cope with ostracism.

This chapter showed that the social context that children are part of, in particular whether this context is inclusive or exclusive, influences their subsequent recognition of facial emotions. Interestingly, this influence seems to be present only in early childhood (i.e., at 5 years of age), while it disappears later in development (i.e., absent at 7 and 10 years of age).

References

Abrams, D., Weick, M., Thomas, D., Colbe, H., & Franklin, K. M. (2011). On-line ostracism affects children differently from adolescents and adults: Ostracism: children, adolescents, adults. *British Journal of Developmental Psychology*, *29*(1), 110–123. https://doi.org/10.1348/026151010X494089

Ambadar, Z., Schooler, J. W., & Cohn, J. F. (2005). Deciphering the Enigmatic Face: The Importance of Facial Dynamics in Interpreting Subtle Facial Expressions. *Psychological Science*, *16*(5), 403–410. https://doi.org/10.1111/j.0956-7976.2005.01548.x

Aslin, R. N., Saffran, J. R., & Newport, E. L. (1998). Computation of Conditional Probability Statistics by 8-Month-Old Infants. *Psychological Science*, *9*(4), 321–324. https://doi.org/10.1111/1467-9280.00063

Augusti, E.-M., Melinder, A., & Gredebäck, G. (2010). Look who’s talking: Pre-verbal infants’ perception of face-to-face and back-to-back social interactions. *Frontiers in Psychology*, *1*. https://doi.org/10.3389/fpsyg.2010.00161

Aviezer, H., Ensenberg, N., & Hassin, R. R. (2017). The inherently contextualized nature of facial emotion perception. *Current Opinion in Psychology*, *17*, 47–54. https://doi.org/10.1016/j.copsyc.2017.06.006

Aviezer, H., Trope, Y., & Todorov, A. (2012). Body Cues, Not Facial Expressions, Discriminate Between Intense Positive and Negative Emotions. *Science*, *338*(6111), 1225–1229. https://doi.org/10.1126/science.1224313

Barrett, L. F., Mesquita, B., & Gendron, M. (2011). Context in Emotion Perception. *Current Directions in Psychological Science*, *20*(5), 286–290. https://doi.org/10.1177/0963721411422522

Batty, M., Meaux, E., Wittemeyer, K., Rogé, B., & Taylor, M. J. (2011). Early processing of emotional faces in children with autism: An event-related potential study. *Journal of Experimental Child Psychology, 109*(4), 430–444. https://doi.org/10.1016/j.jecp.2011.02.001

Baumeister, R. F., & Leary, M. R. (1995). The Need to Belong: Desire for Interpersonal Attachments as a Fundamental Human Motivation. *Psychological Bulletin, 117*(3), 34.

Baumeister, R. F., Twenge, J. M., & Nuss, C. K. (2002). Effects of social exclusion on cognitive processes: Anticipated aloneness reduces intelligent thought. *Journal of Personality and Social Psychology, 83*(4), 817–827. https://doi.org/10.1037/0022-3514.83.4.817

Bernstein, M. J., Young, S. G., Brown, C. M., Sacco, D. F., & Claypool, H. M. (2008). Adaptive Responses to Social Exclusion: Social Rejection Improves Detection of Real and Fake Smiles. *Psychological Science, 19*(10), 981–983. https://doi.org/10.1111/j.1467-9280.2008.02187.x

Bulf, H., Brenna, V., Valenza, E., Johnson, S. P., & Turati, C. (2015). Many faces, one rule: The role of perceptual expertise in infants’ sequential rule learning. *Frontiers in Psychology, 6*. https://doi.org/10.3389/fpsyg.2015.01595

Bulf, H., Johnson, S. P., & Valenza, E. (2011). Visual statistical learning in the newborn infant. *Cognition*, *121*(1), 127–132. https://doi.org/10.1016/j.cognition.2011.06.010

Calder, A. J., Young, A. W., Perrett, D. I., Etcoff, N. L., & Rowland, D. (1996). Categorical Perception of Morphed Facial Expressions. *Visual Cognition*, *3*(2), 81–118. https://doi.org/10.1080/713756735

Camras, L. A., & Allison, K. (1985). Children’s understanding of emotional facial expressions and verbal labels. *Journal of Nonverbal Behavior, 9*(2), 84–94. https://doi.org/10.1007/BF00987140

Carroll, J. M., & Russell, J. A. (1996). Do Facial Expressions Signal Specific Emotions? Judging Emotion From the Face in Context. *Journal of Personality and Social Psychology, 70*(2), 205.

Carter-Sowell, A. R., Chen, Z., & Williams, K. D. (2008). Ostracism increases social susceptibility. *Social Influence*, *3*(3), 143–153. https://doi.org/10.1080/15534510802204868

Cheung, E. O., Slotter, E. B., & Gardner, W. L. (2015). Are you feeling what I'm feeling? The role of facial mimicry in facilitating reconnection following social exclusion. *Motivation and Emotion*, *39*(4), 613–630. https://doi.org/10.1007/s11031-015-9479-9

Choudhury, S., Blakemore, S.-J., & Charman, T. (2006). Social cognitive development during adolescence. *Social Cognitive and Affective Neuroscience*, *1*(3), 165–174. https://doi.org/10.1093/scan/nsl024

Conte, S., Richards, J. E., Guy, M. W., Xie, W., & Roberts, J. E. (2020). Face-sensitive brain responses in the first year of life. *NeuroImage*, *211*, 116602. https://doi.org/10.1016/j.neuroimage.2020.116602

Csibra, G., Hernik, M., Mascaro, O., Tatone, D., & Lengyel, M. (2016). Statistical treatment of looking-time data. *Developmental Psychology*, *52*(4), 521–536. https://doi.org/10.1037/dev0000083

Curtis, W. J., & Cicchetti, D. (2013). Affective Facial Expression Processing in 15-Month-Old Infants Who Have Experienced Maltreatment: An Event-Related Potential Study. *Child Maltreatment*, *18*(3), 140–154. https://doi.org/10.1177/1077559513487944

Dawson, G., Webb, S. J., Carver, L., Panagiotides, H., & McPartland, J. (2004). Young children with autism show atypical brain responses to fearful versus neutral facial expressions of emotion. *Developmental Science, 7*(3), 340–359. https://doi.org/10.1111/j.1467-7687.2004.00352.x

De Haan, M., Johnson, M. H., & Halit, H. (2003). Development of face-sensitive event-related potentials during infancy: A review. *International Journal of Psychophysiology*, *51*(1), 45–58. https://doi.org/10.1016/S0167-8760(03)00152-1

de Haan, M., & Nelson, C. A. (1999). Brain Activity Differentiates Face and Object Processing in 6-Month-Old Infants. *Developmental Psychology*, *35*(4), 1113.

De Haan, M., Pascalis, O., & Johnson, M. H. (2002). Specialization of Neural Mechanisms Underlying Face Recognition in Human Infants. *Journal of Cognitive Neuroscience*, *14*(2), 199–209. https://doi.org/10.1162/089892902317236849

Dennis, T. A., Malone, M. M., & Chen, C.-C. (2009). Emotional Face Processing and Emotion Regulation in Children: An ERP Study. *Developmental Neuropsychology*, *34*(1), 85–102. https://doi.org/10.1080/87565640802564887

DeWall, C. N., Maner, J. K., & Rouby, D. A. (2009a). Social Exclusion and Early-Stage Interpersonal Perception: Selective Attention to Signs of Acceptance. *Journal of Personality and Social Psychology*, *96*(4), 729.

DeWall, C. N., Maner, J. K., & Rouby, D. A. (2009b). Social exclusion and early-stage interpersonal perception: Selective attention to signs of acceptance. *Journal of Personality and Social Psychology*, *96*(4), 729–741. https://doi.org/10.1037/a0014634

Di Lorenzo, R., van den Boomen, C., Kemner, C., & Junge, C. (2020). Charting development of ERP components on face-categorization: Results from a large longitudinal sample of infants. *Developmental Cognitive Neuroscience*, *45*, 100840. https://doi.org/10.1016/j.dcn.2020.100840

Dolan, R. J., Morris, J. S., & de Gelder, B. (2001). Crossmodal binding of fear in voice and face. *Proceedings of the National Academy of Sciences*, *98*(17), 10006–10010. https://doi.org/10.1073/pnas.171288598

D’Souza, J., & Gurin, M. (2016). The universal significance of Maslow’s concept of self-actualization. *The Humanistic Psychologist, 44*(2), 210–214. https://doi.org/10.1037/hum0000027

Durand, K., Gallay, M., Seigneuric, A., Robichon, F., & Baudouin, J.-Y. (2007). The development of facial emotion recognition: The role of configural information. *Journal of Experimental Child Psychology*, *97*(1), 14–27. https://doi.org/10.1016/j.jecp.2006.12.001

Eisenberger, N. I., Lieberman, M. D., & Williams, K. D. (2003). *Does Rejection Hurt? An fMRI Study of Social Exclusion*. *302*, 3.

Ekman, P. (1992). An argument for basic emotions. *Cognition and Emotion*, *6*(3–4), 169–200. https://doi.org/10.1080/02699939208411068

Farroni, T., Menon, E., Rigato, S., & Johnson, M. H. (2007). The perception of facial expressions in newborns. *European Journal of Developmental Psychology*, *4*(1), 2–13. https://doi.org/10.1080/17405620601046832

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, *39*(2), 175–191. https://doi.org/10.3758/BF03193146

Fawcett, C., & Gredebäck, G. (2013). Infants use social context to bind actions into a collaborative sequence. *Developmental Science*, n/a-n/a. https://doi.org/10.1111/desc.12074

Gao, X., & Maurer, D. (2009). Influence of intensity on children’s sensitivity to happy, sad, and fearful facial expressions. *Journal of Experimental Child Psychology*, *102*(4), 503–521. https://doi.org/10.1016/j.jecp.2008.11.002

Gao, X., & Maurer, D. (2010). A happy story: Developmental changes in children's sensitivity to facial expressions of varying intensities. *Journal of Experimental Child Psychology, 107*(2), 67–86. https://doi.org/10.1016/j.jecp.2010.05.003

Gardner, W. L., Pickett, C. L., & Brewer, M. B. (2000). Social Exclusion and Selective Memory: How the Need to belong Influences Memory for Social Events. *Personality and Social Psychology Bulletin*, *26*(4), 486–496. https://doi.org/10.1177/0146167200266007

Geangu, E., Hauf, P., Bhardwaj, R., & Bentz, W. (2011). Infant Pupil Diameter Changes in Response to Others' Positive and Negative Emotions. *PLoS ONE*, *6*(11), e27132. https://doi.org/10.1371/journal.pone.0027132

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), R663–R664. https://doi.org/10.1016/j.cub.2016.05.072

Gebhart, A. L., Newport, E. L., & Aslin, R. N. (2009). Statistical learning of adjacent and nonadjacent dependencies among nonlinguistic sounds. *Psychonomic Bulletin & Review*, *16*(3), 486–490. https://doi.org/10.3758/PBR.16.3.486

Gendron, M., Mesquita, B., & Barrett, L. F. (2013). *Emotion Perception: Putting the Face in Context*. Oxford University Press. https://doi.org/10.1093/oxfordhb/9780195376746.013.0034

Gonsalkorale, K., & Williams, K. D. (2007). The KKK won't let me play: Ostracism even by a despised outgroup hurts. *European Journal of Social Psychology, 37*(6), 1176–1186. https://doi.org/10.1002/ejsp.392

Grossmann, T., Striano, T., & Friederici, A. D. (2006). Crossmodal integration of emotional information from face and voice in the infant brain. *Developmental Science, 9*(3), 309–315. https://doi.org/10.1111/j.1467-7687.2006.00494.x

Grossmann, T., Striano, T., & Friederici, A. D. (2007). Developmental changes in infants' processing of happy and angry facial expressions: A neurobehavioral study. *Brain and Cognition*, *64*(1), 30–41. https://doi.org/10.1016/j.bandc.2006.10.002

Hannon, E. E., & Johnson, S. P. (2005). Infants use meter to categorize rhythms and melodies: Implications for musical structure learning. *Cognitive Psychology*, *50*(4), 354–377. https://doi.org/10.1016/j.cogpsych.2004.09.003

Hartgerink, C. H. J., van Beest, I., Wicherts, J. M., & Williams, K. D. (2015). The Ordinal Effects of Ostracism: A Meta-Analysis of 120 Cyberball Studies. *PLOS ONE*, *10*(5), e0127002. https://doi.org/10.1371/journal.pone.0127002

Hawes, D. J., Zadro, L., Fink, E., Richardson, R., O'Moore, K., Griffiths, B., Dadds, M. R., & Williams, K. D. (2012). The effects of peer ostracism on children's cognitive processes. *European Journal of Developmental Psychology*, *9*(5), 599–613. https://doi.org/10.1080/17405629.2011.638815

Hillyard, S. A., & Anllo-Vento, L. (1998). Event-related brain potentials in the study of visual selective attention. *Proceedings of the National Academy of Sciences*, *95*(3), 781–787. https://doi.org/10.1073/pnas.95.3.781

Hoehl, S., Palumbo, L., Heinisch, C., & Striano, T. (2008). *Infants' attention is biased by emotional expressions and eye gaze direction*. 4.

Hopkins, Z. L., & Branigan, H. P. (2020). Children show selectively increased language imitation after experiencing ostracism. *Developmental Psychology*, *56*(5), 897–911. https://doi.org/10.1037/dev0000915

Hunnius, S., de Wit, T. C. J., Vrins, S., & von Hofsten, C. (2011a). Facing threat: Infants' and adults' visual scanning of faces with neutral, happy, sad, angry, and fearful emotional expressions. *Cognition & Emotion*, *25*(2), 193–205. https://doi.org/10.1080/15298861003771189

Hunnius, S., de Wit, T. C. J., Vrins, S., & von Hofsten, C. (2011b). Facing threat: Infants' and adults' visual scanning of faces with neutral, happy, sad, angry, and fearful emotional expressions. *Cognition & Emotion*, *25*(2), 193–205. https://doi.org/10.1080/15298861003771189

Iidaka, T., Saito, D. N., Komeda, H., Mano, Y., Kanayama, N., Osumi, T., Ozaki, N., & Sadato, N. (2010). Transient Neural Activation in Human Amygdala Involved in Aversive Conditioning of Face and Voice. *Journal of Cognitive Neuroscience*, *22*(9), 2074–2085. https://doi.org/10.1162/jocn.2009.21347

Itier, R. J., & Taylor, M. J. (2002). Inversion and Contrast Polarity Reversal Affect both Encoding and Recognition Processes of Unfamiliar Faces: A Repetition Study Using ERPs. *NeuroImage*, *15*(2), 353–372. https://doi.org/10.1006/nimg.2001.0982

Izard, C. E. (1994). *Innate and Universal Facial Expressions: Evidence From Developmental and Cross-Cultural Research*. 288.

Jack, R. E., Garrod, O. G. B., Yu, H., Caldara, R., & Schyns, P. G. (2012). Facial expressions of emotion are not culturally universal. *Proceedings of the National Academy of Sciences*, *109*(19), 7241–7244. https://doi.org/10.1073/pnas.1200155109

Johnson, S. P., & Aslin, R. N. (1996). Perception of object unity in young infants: The roles of motion, depth, and orientation. *Cognitive Development*, *11*(2), 161–180. https://doi.org/10.1016/S0885-2014(96)90001-5

Kawamoto, T., Nittono, H., & Ura, M. (2014a). Social exclusion induces early-stage perceptual and behavioral changes in response to social cues. *Social Neuroscience*, *9*(2), 174–185. https://doi.org/10.1080/17470919.2014.883325

Kawamoto, T., Nittono, H., & Ura, M. (2014b). Social exclusion induces early-stage perceptual and behavioral changes in response to social cues. *Social Neuroscience*, *9*(2), 174–185. https://doi.org/10.1080/17470919.2014.883325

Kirkham, N. Z., Slemmer, J. A., & Johnson, S. P. (2002). Visual statistical learning in infancy: Evidence for a domain general learning mechanism. *Cognition*, *83*(2), B35–B42. https://doi.org/10.1016/S0010-0277(02)00004-5

Kirkham, N. Z., Slemmer, J. A., Richardson, D. C., & Johnson, S. P. (2007). Location, Location, Location: Development of Spatiotemporal Sequence Learning in Infancy. *Child Development*, *78*(5), 1559–1571. https://doi.org/10.1111/j.1467-8624.2007.01083.x

Kobiella, A., Grossmann, T., Reid, V. M., & Striano, T. (2008). The discrimination of angry and fearful facial expressions in 7-month-old infants: An event-related potential study. *Cognition and Emotion*, *22*(1), 134–146. https://doi.org/10.1080/02699930701394256

Koechlin, E. (1997). Numerical Transformations in Five-month-old Human Infants. *Mathematical Cognition*, *3*(2), 89–104. https://doi.org/10.1080/135467997387425

Kotsoni, E., de Haan, M., & Johnson, M. H. (2001). Categorical Perception of Facial Expressions by 7-Month-Old Infants. *Perception*, *30*(9), 1115–1125. https://doi.org/10.1068/p3155

Kuchuk, A., Vibbert, M., & Bornstein, M. H. (1986). The Perception of Smiling and Its Experiential Correlates in Three-Month-Old Infants. *Child Development*, 1054–1061.

Lakin, J. L., Chartrand, T. L., & Arkin, R. M. (2008). I Am Too Just Like You: Nonconscious Mimicry as an Automatic Behavioral Response to Social Exclusion. *Psychological Science*, *19*(8), 816–822. https://doi.org/10.1111/j.1467-9280.2008.02162.x

Leppänen, J. M., Moulson, M. C., Vogel-Farley, V. K., & Nelson, C. A. (2007a). An ERP Study of Emotional Face Processing in the Adult and Infant Brain. *Child Development*, *78*(1), 232–245. https://doi.org/10.1111/j.1467-8624.2007.00994.x

Leppänen, J. M., Moulson, M. C., Vogel-Farley, V. K., & Nelson, C. A. (2007b). An ERP Study of Emotional Face Processing in the Adult and Infant Brain. *Child Development*, *78*(1), 232–245. https://doi.org/10.1111/j.1467-8624.2007.00994.x

Leppänen, J. M., & Nelson, C. A. (2009). Tuning the developing brain to social signals of emotions. *Nature Reviews Neuroscience, 10*(1), 37–47. https://doi.org/10.1038/nrn2554

Li, W., Zinbarg, R. E., Boehm, S. G., & Paller, K. A. (2008). Neural and Behavioral Evidence for Affective Priming from Unconsciously Perceived Emotional Facial Expressions and the Influence of Trait Anxiety. *Journal of Cognitive Neuroscience, 20*(1), 95–107.

Ludemann, P. M., & Nelson, C. A. (1988). *Categorical Representation of Facial Expressions by 7-Month-Old Infants*. 10.

MacDonald, G., & Leary, M. R. (2005). Why Does Social Exclusion Hurt? The Relationship Between Social and Physical Pain. *Psychological Bulletin*, *131*(2), 202–223. https://doi.org/10.1037/0033-2909.131.2.202

Marinović, V., & Träuble, B. (2018). Vicarious social exclusion and memory in young children. *Developmental Psychology*, *54*(11), 2067–2076. https://doi.org/10.1037/dev0000593

Marinović, V., Wahl, S., & Träuble, B. (2017). “Next to you”—Young children sit closer to a person following vicarious ostracism. *Journal of Experimental Child Psychology, 156,* 179–185. https://doi.org/10.1016/j.jecp.2016.11.011

Masuda, T., Ellsworth, P. C., Mesquita, B., Leu, J., Tanida, S., & Van de Veerdonk, E. (2008). Placing the face in context: Cultural differences in the perception of facial emotion. *Journal of Personality and Social Psychology, 94*(3), 365–381. https://doi.org/10.1037/0022-3514.94.3.365

Meeren, H. K. M., van Heijnsbergen, C. C. R. J., & de Gelder, B. (2005). Rapid perceptual integration of facial expression and emotional body language. *Proceedings of the National Academy of Sciences, 102*(45), 16518–16523. https://doi.org/10.1073/pnas.0507650102

Meier, I. M., van Honk, J., Bos, P. A., & Terburg, D. (2020). *Social touch increases dominant gaze in social confrontations* [Preprint]. PsyArXiv. https://doi.org/10.31234/osf.io/ubyv3

Meyer, M., Baldwin, D. A., & Sage, K. (2011). *Assessing Young Children’s Hierarchical Action Segmentation*. 7.

Monroy, C., Meyer, M., Gerson, S., & Hunnius, S. (2017). Statistical learning in social action contexts. *PLOS ONE, 12*(5), e0177261. https://doi.org/10.1371/journal.pone.0177261

Monroy, C., Meyer, M., Schröer, L., Gerson, S. A., & Hunnius, S. (2019). The infant motor system predicts actions based on visual statistical learning. *NeuroImage, 185,* 947–954. https://doi.org/10.1016/j.neuroimage.2017.12.016

Montague, D. P. F., & Walker-Andrews, A. S. (2001). Peekaboo: A new look at infants’ perception of emotion expressions. *Developmental Psychology, 37*(6), 826–838. https://doi.org/10.1037/0012-1649.37.6.826

Müller, V. I., Habel, U., Derntl, B., Schneider, F., Zilles, K., Turetsky, B. I., & Eickhoff, S. B. (2011). Incongruence effects in crossmodal emotional integration. *NeuroImage*, *54*(3), 2257–2266. https://doi.org/10.1016/j.neuroimage.2010.10.047

Mumenthaler, C., & Sander, D. (2012). Social appraisal influences recognition of emotions. *Journal of Personality and Social Psychology*, *102*(6), 1118–1135. https://doi.org/10.1037/a0026885

Nelson, C. A., & De Haan, M. (1996). Neural correlates of infants' visual responsiveness to facial expressions of emotion. *Developmental Psychobiology*, *29*(7), 577–595. https://doi.org/10.1002/(SICI)1098-2302(199611)29:7<577::AID-DEV3>3.0.CO;2-R

Niedenthal, P. M., Halberstadt, J. B., & Margolin, J. (2000). Emotional state and the detection of change in facial expression of emotion. *Eur. J. Soc. Psychol.*, 12.

Nielsen, M. (2006). Copying actions and copying outcomes: Social learning through the second year. *Developmental Psychology, 42*(3), 555–565. https://doi.org/10.1037/0012-1649.42.3.555

Oakes, L. M. (2017). Sample Size, Statistical Power, and False Conclusions in Infant Looking-Time Research. *Infancy*, *22*(4), 436–469. https://doi.org/10.1111/infa.12186

Over, H., & Carpenter, M. (2009a). Priming third-party ostracism increases affiliative imitation in children. *Developmental Science*, *12*(3), F1–F8. https://doi.org/10.1111/j.1467-7687.2008.00820.x

Over, H., & Carpenter, M. (2009b). Eighteen-Month-Old Infants Show Increased Helping Following Priming with Affiliation. *Psychological Science*, *20*(10), 1189–1193. https://doi.org/10.1111/j.1467-9280.2009.02419.x

Palama, A., Malsert, J., & Gentaz, E. (2018). Are 6-month-old human infants able to transfer emotional information (happy or angry) from voices to faces? An eye-tracking study. *PLOS ONE*, *13*(4), e0194579. https://doi.org/10.1371/journal.pone.0194579

Palermo, R., O’Connor, K. B., Davis, J. M., Irons, J., & McKone, E. (2013). New Tests to Measure Individual Differences in Matching and Labelling Facial Expressions of Emotion, and Their Association with Ability to Recognise Vocal Emotions and Facial Identity. *PLoS ONE*, *8*(6), e68126. https://doi.org/10.1371/journal.pone.0068126

Peltola, M. J., Leppänen, J. M., Palokangas, T., & Hietanen, J. K. (2008). Fearful faces modulate looking duration and attention disengagement in 7-month-old infants. *Developmental Science*, *11*(1), 60–68. https://doi.org/10.1111/j.1467-7687.2007.00659.x

Phelps, E. A., O’Connor, K. J., Cunningham, W. A., Funayama, E. S., Gatenby, J. C., Gore, J. C., & Banaji, M. R. (2000). Performance on Indirect Measures of Race Evaluation Predicts Amygdala Activation. *Journal of Cognitive Neuroscience*, *12*(5), 729–738.

Pickett, C. L., Gardner, W. L., & Knowles, M. (2004). Getting a Cue: The Need to Belong and Enhanced Sensitivity to Social Cues. *Personality and Social Psychology Bulletin*, *30*(9), 1095–1107. https://doi.org/10.1177/0146167203262085

Pollak, S. D., Messner, M., Kistler, D. J., & Cohn, J. F. (2009). Development of perceptual expertise in emotion recognition. *Cognition*, *110*(2), 242–247. https://doi.org/10.1016/j.cognition.2008.10.010

Pollak, S. D., & Sinha, P. (2002). Effects of early experience on children’s recognition of facial displays of emotion. *Developmental Psychology*, *38*(5), 784–791. https://doi.org/10.1037/0012-1649.38.5.784

Pourtois, G., Dan, E. S., Grandjean, D., Sander, D., & Vuilleumier, P. (2005). Enhanced extrastriate visual response to bandpass spatial frequency filtered fearful faces: Time course and topographic evoked-potentials mapping. *Human Brain Mapping*, *26*(1), 65–79. https://doi.org/10.1002/hbm.20130

Quadrelli, E., Conte, S., Macchi Cassia, V., & Turati, C. (2019). Emotion in motion: Facial dynamics affect infants’ neural processing of emotions. *Developmental Psychobiology*, *61*(6), 843–858. https://doi.org/10.1002/dev.21860

Quadrelli, E., Monacò, S., Turati, C., & Bulf, H. (2020). Social context influences infants’ ability to extract statistical information from a sequence of gestures. *Infant Behavior and Development*, *61*, 101506. https://doi.org/10.1016/j.infbeh.2020.101506

Quadrelli, E., Roberti, E., Polver, S., Bulf, H., & Turati, C. (2021). Sensorimotor Activity and Network Connectivity to Dynamic and Static Emotional Faces in 7-Month-Old Infants. *Brain Sciences*, *11*(11), 1396. https://doi.org/10.3390/brainsci11111396

Rajhans, P., Jessen, S., Missana, M., & Grossmann, T. (2016). Putting the face in context: Body expressions impact facial emotion processing in human infants. *Developmental Cognitive Neuroscience*, *19*, 115–121. https://doi.org/10.1016/j.dcn.2016.01.004

Reichenbach, L., & Masters, J. C. (2021). *Children’s Use of Expressive and Contextual Cues in Judgments of Emotion*. 13.

Righart, R., & De Gelder, B. (2006). Context Influences Early Perceptual Analysis of Faces—An Electrophysiological Study. *Cerebral Cortex*, *16*(9), 1249–1257. https://doi.org/10.1093/cercor/bhj066

Roseberry, S., Richie, R., Hirsh-Pasek, K., Golinkoff, R. M., & Shipley, T. F. (2011). Babies Catch a Break: 7- to 9-Month-Olds Track Statistical Probabilities in Continuous Dynamic Events. *Psychological Science*, *22*(11), 1422–1424. https://doi.org/10.1177/0956797611422074

Rosenqvist, J., Lahti-Nuuttila, P., Laasonen, M., & Korkman, M. (2014). Preschoolers’ recognition of emotional expressions: Relationships with other neurocognitive capacities. *Child Neuropsychology*, *20*(3), 281–302. https://doi.org/10.1080/09297049.2013.778235

Rossion, B., & Caharel, S. (2011). ERP evidence for the speed of face categorization in the human brain: Disentangling the contribution of low-level visual cues from face perception. *Vision Research*, *51*(12), 1297–1311. https://doi.org/10.1016/j.visres.2011.04.003

Ruba, A. L., Johnson, K. M., Harris, L. T., & Wilbourn, M. P. (2017). Developmental changes in infants' categorization of anger and disgust facial expressions. *Developmental Psychology*, *53*(10), 1826–1832. https://doi.org/10.1037/dev0000381

Sacco, D. F., Wirth, J. H., Hugenberg, K., Chen, Z., & Williams, K. D. (2011a). The world in black and white: Ostracism enhances the categorical perception of social information. *Journal of Experimental Social Psychology, 47*(4), 836–842. https://doi.org/10.1016/j.jesp.2011.03.001

Sacco, D. F., Wirth, J. H., Hugenberg, K., Chen, Z., & Williams, K. D. (2011b). The world in black and white: Ostracism enhances the categorical perception of social information. *Journal of Experimental Social Psychology*, *47*(4), 836–842. https://doi.org/10.1016/j.jesp.2011.03.001

Saffran, J. R. (2018). Statistical learning as a window into developmental disabilities. *Journal of Neurodevelopmental Disorders*, *10*(1), 35. https://doi.org/10.1186/s11689-018-9252-y

Saffran, J. R., Aslin, R. N., & Newport, E. L. (1996a). Statistical Learning by 8-Month-Old Infants. *Science*, *274*(5294), 1926–1928. https://doi.org/10.1126/science.274.5294.1926

Saffran, J. R., Aslin, R. N., & Newport, E. L. (1996b). Statistical Learning by 8-Month-Old Infants. *Science*, *274*(5294), 1926–1928. https://doi.org/10.1126/science.274.5294.1926

Saffran, J. R., Johnson, E. K., Aslin, R. N., & Newport, E. L. (1999). Statistical learning of tone sequences by human infants and adults. *Cognition*, *70*(1), 27–52. https://doi.org/10.1016/S0010-0277(98)00075-4

Saffran, J. R., & Kirkham, N. Z. (2018). Infant Statistical Learning. *Annual Review of Psychology*, *69*(1), 181–203. https://doi.org/10.1146/annurev-psych-122216-011805

Saffran, J. R., Pollak, S. D., Seibel, R. L., & Shkolnik, A. (2007). Dog is a dog is a dog: Infant rule learning is not specific to language. *Cognition*, *105*(3), 669–680. https://doi.org/10.1016/j.cognition.2006.11.004

Saylor, M. M., Baldwin, D. A., Baird, J. A., & LaBounty, J. (2007). Infants' On-line Segmentation of Dynamic Human Action. *Journal of Cognition and Development*, *8*(1), 113–128. https://doi.org/10.1080/15248370709336996

Schyns, P. G., Petro, L. S., & Smith, M. L. (2007). Dynamics of Visual Information Integration in the Brain for Categorizing Facial Expressions. *Current Biology*, *17*(18), 1580–1585. https://doi.org/10.1016/j.cub.2007.08.048

Smith, M. L., Cottrell, G. W., Gosselin, F., & Schyns, P. G. (2005). Transmitting and Decoding Facial Expressions. *Psychological Science*, *16*(3), 184–189. https://doi.org/10.1111/j.0956-7976.2005.00801.x

Song, R., Over, H., & Carpenter, M. (2015). Children draw more affiliative pictures following priming with third-party ostracism. *Developmental Psychology*, *51*(6), 831–840. https://doi.org/10.1037/a0039176

Stahl, A. E., Romberg, A. R., Roseberry, S., Golinkoff, R. M., & Hirsh-Pasek, K. (2014). Infants Segment Continuous Events Using Transitional Probabilities. *Child Development*, n/a-n/a. https://doi.org/10.1111/cdev.12247

Tager-Flusberg, H. (2010). The origins of social impairments in autism spectrum disorder: Studies of infants at risk. *Neural Networks*, *23*(8–9), 1072–1076. https://doi.org/10.1016/j.neunet.2010.07.008

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. https://doi.org/10.1111/cdev.12348

Teinonen, T., Fellman, V., Näätänen, R., Alku, P., & Huotilainen, M. (2009). Statistical language learning in neonates revealed by event-related brain potentials. *BMC Neuroscience*, *10*(1), 21. https://doi.org/10.1186/1471-2202-10-21

Thiele, M., Hepach, R., Michel, C., Gredebäck, G., & Haun, D. B. M. (2021). Social interaction targets enhance 13-month-old infants' associative learning. *Infancy*, *26*(3), 409–422. https://doi.org/10.1111/infa.12393

Tottenham, N., Tanaka, J. W., Leon, A. C., McCarry, T., Nurse, M., Hare, T. A., Marcus, D. J., Westerlund, A., Casey, B., & Nelson, C. (2009). The NimStim set of facial expressions: Judgments from untrained research participants. *Psychiatry Research*, *168*(3), 242–249. https://doi.org/10.1016/j.psychres.2008.05.006

Twenge, J. M., Baumeister, R. F., Tice, D. M., & Stucke, T. S. (2001). If you can't join them, beat them: Effects of social exclusion on aggressive behavior. *Journal of Personality and Social Psychology*, *81*(6), 1058–1069. https://doi.org/10.1037/0022-3514.81.6.1058

Vacaru, S. V., van Schaik, J. E., de Water, E., & Hunnius, S. (2020). Five-year-olds' facial mimicry following social ostracism is modulated by attachment security. *PLOS ONE*, *15*(12), e0240680. https://doi.org/10.1371/journal.pone.0240680

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. https://doi.org/10.1037/0033-2909.134.3.383

van Heijnsbergen, C. C. R. J., Meeren, H. K. M., Grèzes, J., & de Gelder, B. (2007). Rapid detection of fear in body expressions, an ERP study. *Brain Research*, *1186*, 233–241. https://doi.org/10.1016/j.brainres.2007.09.093

Vicari, S., Reilly, J. S., Pasqualetti, P., Vizzotto, A., & Caltagirone, C. (2000). Recognition of facial expressions of emotions in school-age children: The intersection of perceptual and semantic categories. *Acta Paediatrica*, *89*(7), 836–845. https://doi.org/10.1111/j.1651-2227.2000.tb00392.x

Vlach, H. A., & Johnson, S. P. (2013). Memory constraints on infants' cross-situational statistical learning. *Cognition*, *127*(3), 375–382. https://doi.org/10.1016/j.cognition.2013.02.015

Vuilleumier, P., & Pourtois, G. (2007). Distributed and interactive brain mechanisms during emotion face perception: Evidence from functional neuroimaging. *Neuropsychologia*, *45*(1), 174–194. https://doi.org/10.1016/j.neuropsychologia.2006.06.003

Warburton, W. A., Williams, K. D., & Cairns, D. R. (2006a). When ostracism leads to aggression: The moderating effects of control deprivation. *Journal of Experimental Social Psychology*, *42*(2), 213–220. https://doi.org/10.1016/j.jesp.2005.03.005

Warburton, W. A., Williams, K. D., & Cairns, D. R. (2006b). When ostracism leads to aggression: The moderating effects of control deprivation. *Journal of Experimental Social Psychology*, *42*(2), 213–220. https://doi.org/10.1016/j.jesp.2005.03.005

Watson-Jones, R. E., Legare, C. H., Whitehouse, H., & Clegg, J. M. (2014). Task-specific effects of ostracism on imitative fidelity in early childhood. *Evolution and Human Behavior*, *35*(3), 204–210. https://doi.org/10.1016/j.evolhumbehav.2014.01.004

Watson-Jones, R. E., Whitehouse, H., & Legare, C. H. (2016). In-Group Ostracism Increases High-Fidelity Imitation in Early Childhood. *Psychological Science, 27*(1), 34–42. https://doi.org/10.1177/0956797615607205

Widen, S. C., & Russell, J. A. (2008). Children acquire emotion categories gradually. *Cognitive Development*, *23*(2), 291–312. https://doi.org/10.1016/j.cogdev.2008.01.002

Widen, S. C., & Russell, J. A. (2010). Differentiation in preschooler's categories of emotion. *Emotion*, *10*(5), 651–661. https://doi.org/10.1037/a0019005

Wieser, M. J., & Brosch, T. (2012). Faces in Context: A Review and Systematization of Contextual Influences on Affective Face Processing. *Frontiers in Psychology, 3*. https://doi.org/10.3389/fpsyg.2012.00471

Wieser, M. J., Gerdes, A. B. M., Büngel, I., Schwarz, K. A., Mühlberger, A., & Pauli, P. (2014). Not so harmless anymore: How context impacts the perception and electrocortical processing of neutral faces. *NeuroImage*, *92*, 74–82. https://doi.org/10.1016/j.neuroimage.2014.01.022

Williams, K. D. (2007). Ostracism. *Annual Review of Psychology*, *58*(1), 425–452. https://doi.org/10.1146/annurev.psych.58.110405.085641

Williams, K. D. (2009). Ostracism: A Temporal Need-Threat Model. In *Advances in Experimental Social Psychology* (Vol. 41, pp. 275–314). Elsevier. https://doi.org/10.1016/S0065-2601(08)00406-1

Williams, K. D., Cheung, C. K. T., & Choi, W. (2000). Cyberostracism: Effects of being ignored over the Internet. *Journal of Personality and Social Psychology*, *79*(5), 748–762. https://doi.org/10.1037/0022-3514.79.5.748

Williams, K. D., & Nida, S. A. (2011a). Ostracism: Consequences and Coping. *Current Directions in Psychological Science, 20*(2), 71–75. https://doi.org/10.1177/0963721411402480

Williams, K. D., & Nida, S. A. (2011b). Ostracism: Consequences and Coping. *Current Directions in Psychological Science*, *20*(2), 71–75. https://doi.org/10.1177/0963721411402480

Wölfer, R., & Scheithauer, H. (2013). Ostracism in childhood and adolescence: Emotional, cognitive, and behavioral effects of social exclusion. *Social Influence*, *8*(4), 217–236. https://doi.org/10.1080/15534510.2012.706233

Yan, X., Andrews, T. J., & Young, A. W. (2016). Cultural similarities and differences in perceiving and recognizing facial expressions of basic emotions. *Journal of Experimental Psychology: Human Perception and Performance*, *42*(3), 423–440. https://doi.org/10.1037/xhp0000114

Zadro, L., & Gonsalkorale, K. (2014). Sources of Ostracism: The Nature and Consequences of Excluding and Ignoring Others. *Current Directions in Psychological Science*, *23*(2), 93–97. https://doi.org/10.1177/0963721413520321

Zadro, L., Hawes, D. J., Iannuzzelli, R. E., Godwin, A., MacNevin, G., Griffiths, B., & Gonsalkorale, K. (2013). Ostracism and Children: A Guide to Effectively Using the Cyberball Paradigm With a Child Sample. *International Journal of Developmental Science*, *7*(1), 7–11. https://doi.org/10.3233/DEV-1312112

Conclusion

Recent research on adults has demonstrated that although facial expressions do convey crucial emotional information, their processing is highly susceptible to contextual influences (Aviezer et al., 2017; Wieser & Brosch, 2012). Indeed, adults' neural processing, recognition and evaluation of facial expressions were found to be highly modulated by a large variety of contextual cues, ranging from a simple visual background (Righart & De Gelder, 2006), to individuals' social and affective experiences (Cheung et al., 2015; Iidaka et al., 2010; Pickett et al., 2004; Sacco et al., 2011a). Nonetheless, evidence of such contextual influence on the processing of emotional faces in infancy and childhood is still scarce and limited to a very small subset of contextual cues.

This thesis aimed to extend previous evidence of contextual effects to cues that were never examined previously in infants and children, and to examine whether such effects applied to different developmental stages. In particular, it focused on two types of cues, emotional (chapter 1 and 2) and social contextual cues (chapter 3 and 4), and on their influence on different aspects of emotional facial processing in infants and children.

The first chapter of this thesis showed that the **surrounding facial emotional context influences 12-months-old infants' attention to facial emotions**. In particular, this study indicated that the specific order in which facial emotions were presented oriented infants' looking times to the different emotions, reflecting their capacity to learn regularities in their order of presentation. The second chapter, although based on preliminary results, suggests that **emotional contextual cues presented under the form of priming action kinematics influence the subsequent neural processing of emotional faces in 12-months-old infants**. In particular, their early visual neural processing was modulated by the affective content of the previous action kinematics. Nonetheless, these results are preliminary and the sample size needs to be considerably increased to be able to draw reliable conclusions. The third chapter, also based on intermediate results, indicates that **previous contextual cues of social inclusion and exclusion influence 13-months-olds' subsequent neural processing of emotional faces**. Specifically, contextual effects were observed at the level of early visual neural processes, and differed between facial emotions. Finally, the fourth chapter of this thesis shows that **the social context in which children are involved, in particular whether they are socially included or excluded, influences their subsequent recognition of facial emotions**. Importantly, this modulation in emotion recognition seemed to vary as a function of children's age (i.e., present only in 5-year-olds), and of the emotion considered.

Altogether, the four studies presented in this thesis added new insights to the current literature by showing that different types of contextual cues affected various aspects of infants' and children's processing of emotional faces. First of all, the influence of emotional context on infants' processing of emotional faces, which was so far limited to contextual voices (Grossmann et al., 2006; Palama et al., 2018), bodies (Rajhans et al., 2016), and situations (Reichenbach & Masters, 2021; Widen & Russell, 2010), was extended to facial emotional context (Chapter 1) and emotional kinematic contextual cues (Chapter 2). In addition, contextual cues of social inclusion and exclusion were shown to modulate infants' and children's processing of facial expressions (Chapters 3 and 4), adding to the few previous evidence of contextual effects induced by social cues, such as familiar peekaboo game context (Montague & Walker-Andrews, 2001) or past experience of physical abuse (Pollak et al., 2009), on children's recognition of emotions. Importantly, in all four studies, contextual cues were presented previously, and not simultaneously, to the emotional faces. Besides ensuring that the observed contextual effects are not induced by differences in low-level features, it also emphasizes the strength of the contextual cues, which are powerful enough to influence the subsequent processing of facial expressions.

Interestingly, contextual cues were found to affect infants' and children's processing of emotional faces at different levels. Indeed, Chapters 2 and 3 showed that emotional and social cues induced very early stage automatic changes in infants' neural processing of facial expressions. On the other hand, Chapter 1 indicated contextual effects on later automatic attentional processes, observed at the behavioral level in infants. Finally, Chapter 4 evidenced the presence of contextual effects at the level of the more "controlled" process of emotion recognition in children. Thus, contextual effects seem to be visible at each level of the processing of facial expressions. Future research should investigate whether the changes observed at the different levels are fully distinct or rather inter-dependent, and whether the presence of contextual effects on one level of processing entails their presence on another level.

Finally, in addition to confirm the existence of contextual effects at different developmental stages (i.e., infancy and childhood), the studies exposed in this thesis suggest that these effects vary in function of the individuals' age. In particular, Chapter 4 shows that the exact same social context modulates the recognition of facial expressions in 5-, but not 7 and 10-year-olds, and that this modulation differs from that previously found in adults (Cheung et al., 2015; Pickett et al., 2004). Thus, the influence of context on the processing of facial expressions, despite being present in infancy, childhood and adulthood, seem to evolve with development. This evolution might reflect differences in experience of social and emotional situations, in basic neural processes or in other cognitive abilities (e.g., attention, understanding of social situations, or perspective taking; Choudhury et al., 2006; Rosenqvist et al., 2014), or might even be a results of all these factors. Future research could address this question through the implementation of longitudinal studies examining the contextual effects of identical cues on populations of different ages and developmental stages.

In sum, this thesis suggests that the influence of context on facial emotion processing varies as a function of the type of contextual cues, the level of processing, and of the developmental stage of the perceiver. Contextual cues, whether they are presented concurrently or prior to the target facial expressions, seem to consistently modulate emotional processing. This is not entirely surprising given that in real life, when observing a facial expression, individuals will not only receive inputs from the expresser's face but also from a variety of additional factors surrounding or intrinsic to the perceiver. In particular, three main categories of contextual cues will influence emotion processing: contextual cues originated from the expresser, such as the expresser's body movement (similarly to Chapter 2) or vocalization; contextual cues present in the environment, for instance the presence of other persons (similarly to Chapter 1) or the background scene; and contextual cues internal to the perceiver, such as their past experiences (similarly to Chapter 3 and 4) or psychophysiological state (Aviezer et al., 2017). All these factors, even when not directly – or at all – informative of the expresser's emotional state, will shape the way the facial expression is processed (Gendron et al., 2013), potentially affecting several levels of the processing such as at the neural (Chapter 2 and 3), attentional (Chapter 1) or behavioral (Chapter 4) levels. Therefore, as illustrated by the four studies presented in this thesis, different contextual factors will have a different influence on the processing of facial emotions, potentially modulating a different level of this processing.

These results are consistent with the embodied cognition theory, which states that the body as well as the environment it is embedded in are inextricably linked to cognition (Barsalou, 2008a; Clark, 2011; Schubert, & Semin, 2009; Stapleton, 2013). This theory puts a particular emphasis on the idea that cognition is defined by individuals' interactions with their environment and the specific sensorimotor and neurophysiological changes resulting from these interactions (Ferreira 2021; Schilbart 2013). Environmental factors, although often neglected in developmental research, play a fundamental part in human cognition from the very beginning of their life. Indeed, infants and children essentially learn by perceiving and acting upon the world, constantly interacting with their environment (Needham & Libertus, 2011; Smith & Gasser 2015). This suggests that as the body grows and undergoes drastic changes throughout infancy and childhood, their interactions with the environment evolve, and so does their cognition. Thus, the way individuals process stimuli and the influence environmental and contextual factors have on this processing is likely to change as a function of their development stage. Indeed, this thesis indicates that infants' emotional processing is already highly modulated by contextual cues at one year of age, and that contextual effects greatly vary from one year to another during development. This suggests that the role of context on emotion processing in real life is much more significant that previously assumed. In fact, given that individuals are always integrated in a certain physical context, and that their internal state and past experiences themselves constitute a certain social emotional context, does "de-contextualized" emotional processing even exist? As Gendron and colleagues (Gendron et al., 2013) elegantly formulated: "*context not only influences emotion perception, but it might be intrinsic to seeing an emotion in the first place*".

References

Aviezer, H., Ensenberg, N., & Hassin, R. R. (2017). The inherently contextualized nature of facial emotion perception. Current Opinion in Psychology, 17, 47–54. https://doi.org/10.1016/j.copsyc.2017.06.006

Barsalou, L. W. (2008). Grounded Cognition. Annual Review of Psychology, 59(1), 617–645. https://doi.org/10.1146/annurev.psych.59.103006.093639

Cheung, E. O., Slotter, E. B., & Gardner, W. L. (2015). Are you feeling what I'm feeling? The role of facial mimicry in facilitating reconnection following social exclusion. Motivation and Emotion, 39(4), 613–630. https://doi.org/10.1007/s11031-015-9479-9

Choudhury, S., Blakemore, S.-J., & Charman, T. (2006). Social cognitive development during adolescence. Social Cognitive and Affective Neuroscience, 1(3), 165–174. https://doi.org/10.1093/scan/nsl024

Clark, A. (2011). Précis of Supersizing the mind: Embodiment, action, and cognitive extension (Oxford University Press, NY, 2008). Philosophical Studies, 152(3), 413–416. https://doi.org/10.1007/s11098-010-9597-x

Ferreira, J. M. (2021). What If We Look at the Body? An Embodied Perspective of Collaborative Learning. Educational Psychology Review, 33(4), 1455–1473. https://doi.org/10.1007/s10648-021-09607-8

Gendron, M., Mesquita, B., & Barrett, L. F. (2013). Emotion Perception: Putting the Face in Context. Oxford University Press. https://doi.org/10.1093/oxfordhb/9780195376746.013.0034

Grossmann, T., Striano, T., & Friederici, A. D. (2006). Crossmodal integration of emotional information from face and voice in the infant brain. Developmental Science, 9(3), 309–315. https://doi.org/10.1111/j.1467-7687.2006.00494.x

Hunnius, S., de Wit, T. C. J., Vrins, S., & von Hofsten, C. (2011). Facing threat: Infants' and adults' visual scanning of faces with neutral, happy, sad, angry, and fearful emotional expressions. Cognition & Emotion, 25(2), 193–205. https://doi.org/10.1080/15298861003771189

Leppänen, J. M., Moulson, M. C., Vogel-Farley, V. K., & Nelson, C. A. (2007). An ERP Study of Emotional Face Processing in the Adult and Infant Brain. Child Development, 78(1), 232–245. https://doi.org/10.1111/j.1467-8624.2007.00994.x

Montague, D. P. F., & Walker-Andrews, A. S. (2001). Peekaboo: A new look at infants' perception of emotion expressions. Developmental Psychology, 37(6), 826–838. https://doi.org/10.1037/0012-1649.37.6.826

Needham, A., & Libertus, K. (2011). Embodiment in early development. WIREs Cognitive Science, 2(1), 117–123. https://doi.org/10.1002/wcs.109

Palama, A., Malsert, J., & Gentaz, E. (2018). Are 6-month-old human infants able to transfer emotional information (happy or angry) from voices to faces? An eye-tracking study. PLOS ONE, 13(4), e0194579. https://doi.org/10.1371/journal.pone.0194579

Pickett, C. L., Gardner, W. L., & Knowles, M. (2004). Getting a Cue: The Need to Belong and Enhanced Sensitivity to Social Cues. Personality and Social Psychology Bulletin, 30(9), 1095–1107. https://doi.org/10.1177/0146167203262085

Pollak, S. D., Messner, M., Kistler, D. J., & Cohn, J. F. (2009). Development of perceptual expertise in emotion recognition. Cognition, 110(2), 242–247. https://doi.org/10.1016/j.cognition.2008.10.010

Quadrelli, E., Conte, S., Macchi Cassia, V., & Turati, C. (2019). Emotion in motion: Facial dynamics affect infants' neural processing of emotions. Developmental Psychobiology, 61(6), 843–858. https://doi.org/10.1002/dev.21860

Rajhans, P., Jessen, S., Missana, M., & Grossmann, T. (2016). Putting the face in context: Body expressions impact facial emotion processing in human infants. Developmental Cognitive Neuroscience, 19, 115–121. https://doi.org/10.1016/j.dcn.2016.01.004

Reichenbach, L., & Masters, J. C. (2021). Children's Use of Expressive and Contextual Cues in Judgments of Emotion. 13.

Rosenqvist, J., Lahti-Nuuttila, P., Laasonen, M., & Korkman, M. (2014). Preschoolers' recognition of emotional expressions: Relationships with other neurocognitive capacities. Child Neuropsychology, 20(3), 281–302. https://doi.org/10.1080/09297049.2013.778235

Schilbach, L., Timmermans, B., Reddy, V., Costall, A., Bente, G., Schlicht, T., & Vogeley, K. (2013). Toward a second-person neuroscience. Behavioral and Brain Sciences, 36(4), 393–414. https://doi.org/10.1017/S0140525X12000660

Schubert, T. W., & Semin, G. R. (2009). Embodiment as a unifying perspective for psychology. European Journal of Social Psychology, 39(7), 1135–1141. https://doi.org/10.1002/ejsp.670

Smith, L., & Gasser, M. (2005). The Development of Embodied Cognition: Six Lessons from Babies. Artificial Life, 11(1–2), 13–29. https://doi.org/10.1162/1064546053278973

Stapleton, M. (2013). Steps to a "Properly Embodied" cognitive science. Cognitive Systems Research, 22–23, 1–11. https://doi.org/10.1016/j.cogsys.2012.05.001

Widen, S. C., & Russell, J. A. (2010). Differentiation in preschooler's categories of emotion. Emotion, 10(5), 651–661. https://doi.org/10.1037/a0019005

Acknowledgment

I would like to thank the people who helped and supported me throughout these three years of PhD, and contributed to make it a stimulating and pleasant journey.

First of all, I would like to thank my supervisors, Chiara Turati and Hermann Bulf, for teaching me a lot, always giving me great advice and useful feedback, and supporting me through all the steps of this PhD.

I would also like to thank Ermanno Quadrelli, who taught me a lot during these three years and always took the time to help me when I was stuck, and to share/lose a game of “Spot It” when I needed distraction.

Thank you to the entire team of the Babylab, who always managed to bring some kindness and happiness to the lab. It is extremely precious to work in a spirit of mutual aid and friendship. Special thanks to Giada, Anna, Caterina and Alessia, who made the 8am testings a little bit easier, not only for the croissants they brought, but also thanks to their enthusiasm and kindness.

I am extremely grateful to my family, for its unconditional support and encouragements throughout my entire academic journey, and for the anonymous bottle of Champagne I received after submitting my thesis. None of this would have been possible without you.

Last but not least, a huge thank you to Duccio, who supported my ups and downs, always found the right words to motivate and comfort me, and to make me forget about work during weekends. But above all, thank you for accepting to be part of one of my studies. I believe you have a great career of actor ahead of you!

The work described in this doctoral thesis has been carried out as part of the European Union’s Horizon 2020 research and innovation program under the Marie Skłodowska-Curie grant agreement No. 765298.