



# Individual differences in infants' neural responses to their peers' cry and laughter

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## ABSTRACT

Infants' ability to process others' emotional expressions is fundamental for their social development. While infants' processing of emotions expressed by faces and speech has been more extensively investigated, less is known about how infants process non-verbal vocalizations of emotions. Here, we recorded frontal N100, P200, and LPC event-related potentials (ERPs) from 8-month-old infants listening to sounds of other infants crying, laughing, and coughing. Infants' temperament was measured via parental report. Results showed that processing of emotional information from non-verbal vocalizations was associated with more negative N100 and greater LPC amplitudes for peer's crying sounds relative to positive and neutral sounds. Temperament was further related to the N100, P200, and LPC difference scores between conditions. One important finding was that infants with improved ability to regulate arousal exhibited increased sustained processing of peers' cry sounds compared to both laughter and cough sounds. These results emphasize the relevance of considering the temperamental characteristics in understanding the development of infant emotion information processing, as well as for formulating comprehensive theoretical models of typical and atypical social development.

## 1. Introduction

Nonverbal vocalizations of emotions such as laughter and crying are human universals, providing unambiguous and genuine information about our emotions (Barr, Hopkins, & Green, 2000; Dunbar, Baron, & Frangou, 2012; Paulmann & Kotz, 2008; Provine, 2004, 2016; Sauter, Eisner, Ekman, & Scott, 2010; Scherer, 1986, 1995). Both the production and the accurate interpretation of these social signals are thought to play crucial roles in communication, social bonding and elicitation of prosocial behaviors, and may be early precursors to empathy development (Decety, 2015; Decety & Howard, 2013; Geangu, 2015; Hoffman, 2000). Evidence suggests that nonverbal vocalizations of emotions may be important for our early social lives (e.g., Barr et al., 2000; Ostwald & Murry, 1985; Ross, Owren, & Zimmermann, 2009). For example, the presence of adults' laughter during adult-infant encounters is important for generating humorous situations which promote social closeness and interaction, potentially contributing to the development of mental state understanding (Ishijima & Negayama, 2017; Mireault, Sparrow, Poutre, Perdue, & Macke, 2012; Mireault, Poutre et al., 2012). Both the atypical sensitivity to others' nonverbal vocalizations of emotions and their production have been associated

with risk for developmental disorders characterized by impaired social functioning, such as autism (Blasi et al., 2015; Esposito, Nakazawa, Venuti, & Bornstein, 2013; Esposito, Venuti, & Bornstein, 2011; Reddy, Williams, & Vaughan, 2002). Despite their significance, the processing and use of nonverbal vocalizations of emotions, particularly during early development, remains understudied (Dunbar et al., 2012; Geangu, 2015; Pell et al., 2015; Provine, 1996).

Infancy is a crucial time period for tuning and optimising the brain circuitry for processing stimuli with socio-emotional relevance and emotional responsivity, setting the stage for both the refinement of the early acquired social skills and the emergence of new and more complex ones later in life (Johnson, 2011; Karmiloff-Smith, 1998). Both typical and atypical social developmental outcomes are the result of complex interactions between the developing social brain and the child's environment. While some of the outcomes are the direct consequence of the initial genetic or environmental characteristics, some reflect secondary 'cascading' effects of the genes-environment interactions at different points during ontogeny (Johnson, Gliga, Jones, & Charman, 2015). For example, it has been shown that 7-month-old infants with reduced attentional biases towards threat cues (e.g., facial expressions of fear) are more likely to develop disorganized patterns of

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attachment with their caregivers, compared to infants with normative manifestations of such emotional biases (Peltola, Forssman, Puura, van IJzendoorn, & Leppänen, 2015). The development within this disorganized relational environment may further shape representational, physiological, and behavioural responses to emotional information, contributing to atypical social outcomes such as externalizing behaviours and poor social competence with peers (Groh et al., 2014). At the manifestation stage of atypical developmental outcomes, access to the early mechanisms precipitating their emergence is lost (Johnson et al., 2015; Morales, Fu, & Pérez-Edgar, 2016). From this perspective, the investigation of the neurocognitive mechanisms underlying emotional information processing and potential individual variations during infancy is essential for understanding typical and atypical social development, as well as for identifying methods for early detection and intervention (e.g., Bunford, Kujawa, Swain et al., 2017; Johnson et al., 2015; Morales et al., 2016). Towards this aim, the current study investigates infants' neural responses to their peers' nonverbal vocalizations of emotions and temperamental variations in such responses by using event-related potentials (ERPs).

Within a few hours after birth infants already manifest distress vocalizations when they hear the sound of another infant crying (Dondi, Simion & Caltran, 1999; Field, Diego, Hernandez-Reif, & Fernandez, 2007; Geangu, Benga, Stahl & Striano, 2010; Martin & Clark, 1982; Sagi & Hoffman, 1976; Simner, 1971). Such distress responses are more intense when neonates hear a human infant cry rather than an infant chimpanzee cry (Martin & Clark, 1982), while artificial noise does not elicit such responses (Sagi & Hoffman, 1976; Simner, 1971). Neonates also have the capacity to perceptually discriminate between their own cry and the cry of another same age infant (Dondi et al., 1999; Martin & Clark, 1982). Throughout the first year of life, infants continue to respond with facial and vocal distress to the crying sounds of their peers (Geangu et al., 2010), and this increase in arousal persists throughout toddlerhood, although with lesser intensity (Nichols, Svetlova, & Brownell, 2009; Nichols, Svetlova, & Brownell, 2015). When jointly presented with the corresponding facial expressions, the overt responses elicited by peer emotional vocalizations are accompanied by autonomic arousal changes. In 6-, 12-, and 15-month-old infants (Geangu, Hauf, Bhardwaj, & Bentz, 2011; Upshaw, Kaiser, & Sommerville, 2015), observation of audio-video recordings of a peer crying or laughing elicited an increase in pupil diameter reflecting autonomic sympathetic activation (Bradley, Miccoli, Escrig, & Lang, 2008). The valence of the stimuli, however, moderated the latency of pupil response with crying eliciting an early response already present at 6-months, while laughter had a delayed pupil response at 6-months, it shared a similar latency as crying by 12-months (Geangu et al., 2011). Overall, observing crying peers elicited greater arousal compared to observing laughter (Geangu et al., 2011; Upshaw et al., 2015). Taken together, these early signs of affect sharing suggest that infants' ability to detect and process non-verbal vocalizations of emotions is present from birth and continues to develop throughout infancy. However, it is unclear whether these behavioral and physiological responses reflect developments in the sensory encoding of the stimuli and/or perceptual and cognitive processing.

Measuring neural responses via event-related potentials (ERPs) can provide further information in this respect. One important characteristic of this method is its unique temporal resolution, allowing millisecond precision in detecting the change of the electrical activity of the brain locked to the stimulus onset and associated with different sensory and cognitive processes (Luck, 2015). This method is also suitable and accessible for studying individuals across the entire lifespan starting with birth (unlike some neuroimaging methods – e.g., functional magnetic resonance imaging [fMRI]), which facilitates the understanding of sensory and cognitive development in relation to brain maturation (de Haan & Johnson, 2005). Moreover, these features also facilitate the study of individual variability across ontogeny which is not otherwise observable by using behavioural methods alone (Bunford,

Kujawa, Fitzgerald et al., 2017).

Based on electrophysiological evidence from adults, Schirmer and Kotz (2006) proposed a three-stage model for processing emotional vocalizations. At the first stage of processing, the brain shows sensitivity to the embedded emotional information as early as 100–200 ms after stimulus onset; indexed by the emergence of an N100 and P200 (Jessen & Kotz, 2011; Liu et al., 2012; Pell et al., 2015; Paulmann, Bleichner, & Kotz, 2013; Schirmer, Kotz, & Friederici, 2005). The N100, a negative deflection in the ERP waveform occurring around 100 ms, is considered to be an index of early sensory encoding of the physical properties of the sound (Näätänen & Picton, 1987) and the effort associated with the allocation of processing resources to form and maintain a sensory memory trace (Obleser & Kotz, 2011). Recently, evidence suggests that the amplitude of the N100 is modulated by the emotional valence of auditory stimuli (Jessen & Kotz, 2011; Liu et al., 2012). The positive component observed around 200 ms (P200) is proposed to reflect the processing of the semantically-relevant acoustic parameters involved in the early meaning detection or general stimulus categorization at the second stage of the model (García-Larrea, Lukaszewicz, & Mauguière, 1992; Pell et al., 2015). The P200 is modulated by the motivational saliency of the acoustic signal as indicated by both the discrete emotional qualities of the stimulus and the associated arousal (Paulmann et al., 2013). The latency of both the N100 and the P200 shows that nonverbal vocalizations of emotions are processed much faster than emotional speech prosody, emphasizing the heightened relevance afforded by these crude means of expressing genuine emotions (Pell et al., 2015). More advanced analysis of the emotional meaning expressed by human emotional vocalizations are associated with the third stage of processing evidenced by neural components with longer latencies such as the late positive complex (LPC) (Jessen & Kotz, 2011; Kotz & Paulmann, 2011; Paulmann & Pell, 2010; Schirmer & Kotz, 2003, 2006; Schirmer, Chen, Ching, Tan, & Hong, 2013). For example, the amplitude of the LPC has been found to vary as a function of stimulus level of arousal and emotional expression, with increased amplitude for cues of threat (e.g., anger) compared to non-threat (e.g., sadness, happiness) or for expressions with higher versus lower levels of arousal (Paulmann et al., 2013; Pell et al., 2015). Such differences may reflect the evaluation of the stimulus meaning as related to the representations stored in an individual's memory; with preferential allocation of processing resources to the stimuli highly relevant for the individual (Hinojosa, Carretié, Valcárcel, Méndez-Bértolo, & Pozo, 2009; Kanske & Kotz, 2007; Paulmann et al., 2013; Pell et al., 2015). The emotional modulations of the LPC are also more pronounced and faster for nonverbal vocalizations of emotions compared to emotional prosody embedded in speech (Pell et al., 2015), suggesting that the emotional meaning of nonverbal vocalizations maintain prioritised processing continuing into adulthood.

Although studies exist to suggest that socially salient auditory information, including emotionally loaded human vocalizations, modulate infant neural responses, the findings have been mixed. The infant brain seems to differentiate between emotional prosody embedded in speech soon after birth (Cheng, Lee, Chen, Wang, & Decety, 2012; Zhang et al., 2014), probably relying on automatic discrimination processes related to the activity of primary and non-primary auditory areas in the temporal cortex (Näätänen, Paavilainen, Rinne, & Alho, 2007). While there is limited evidence to make such claims, auditory processing of emotion prosody in infancy seems to resemble adult-like processing demonstrating sensitivity to emotional content both at early processing stages (Grossmann et al., 2013) and at later ones (Grossmann, Striano, & Friederici, 2005). Recent evidence suggests that 8-month-olds' ERP responses may also be sensitive to peers' nonverbal vocalizations of emotions. Missana, Alvater-Mackensen, and Grossman (2017) presented infants with the sounds of peers' cry and laughter, as well as the neutral humming of an adult. While the early positive and negative components responded selectively to either peer crying or laughter, no differentiation between emotions was reported at later

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