



Negative affect is related to reduced differential neural responses to social and non-social stimuli in 5-to-8-month-old infants: A functional near-infrared spectroscopy-study



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ABSTRACT

Both social perception and temperament in young infants have been related to social functioning later in life. Previous functional Near-Infrared Spectroscopy (fNIRS) data (Lloyd-Fox et al., 2009) showed larger blood-oxygenation changes for social compared to non-social stimuli in the posterior temporal cortex of five-month-old infants. We sought to replicate and extend these findings by using fNIRS to study the neural basis of social perception in relation to infant temperament (*Negative Affect*) in 37 five-to-eight-month-old infants.

Infants watched short videos displaying either hand and facial movements of female actors (social dynamic condition) or moving toys and machinery (non-social dynamic condition), while fNIRS data were collected over temporal brain regions. *Negative Affect* was measured using the *Infant Behavior Questionnaire*.

Results showed significantly larger blood-oxygenation changes in the right posterior-temporal region in the social compared to the non-social condition. Furthermore, this differential activation was smaller in infants showing higher *Negative Affect*.

Our results replicate those of Lloyd-Fox et al. and confirmed that five-to-eight-month-old infants show cortical specialization for social perception. Furthermore, the decreased cortical sensitivity to social stimuli in infants showing high *Negative Affect* may be an early biomarker for later difficulties in social interaction.

1. Introduction

Recent research using electroencephalography and functional near-infrared spectroscopy (fNIRS) has greatly advanced our knowledge of the development and specialization of the “social brain” in infancy (for review see Grossmann, 2015; Grossmann and Johnson, 2007). The sensitivity of the neural correlates of social perception to genetic and environmental factors however is less explored (Grossmann et al., 2011). In the present study, we investigated the impact of infant temperament on the early cortical specialization for processing social stimuli.

Temperament may be defined as a set of biologically-based psychological tendencies (McCrae et al., 2000; Rothbart and Bates, 1998, 2006). It comprises individual differences in reactivity (i.e., latency, intensity and duration of emotional, attentional and motor responses to changes in the internal and external environments) and regulation (i.e.,

processes of effortful control and orienting that modulate reactivity) (Rothbart and Bates, 2006; Salley et al., 2013). Temperamental features have regularly been shown to be continuous from infancy into childhood and even into adulthood (Caspi, 2000; Kandler et al., 2013). Moreover, individual differences in temperament predict individual differences in social functioning, family functioning, academic achievement, and internalizing and externalizing behavior later in life (Sanson et al., 2004). The strongest developmental continuity has been found for the temperamental dimension *Negative Affect*, which is also the first emerging form of reactivity (Putnam et al., 2001; Rothbart et al., 2000). During infancy, *Negative Affect* comprises behaviors such as anger, frustration, sadness, social fear/shyness, general distress-proneness and poor soothability (Rothbart et al., 2001). High levels of *Negative Affect* in infancy have been associated with several aspects of poorer social functioning later in life, including social competence (Sanson et al., 2004; Rothbart et al., 2001), social responsiveness, social

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awareness, social information processing, capacity for reciprocal social communication, social motivation, and repetitive/restricted interest (Salley et al., 2013). In addition, high *Negative Affect* has been associated with infants being less frequently involved in joint attention, which is considered to be a key factor in infants' social-cognitive development (Salley and Dixon, 2007; Todd and Dixon, 2010; Vaughan et al., 2003; Vaughan Van Hecke et al., 2007).

A considerable number of studies have linked temperament, including *Negative Affect*, to differential activation in, and connectivity between subcortical and cortical brain regions which are part of the “social brain network”, including the amygdala, ACC, medial PFC and posterior STS/TPJ (Ball et al., 2012; Davey et al., 2015; Harnett et al., 2015; Perlman et al., 2015; Whittle et al., 2006; Vrticka et al., 2013). However, these studies almost exclusively involve school-age children, adolescents and adults. The neural correlates of social perception observed in infants have been shown to be largely similar to those observed in adults, and predominantly include bilateral temporal and (orbito-) frontal cortical regions (Blasi et al., 2007; Lloyd-Fox et al., 2009; Lloyd-Fox et al., 2013; Minagawa-Kawai et al., 2009; Nakato et al., 2011; Vanderwert and Nelson, 2014; Grossmann, 2015). There are only two infant studies linking individual differences in *Negative Affect* to differential brain activation for social perception, one EEG-study (Martinot et al., 2012) and one fNIRS-study (Ravicz et al., 2015); both studies found a relation between processing of social information, specifically facial emotion, in fronto-central brain regions and infants' level of *Negative Affect*.

A recent series of fNIRS studies has shed light on the cortical specialization for social information processing by robustly demonstrating the involvement of the posterior temporal lobe in the processing of social dynamic stimuli compared to non-social dynamic stimuli in young infants (Lloyd-Fox et al., 2009, 2011, 2013, 2014, 2016; Farroni et al., 2013). Within the posterior temporal lobe, activation in the pSTS is associated with processing of gaze shifts, gestures and biological motion in adults (e.g. Burnett et al., 2011; Lotze et al., 2006; Pelphrey et al., 2005); thus, it is likely that infant hemodynamic responses to social dynamic stimuli underlie pSTS activation. Relevant for our study, infants at risk for autism (who often score high on *Negative Affect*) showed less differential activation in temporal regions in response to social dynamic stimuli than their typically developing peers (Lloyd-Fox et al., 2013).

In the present study, we aim to replicate the results of Lloyd-Fox et al. (2009) and investigate the impact of infant *Negative Affect* (as measured by parental questionnaire) on the early cortical specialization for processing social dynamic stimuli. To this end, we used a similar fNIRS paradigm and the same stimuli as used previously by Lloyd-Fox et al. (2009, Experiment 2). Functional Near-Infrared Spectroscopy makes use of differences in light absorption by Oxygenated and Deoxygenated hemoglobin to measure blood oxygenation changes in the cortex, an indicator of neural activity (see Gervain et al., 2011 for an introduction to the basic methodology of fNIRS). We studied typically-developing children aged 5–8 months to a) determine whether cortical specialization for social dynamic stimuli remains stable over these ages and b) assess the influence of *Negative Affect* on the processing of social stimuli. The paradigm used in this study compares the perception of dynamic social stimuli to the perception of dynamic non-social stimuli. Since no explicit emotional valence is present, this allows us to assess the association between temperament and social processing independent of emotional processing. In line with earlier findings (Lloyd-Fox et al., 2009), we focused our data analysis on the posterior temporal region, i.e. the posterior channels of the optode layout. We hypothesized that infants with higher scores on *Negative Affect* would show weaker hemodynamic response to social compared to non-social stimuli in the posterior-temporal cortex, based on three findings discussed above: 1) the observed relation between *Negative Affect* and joint attention in infancy, 2) the overlap between brain regions associated with *Negative Affect* and social information processing, and 3) the

observed reduced sensitivity in posterior temporal regions to social dynamic stimuli in infants at risk for autism.

2. Methods

2.1. Participants

Thirty-seven healthy infants between 5 and 8 months of age participated in the study (mean age = 185.1 days, SD = 29.0 days, range: 142–275 days; 16 females and 21 males). An additional 32 infants were tested but excluded from the NIRS data analysis because they failed to look at the stimuli for the minimum number of trials ($n = 17$) or because they did not have usable data in at least one of the relevant channels ($n = 15$). See the data pre-processing section for further explanation. Infants were recruited through direct mail after birth and invited to participate in the study over telephone when they reached the appropriate age. Addresses were provided by the Leiden city council. The study protocol was approved by the Leiden University Cognitive Psychology Ethics Committee. The mean average education level of the parents was 4.42 (SD = 0.61, range: 3–5) on a 5-point scale (1: primary school, 2: vocational school, 3: secondary school, 4: post-secondary applied education, 5: university degree). Infants who were excluded from the NIRS analysis did not differ from the included infants in gender, age, mean parental education level, or *Negative Affect* ($p_s > 0.18$).

2.2. Procedure

The participating infant's parent was first fully informed about the procedure and asked to sign the consent form. The head circumference of the infant was measured, and a cap of the appropriate size was chosen and prepared for the experiment (Easycap infant caps for head sizes 42–48 cm). During fNIRS recording, the infant sat on the parent's lap in a sound-proof booth facing a 42-inch screen at approximately 70 cm distance. The NIRS cap was placed on the infant's head, positioning it relative to the ears and the midline. Optode cables were supported by a cable arm and cable trees at the back of the head to reduce optode movement. During the session infants were recorded by a video camera placed under the screen. Stimulus presentation lasted a maximum of 13 min, but was stopped earlier if the infants became bored or fussy.

Our experiment used identical stimuli to those in Experiment 2 from Lloyd-Fox et al. (2009) and closely followed its procedure. It included a social dynamic and a non-social dynamic experimental condition, in addition to a static baseline condition. The social dynamic condition consisted of video clips displaying a female actor performing different combinations of eye movements, silent vowel mouth-movements or playing “peek-a-boo” and “incy-wincy spider” games with her hands. The non-social dynamic condition consisted of video clips showing different combinations of moving machine cogs, pistons and spinning toys. The baseline condition consisted of still images of different types of transport (i.e., cars and helicopters) presented randomly for a pseudorandom duration (1–3 s). The video clips and still images were each presented for 16 s. They were displayed at a size of 30 × 20 cm, where the female actors' face was approximately life-size. None of the stimulus videos contained sound, but continuous instrumental music was played softly during stimulus presentation.

Each recording session started with a resting period (30s) during which the infant was shown small animal pictures in randomly varying positions on the screen to familiarize the infant with the setup and to allow time for calibration. During calibration, the signal for each source-detector combination (channel) is optimized. Following calibration, the presentation of the stimulus trials started. The two experimental conditions were presented in pseudo-random order with a baseline trial following each experimental trial (see Lloyd-Fox et al., 2009 for a graphical representation of the paradigm). Randomization

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