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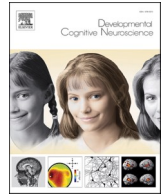
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Frontal EEG asymmetry in infants observing separation and comforting events: The role of infants' attachment relationship

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ABSTRACT

The development of social-cognitive abilities in infancy is subject to an intricate interaction between maturation of neural systems and environmental input. We investigated the role of infants' attachment relationship quality in shaping infants' neural responses to observed social interactions. One-hundred thirty 10-month-old infants participated in an EEG session while they watched animations involving a distressing separation event that ended with either comforting or ignoring behavior. Frontal asymmetry (FA) in the alpha range - which is indicative of approach-withdrawal tendencies - was measured with EEG. Attachment quality was assessed using the Strange Situation procedure at 12 months. Overall, infants with disorganized attachment showed a lack of right-sided - withdrawal related - FA compared to secure and insecure infants. Furthermore, only avoidant infants exhibited reduced right-sided FA responses following the separation. Contrary to our expectations, the type of response (comforting vs. ignoring) did not elicit differences in FA patterns, and attachment quality did not moderate the effects of the type of response on frontal asymmetry. Implications for research on attachment-related biases in social information processing and on the neural underpinnings of prosocial behaviors are discussed.

1. Introduction

Successfully navigating the social world is essential for healthy development. Identification of the neural mechanisms underlying early social competence and the environmental factors that help shape these mechanisms is pivotal for understanding individual variation in the developmental course of social skills. A growing body of behavioral evidence suggests that infants from early on possess a sophisticated level of competence in interpreting and evaluating observed social interactions including prosocial behavior. For example, infants expect that resources and rewards should be distributed fairly (Sloane et al., 2012), they prefer - and expect others to prefer - individuals who help rather than hinder others (Dunfield et al., 2011; Kuhlmeier et al., 2003; Hamlin et al., 2007; Hamlin and Wynn, 2010; but see Salvadori et al., 2015), and they have context-sensitive expectations about comforting behavior (Jin et al., 2018; Biro et al., 2014). Recent studies also showed that infants from at least 6–9 months are able to make predictions about, or to

evaluate the behavior of, interacting characters even when they are depicted as abstract geometrical figures (e.g., Hamlin et al., 2007; Hernik and Southgate, 2012; Hernik et al., 2014; Tauzin and Gergely, 2019).

Recent research has also revealed that individual differences in infants' processing of certain types of prosocial interactions are related to the quality of infants' attachment relationships (e.g., Johnson et al., 2007; Biro et al., 2015, 2017). Attachment behavior in infancy is thought to be a product of an innate behavioral system that drives infants to seek proximity to a caregiver for protection and emotional support (Bowlby, 1969). Infants with a secure attachment relationship actively look for and are reassured by the proximity of their caregivers when they are in distress. Insecurely attached infants are either more reluctant to show their distress to their caregiver (insecure-avoidant) or ambivalent with and not easily comforted by their caregivers (insecure-resistant; Ainsworth, 1978). Infants who have disorganized attachment relationships show momentary lapses in an otherwise coherent (secure or

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insecure) attachment pattern, displaying, for example, contradictory and stereotypic behaviors or freezing (Main and Solomon, 1990). The quality of infants' attachment relationships has been shown to be partly determined by the quality of early infant-caregiver interactions, with sensitivity and responsiveness of the caregiver being associated with increased chances of a secure attachment relationship (Verhage et al., 2016; Bakermans-Kranenburg et al., 2003).

Johnson et al. (2007) showed that secure and insecure infants differ in their expectations about observed social interactions of others concerning comforting behavior. Using the violation of expectation method, they reported that only securely attached 12-month-old infants looked longer at (that is, did not expect to see) an animation depicting unresponsive caregiving behavior involving abstract characters compared to responsive caregiving behavior. In a follow-up study, Johnson et al. (2010) also found that secure and insecure-resistant infants but not insecure-avoidant infants expected a "child" character to seek proximity and comfort from a "parent" character. Attachment quality has also been associated with 12-month-old infants' monitoring strategies during the observation of such animated interactions. Specifically, secure infants compared to insecure infants focused more on the "parent" figure during a distressing separation of a "child" and "parent" character (Biro et al., 2015). In addition, disorganized attachment has been linked to a lack of complementary synchrony in infants' and their mothers' monitoring patterns (Biro et al., 2017). These studies, together with others (Johnson and Chen, 2011; Peltola et al., 2015), provide evidence that attachment-related social information processing biases are already present in early infancy. It has been suggested that these biases might be markers of, as Bowlby (1969) coined the term, infants' developing "internal working models" of attachment, which in cognitive terms, refer to mental representations or prototypes of social relations (Bretherton and Munholland, 2008; Dykas and Cassidy, 2011; Waters and Waters, 2006; Vandevivere et al., 2014).

While these attentional measures are highly informative about cognitive processes, they do not provide direct insight into the question to what extent infants' processing of social interactions involves emotional and motivational engagement with the stimuli. In particular, infants' response to and interpretation of observed distress of others and different types of caregiving behaviors is likely shaped by their own emotional reaction and motivational involvement. Furthermore, the nature and the degree of infants' emotional and motivational involvement in the processing of such observed social interactions can in turn depend on their own experiences in similar situations, which may be reflected in the quality of their attachment relationships. Measures of frontal asymmetry in the EEG alpha frequency range have been successfully used as an indicator of emotional-motivational tendencies during both stimulation and rest in adults as well as in infants (for a review see Harmon-Jones et al., 2010; Gander and Buchheim, 2015). Frontal asymmetry refers to the difference in electrical activity in terms of alpha power between the frontal areas of the two hemispheres. A decrease in alpha power reflects an increase in the activity of the underlying cortical tissue (Cook et al., 1998; Laufs et al., 2003). Greater relative left-sided activity (i.e., decreased alpha power over the left compared to the right hemisphere) is associated with "approach" motivation involving positive anticipation, engagement with the stimuli, expected reward, familiarity and emotions such as joy and interest. Greater relative right-sided activity is associated with "withdrawal" tendencies, disengagement from stimuli, novelty, lack of reward and emotions such as sadness, fear and distress (Davidson, 1993; Harmon-Jones and Gable, 2018; Coan and Allen, 2003). Both state and trait measures of frontal asymmetry are related to intrinsic and environmental factors such as mood, temperament, emotional context or stimuli, and manipulation of motivation (Harmon-Jones et al., 2010).

Previous research with infants showed that exposure to emotional facial expressions can lead to state-related changes in infants' frontal EEG asymmetry. Happy facial expressions, compared to sad facial expressions, have been found to consistently elicit greater left-sided frontal

asymmetry indicating approach tendencies (Diego et al., 2004; Dawson, 1994; Fox and Davidson, 1988; Davidson and Fox, 1982; Field et al., 1998). In addition, infants showed greater right-sided frontal asymmetry consistent with withdrawal-like tendencies when EEG was recorded during separation from the mother compared to a playful interaction (Fox and Davidson, 1987; Fox and Davidson, 1984; Davidson and Fox, 1989). More recently, Cowell and Decety (2015) reported that infants and toddlers showed greater right-sided asymmetry for animated movies involving abstract characters and depicting hindering compared to helping scenarios, indicating that the observation of antisocial behavior elicits withdrawal tendencies whereas observing prosocial behavior is associated with reduction of withdrawal.

While research on the relation between infant attachment and frontal asymmetry is sparse, it has been found that insecure infants exhibited reduced left frontal activity, indicating less strong approach tendencies, during baseline measures and while playing with their mother, and greater right-sided frontal activity during separation from mother, compared to secure infants (Dawson et al., 1992b, 2001). Furthermore, excessive crying during separation from one's own mother – which is most common in insecure-resistant infants – is associated with right-sided frontal asymmetry (Davidson and Fox, 1989; Fox et al., 1992). The relation between disorganized attachment and frontal asymmetry is a relatively uncharted territory. Gander and Buchheim (2015) reported that disorganized infants showed higher EEG activity in both left and right frontal areas during the Strange Situation procedure, interpreted as suggesting dysregulation of emotional-motivational tendencies in response to stress. In adults, a fearful/avoidant attachment style was associated with a mismatch between self-reported emotional arousal and more right-sided frontal asymmetry changes while viewing attachment scenarios eliciting fear or threat (Rognoni et al., 2008).

The aim of the current study was to investigate the involvement of frontal EEG asymmetry – as an indication of emotional-motivational tendencies – in 10-month-old infants' processing of separation and comforting/ignoring behaviors, and to test whether frontal EEG asymmetry responses are related to the quality of the infant-caregiver attachment relationship at 12 months. Infants were shown animations similar to those used by Johnson et al. (2007) and Biro et al. (2015), in which a smaller "child" figure is separated from a larger "parent" figure and starts crying. The animations then either continue with the larger figure returning to the smaller character (comforting) or moving further away (ignoring).

We hypothesized that quality of the infant-parent attachment relationship would moderate the frontal asymmetry response to the observed social interactions. On the basis of previous research associating insecure infant attachment with greater right-sided asymmetry during separation from the mother (Dawson et al., 1992b, 2001; Davidson and Fox, 1989; Fox et al., 1992) and with less attentional focus on the "parent" figure during observed separation scenarios (Biro et al., 2015), we hypothesized that insecure infants (particularly insecure-resistant infants) would show greater right-sided – withdrawal related – frontal asymmetry during the separation part of the animation.

Furthermore, based on the findings that secure infants expect comforting after separation (Johnson et al., 2007, 2010) and show stronger approach-associated frontal activation tendencies during positive social interactions (Dawson et al., 1992b, 2001), we hypothesized that viewing comforting would elicit more left-sided – approach related – frontal activity in securely attached infants. Secure infants would thus be assumed to regard comforting as a more positive, familiar and rewarding outcome, while for insecure (particularly insecure-avoidant) infants, proximity of a caregiver might be associated with a less rewarding experience. As ignoring is considered as being negative or aversive, we expected that it would elicit greater right-sided frontal asymmetry, indicating stronger withdrawal tendencies, compared to comforting (see Cowell and Decety, 2015), and that the difference in frontal asymmetry response between comforting and ignoring might thus be more prominent in secure infants.

On the basis of studies reporting dysregulation of approach-withdrawal tendencies and a lack of attentional bias for emotional stimuli in disorganized infants (Rognoni et al., 2008; Peltola et al., 2015), coupled with the observation of contradictory responses to the separation and reunion with their caregivers (Main and Solomon, 1990), we hypothesized that disorganized infants' neural response to the animations would differ from infants with organized strategies (secure or insecure). As frightened/frightening caregiving behavior has previously been linked to the formation of disorganized attachment (Schuengel et al., 1999; Main and Hesse, 1990), they may show a flipped pattern, with relatively reduced right-sided frontal asymmetry for the separation and with greater right-sided, withdrawal associated frontal asymmetry for the comforting outcome, indicating the return of the parent figure as a potentially threatening event. It is important to note however that this study is the very first to investigate attachment-related frontal asymmetry for observing animated social interactions, thus our expectations regarding the direction of differences are only tentative.

Furthermore, since maternal depression, alone and in combination with attachment, has been found to be associated with infant frontal asymmetry patterns (Peltola et al., 2014; Field and Diego, 2008; Dawson et al., 1997, 1992a,b; Field et al., 1998) and it has also been implicated in the formation of attachment relations (Martins and Gaffan, 2000; Van IJzendoorn and Bakermans-Kranenburg, 2012), we controlled for maternal depressive symptoms in our analyses. Due to potential attachment-related baseline differences (Dawson et al., 2001; Stanley, 2006), baseline frontal asymmetry was also controlled for.

Given the low numbers of avoidant and resistant infants, we merged them into one insecure attachment group in our main analysis. However, as insecure-avoidant and insecure-resistant infants can be quite different in terms of their behavioral patterns, physiological arousal and emotion regulation (Calkins and Fox, 1992; Cassidy and Berlin, 1994; Spangler and Grossmann, 1993; Luijk et al., 2010), and studies with adults show differences in EEG frontal asymmetry responses between these groups as well (see Gander and Buchheim, 2015, for a review), we conducted an additional exploratory analysis in which the two insecure infant groups were distinguished.

2. Method

2.1. Participants

One-hundred thirty healthy, full term infants (69 boys and 61 girls) and their mothers were recruited for the study. Families were contacted through direct mail, addresses were provided by the city council. Mothers and infants visited the lab twice, when infants were ten months old (mean age = 309.53 days, $SD = 13.30$ days) and when they were twelve months old (mean age = 376.60 days, $SD = 13.03$ days). A subset of the families (72) also participated in a lab visit when the infants were 7 months old for additional assessments that are not part of the current study. The mothers were all biological mothers of the infants (mothers' mean age = 33.37 years, $SD = 3.94$ years). In 86 % of the families, both parents had the Dutch nationality and in the remaining families one or both parents had another European (10 %) nationality, or one of the parents had an African (1 %), Asian (1 %), or American (2 %) nationality. Using a 5-point scale assessing the education level of both parents (1: primary school, 2: vocational school, 3: secondary school, 4: post-secondary applied education, 5: university degree), the average educational level of the sample based on the mean scores of both parents was 4.30 ($SD = 0.71$, range: 1.5–5.0), which indicates a mostly highly-educated sample. Sixty infants were excluded from the analyses due to experiment error during EEG recording ($n = 12$), infant fussiness ($n = 8$), providing insufficient artefact-free EEG data ($n = 30$, explained in detail in the Data Processing section), or not returning for the attachment assessment during the second visit ($n = 10$). Thus, data from 70 infants were included in the analyses. The included infants did not differ from the excluded infants in terms of gender, age, mother's age, parents'

education level, attachment or maternal depression (all $ps \geq .17$).

2.2. Procedure

During the 10-month visit, infants participated in the EEG measurements. Attachment quality of the infants was assessed using the Strange Situation Procedure (SSP) which was conducted during the 12-month visit. Infants and mothers took part in other measurements during both visits that are not reported in the current study. At both visits mothers signed informed consent. Infants received a gift and a diploma for participation, and travel costs were reimbursed. The study was approved by the Ethics committee of the Institute of Education and Child Studies at Leiden University. Questionnaires on maternal depression (BDI-II; Beck Depression Inventory-II) were filled out digitally by the mothers after each laboratory visit.

2.3. EEG measurement

For EEG recording, infants were fitted with an electrode net (Electrical Geodesics, Inc., Eugene, OR). For a baseline measurement, infants were seated on their mother's lap in the EEG laboratory room facing a female experimenter who was quietly and slowly building and taking apart a tower of Duplo blocks. The experimenter was about 1.5 m from the infant and did not make eye-contact. The baseline lasted a maximum of 3 min, but was stopped earlier if the infant became fussy. Following the baseline measure, the mother was asked to turn her chair with the infant toward a 17" monitor. The door was closed, the room was darkened and the presentation of the animations started (see Stimuli section). The monitor was at eye-level, about 60 cm away from the infant and surrounded by a curtain that hid the cables. A video camera mounted above the monitor recorded the infant. The presentation of the stimuli lasted a maximum of 8.5 min, but was stopped earlier if the infant became fussy. Mothers were instructed to try to keep the infant's hands away from the wires, but otherwise not to interact with the infant.

2.4. Stimuli

Infants were presented with two types of animations, see Fig. 1, each type lasting 16.3 s. The animations appeared full screen on the monitor and involved two abstract characters: a larger and a smaller oval shape. The animations used in this study were modified versions of the stimuli used in previous studies (Biro et al., 2015, 2017; Johnson et al., 2007). Each animation started with the two characters first moving together. This was followed by the larger figure moving up a hill and stopping on the plateau while the smaller figure was trying to go uphill but slipped back. Upon separation the sound of a crying baby was played. When the crying sound started, the smaller figure expanded slightly (2 mm) and contracted twice together with a slight change in color, giving the impression that the smaller figure was the source of the sound (Separation section, 8.2 s). Following separation, a brief, attention-getter sound indicated the start of the subsequent movement of the larger figure. In half of the movies, the larger figure moved down the hill and ended up next to the smaller figure (Comforting section, 5.6 s), while in the other half of the movies the larger figure moved further up a second hill and stayed on top of it (Ignoring section, 5.6 s). The color of the larger figure was red and the color of the smaller figure was light blue. Furthermore, to control for potential effects of movement direction in the animations on frontal asymmetry, in half of the movies the figures moved from the left side towards the center, while in other half of the movies the figures moved from the right side towards the center, see Fig. 1.

The stimulus presentation started with a red pulsating circle (1–6 cm in diameter) in the middle of the screen to get the infant's attention. When the infant was looking at the monitor the experimenter started the presentation of the animations. A maximum of 8 blocks of animations were shown, each block with 3 animations that all ended either with the

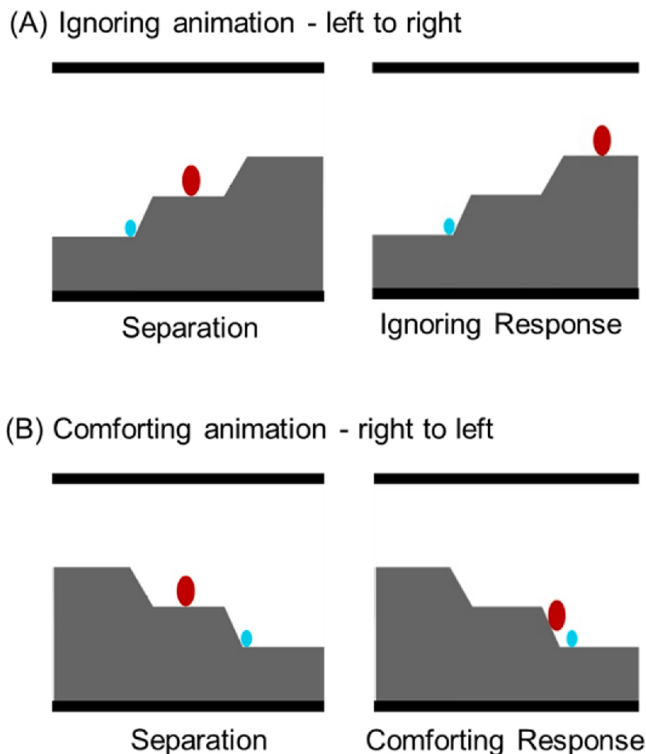


Fig. 1. Frames illustrating the two sections for the two types of animation (A. Ignoring and B. Comforting). Note that each type of animation was presented in both movement directions (“left to right” and “right to left”).

Comforting response or the Ignoring response and either showed left or right direction of movement of the characters. There were thus a maximum of 24 animations with a maximum of 12 Ignoring and 12 Comforting animations. In between the blocks, four short, colorful and dynamic movie clips (e.g., jumping monkeys, swinging turtles, with alerting sounds, 3 s each) were presented that served as a break and kept infants’ attention. The red pulsating fixation circle appeared before each animation. There were four, randomly assigned order conditions across infants: stimulus presentation starting either with two left or two right movement blocks, and starting either with a block of Comforting animations or Ignoring animations.

2.5. EEG data processing

Infants’ EEG was recorded using 128-channel Hydrocel Geodesic Sensor Nets, amplified with a NetAmps300 amplifier, low-pass filtered at 100 Hz, and digitized at a rate of 250 Hz using NetStation software (Electrical Geodesics, Inc., Eugene, OR). Impedances were kept below 50 k Ω . The EEG was referenced to Cz. Common guidelines for infant EEG research (e.g., Hoehl and Wahl, 2012) and frontal asymmetry analysis (Allen et al., 2004; Smith et al., 2017) were followed in EEG recording and analysis. Using the video recording of the infant, point markers were first added to the EEG recording in NetStation that indicated the moments the infant looked away from and looked back at the monitor during the presentation of the animations. EEG data were high-pass filtered at 0.3 Hz (99.9 % pass-band gain, 0.1 % stop-band gain, 1.5 Hz roll-off) before exporting. Further offline processing was done in Brain Vision Analyzer 2.0 (BVA; Brain Products GmbH). The EEG data were low-pass filtered at 30 Hz (-3 dB, 48 dB/octave slope). The baseline EEG recording was then segmented to 1-second long segments with 75 % overlap (matching the procedure selected for the animation sections, see below).

The EEG during each animation was first segmented into Separation and Response sections separately for Comforting and Ignoring

animations. Based on the markers of infant looking the following criteria were used: To include an animation section in the analysis, infants had to watch at least half of the section. In addition, a Response section could only be included if infants watched at least one Separation section prior to the Response section. This was done to make sure that infants’ neural responses reflect their reaction to the parent figure’s behavior *after* seeing the separation. Each animation section was then, similarly to the baseline, further divided into 1-second long segments with 75 % overlap. An overlap of 75 % across consecutive segments was used because of the short duration of the individual trials, i.e., to retain a larger number of segments for the calculation of alpha frequency power (cf. Smith et al., 2017).

Segments containing artifacts on channels around the eyes (1, 8, 14, 21, 25 and 32) were examined with the help of an artifact detection method that marked each segment containing a difference larger than 100 μ V within any 50-ms interval as bad. Marked segments were inspected and manually removed if they contained ocular artifacts. In addition, on each individual channel, artifacts were automatically detected in each segment if the amplitude was lower than -200 μ V or higher than 200 μ V, or if the activity was lower than 0.5 μ V within any 100 ms interval. Channels containing artifacts were then removed from individual segments (see e.g. Huffmeijer et al., 2020, for similar use of automatically-aided artifact rejection procedures). Following Fast Fourier transformation (0.5 Hz resolution, 50 % Hanning window), the amount of signal present at each frequency was averaged across segments in the baseline recording and in each animation section. Power (μ V²) in the infant alpha band (6–9 Hz, see Marshall et al., 2002) was exported for further analysis.

Frontal asymmetry was calculated for 11 channel pairs located over the (dorso-)lateral prefrontal cortex at around the F3 and F4 electrode sites, as hemispheric differences in alpha power between these areas are commonly considered to reflect affective-motivational processes (Davidson, 1988, 2004; Right – left: 124(F4)–24(F3), 123–27, 117–28, 3–23, 116–34, 118–20, 122(F8)–33(F7), 2–26, 111–29, 10–18, 4–19) for the baseline and for both animation sections by subtracting left channel alpha power from right and dividing the result by the sum of the power in the right and left channels. This metric is referred to as “normalized” ratio and argued to be more reliable than the logarithmic difference score (Allen et al., 2014). Negative values indicate right-sided and positive values indicate left-sided asymmetry. The internal consistency was high in all sections (Cronbach alpha = .91–.95). Finally, asymmetry values were averaged across the 11 channels pairs.

For each infant the numbers of excluded and included artifact-free 1 s segments during baseline and in each animation section were calculated. To be included in the analysis infants had to have watched at least 3 animation sections of each type (Separation, Response) in each animation type (Comforting and Ignoring) and to have a minimum of 33 % artifact-free segments in each animation section and in the baseline. The reason for these double criteria for inclusion was to make sure that the neural responses are indeed related to infants’ watching. Included infants, on average, watched 8.61 (SD = 2.39) animation sections (out of the maximum of 12), and had 69 % (SD = 15 %) and 77 % (SD = 13 %) artifact-free 1 s segments on average during the animation sections and baseline, respectively.

2.6. Attachment measures

The Strange Situation Procedure (SSP, Ainsworth, 1978) was used to measure the quality of the infant-parent attachment relationship. In short, the infant is introduced to an unfamiliar lab room and to a female stranger. The mother leaves the room twice and then returns to the room, leaving the infant alone for a short period, first with the stranger and then by her/himself. Attachment behavior during the two reunion episodes was assessed by two experienced coders who were blind to other information about the infants. Coders rated infant behavior on the Ainsworth (1978) interactive behavior scales for proximity seeking,

contact maintaining, avoidance, and resistance in the two reunion episodes of the SSP. On the basis of the patterning of the ratings infants were classified as secure (B), scoring low on avoidance and resistance, or insecure-avoidant (A), scoring high on the avoidance rating scale and rather low on proximity and contact. Infants were classified as insecure-resistant (C) when they were rated high on the resistance scale, and rather high on proximity and contact, or when they showed marked passivity and quite a bit of crying behavior. After the A, B, or C classification infants were rated on the 9-point Main and Solomon rating scale for disorganization of attachment, and a cut-off of 5.5 was used to classify for disorganized attachment (D). This resulted in an ABCD classification of the infants.

On the basis of the ABCD classification, we distinguished secure ($n = 32$), insecure ($n = 21$, including 7 avoidantly and 14 resistantly attached infants) and disorganized ($n = 17$) classifications for the analyses. Twenty randomly selected additional SSPs (that were reported in a previous but related study, see Biro et al., 2017) were coded by both coders. Intercode agreement for these cases was 75 % ($\kappa = .62$, $p = .001$) for ABC and 85 % ($\kappa = .69$, $p = .002$) for disorganization. The attachment classification distribution of infants who were included in the final EEG analysis was not different from the distribution of those who were excluded due to not passing the criteria for EEG data quality ($p = .66$).

2.7. Maternal depression assessment

Mothers were asked to fill out the Dutch version (Van der Does, 2002) of the Beck Depression Inventory-II (Beck et al., 1996) digitally after each visit. The questionnaire contains 21 items. Each item is rated on a 4-point scale ranging from 0 (indicating absence of the symptom) to 3 (strong presence of the symptom). The sum of scores indicates the severity of depression, with a maximum score of 63. The average of the sum scores of the available measurement times was calculated for each mother to gain the most accurate assessment of their symptoms. There were 3 missing values which were imputed based on mothers' age and education and the gender of the infant. The mean depression score was 6.21 (range = 0–21.5, $SD = 5.37$). Based on the clinical interpretation of the scores (Beck et al., 1996), 13 % of the mothers had mild (scores above 11) to moderate (scores above 17) depression. The distribution of the scores was right skewed (standardized skewness = 4.70), therefore, logarithmic transformation of scores resulting in a normal distribution (standardized skewness = $-.86$) was used for the analysis.

3. Results

Preliminary analyses showed that infant gender, education level of the parents and the order in which the two types of animations were presented to the infants had no effect on frontal asymmetry scores, $p_s \geq .13$. There were no significant differences in the number artifact-free segments between the ignoring and comforting type of animations, $F(1,67) = 0.94$, $p = .76$, $\eta_p^2 < .001$, or between the attachment groups during the animation, $F(2,67) = 1.94$, $p = .15$, $\eta_p^2 = .05$, or during baseline $F(2,67) = 1.83$, $p = .17$, $\eta_p^2 = .05$. Attachment classification was not related to maternal depression, $F(2,69) = 0.86$, $p = .43$, $\eta_p^2 = .02$. Baseline frontal asymmetry scores were not related to attachment classification, $F(2,69) = 0.07$, $p = .93$, $\eta_p^2 = .002$ (see also the Supplementary Materials for additional analysis of the baseline data) or maternal depression, $r = .14$, $p = .26$.

A repeated-measures ANOVA was carried out on the frontal asymmetry scores with Section (Separation, Response) and Type of Response (Comforting, Ignoring) as within-subject factors, with Attachment (Secure, Insecure, Disorganized) as a between-subject factor while baseline scores and Maternal Depression were controlled for (included as covariates). The ANOVA revealed an overall main effect of Attachment, $F(2,65) = 7.18$, $p = .002$, $\eta_p^2 = .18$, with the Disorganized group being significantly different from both secure, $p = .01$, and insecure

groups, $p < .001$, while the difference between secure and insecure infants did not reach significance, $p = .13$, see Fig. 2. A one-sample t -test showed that the asymmetry scores in the organized infants differed from zero, $t(52) = -2.96$, $p = .005$, indicating right-sided frontal asymmetry. In addition, a main effect of Section showed that during the Separation Section ($M = -.032$, $SD = .008$) infants overall showed a greater relative right-sided frontal asymmetry compared to the Response Section ($M = -.025$, $SD = .009$), $F(1,65) = 4.66$, $p = .03$, $\eta_p^2 = .07$. The type of animated response (comforting, ignoring) however had no effect on frontal asymmetry scores and did not interact with attachment ($F_s < .70$, $p_s > .40$). The same pattern of results was found when maternal depression was not controlled for with the main effect of attachment, $F(2,66) = 6.81$, $p = .002$, $\eta_p^2 = .17$.

Next, an exploratory analysis was carried out using the ABCD classification. The repeated-measures ANOVA revealed a similar overall main effect of Attachment, $F(3,64) = 4.93$, $p = .004$, $\eta_p^2 = .19$, with the Disorganized group significantly differing from all other groups, the Insecure-Resistant, $p < .001$, the Insecure-Avoidant, $p = .04$, and the Secure group, $p = .01$. The ANOVA also revealed a main effect of Section, $F(1,64) = 4.70$, $p = .034$, $\eta_p^2 = .07$, and an interaction between Section and Attachment, $F(3,64) = 2.99$, $p = .037$, $\eta_p^2 = .12$. To explore the interaction the attachment groups were first examined separately. Only insecure-avoidant infants responded with a significant decrease of right-sided frontal asymmetry during the Response Segment compared to the Separation Segment, $F(1,4) = 29.17$, $p = .006$, $\eta_p^2 = .88$, see Fig. 3. In addition, by separately analyzing the two sections, during the Separation Section, $F(3,64) = 3.62$, $p = .02$, $\eta_p^2 = .14$, both insecure-avoidant, $p = .02$, and insecure-resistant infants, $p = .005$, differed from the disorganized group, while secure infants did not. During the Response Segment on the other hand, $F(3,64) = 5.57$, $p = .002$, $\eta_p^2 = .21$, secure, $p = .003$, and insecure-resistant, $p < .001$, but not insecure-avoidant infants differed from disorganized infants. No effects were found concerning the type of response. The same pattern of results emerged when maternal depression was not controlled for with the main effect of attachment, $F(3,65) = 4.89$, $p = .004$, $\eta_p^2 = .18$, segment, $F(1,65) = 4.07$, $p = .048$, $\eta_p^2 = .06$, and the interaction between attachment and segment, $F(3,65) = 3.94$, $p = .012$, $\eta_p^2 = .15$.

Finally, although maternal depression was not in the focus of our study, we also note that the level of depressive symptoms was not related to frontal asymmetry during baseline or during presentation of the animations in any of our analyses.

4. Discussion

We investigated frontal EEG asymmetry patterns in 10-month-old infants while they observed animations depicting a distressed separation of an abstract "child" and a "parent" character that was followed by a comforting (responsive) or an ignoring (unresponsive) behavior by the

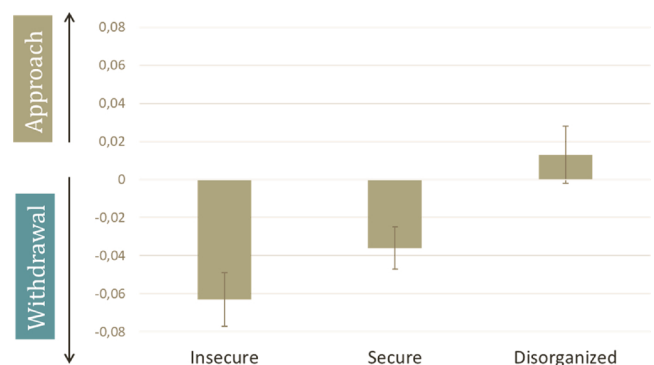


Fig. 2. Mean overall frontal asymmetry scores (controlled for baseline and maternal depression) in Secure, Insecure and Disorganized infants across both types of animations and segments.

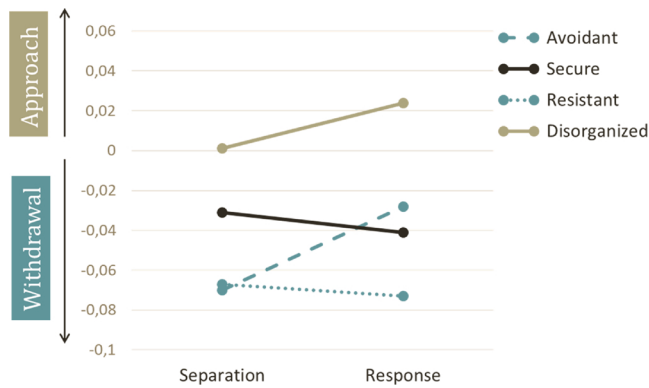


Fig. 3. Mean frontal asymmetry scores (controlled for baseline and maternal depression) during the Separation and Response sections (across both types of animations) by ABCD attachment classification.

“parent” character. We hypothesized that infants’ frontal asymmetry (FA) response to the animations would be related to attachment quality. We found partial support for our hypotheses. Disorganized infants overall showed reduced (or a lack of) right-sided FA compared to secure and insecure infants. Furthermore, our explorative analysis suggested that only avoidant infants showed a reduction in right-sided FA during the response segment. Contrary to our expectations, however, the type of response, comforting vs. ignoring, did not elicit different FA patterns, and the FA scores for the two types of response were not moderated by attachment quality. We will discuss these results below.

One of the main findings that clearly emerged from our analysis is that, overall, disorganized infants did not respond to the animations the same way as organized (secure or insecure) infants did. The right-sided asymmetry that we found with the organized groups confirmed our expectations that due to the overall distressing content of the animations (the combination of the crying sound and the observed events), infants’ frontal asymmetry responses would likely indicate withdrawal tendencies. The finding that disorganized infants did not show this overall response fits with previous studies suggesting dysregulation of emotional-motivational tendencies in individuals with disorganized attachment (Gander and Buchheim, 2015; Rognoni et al., 2008). The lack of withdrawal tendencies in our study may thus indicate that disorganized infants’ regulatory mechanisms are not in place to adaptively disengage from distressing stimulation. It is important to note that the difference between disorganized and organized groups cannot be attributed to a general response to taking part in the EEG lab session as we controlled for baseline FA in our analysis. In addition, there were no significant differences in FA between the attachment groups during baseline. Future research needs to determine whether reduced right-sided asymmetry in disorganized infants in response to other types of emotionally negative stimuli is found (for example to a crying sound alone) or whether it is specific to observed scenarios concerning attachment-related animations.

We also hypothesized that during the separation part of the animation insecure infants would show the greatest relative right-sided asymmetry, indicating the strongest withdrawal tendencies. The difference in FA scores between insecure and secure infants was however not significant. Therefore we did not find evidence suggesting that insecure infants would particularly regard the separation between the child and parent characters as an aversive or a non-rewarding scenario. Furthermore, insecure-avoidant and insecure-resistant infants responded to the separation similarly. This is in contrast with the distinct behavioral pattern they show during separation from their own mother in the Strange Situation procedure. Resistant infants are typically very upset when their mother leaves while avoidant infants often do not show behavioral signs of distress. Physiological measures, however, do show higher arousal or cortisol levels in both avoidant and resistant infants

during the Strange Situation procedure (Spangler and Grossmann, 1993; Sroufe and Waters, 1977; although see review for mixed results by Hane and Fox, 2016). Importantly, in our study the neural responses do not necessarily reflect how infants feel or what they pursue during their own separation but indicate the emotional and motivational components associated with the observation of a separation scenario.

A further finding was that only insecure-avoidant infants showed a significant reduction in right-sided asymmetry during the response part of the animation compared to the separation part. As the change from separation to response segment involved both the ending of the cry sound and the presence of the parent figure’s behavior (regardless of its type), avoidant infants might have reacted to one or both of these aspects with less pronounced withdrawal tendencies. We remain cautious with drawing conclusions from this result as it is based on a small sample. Nevertheless, this finding can serve as a starting point for future studies aiming to investigate the potential uniqueness of avoidant infants’ neural response during observation of social interactions.

Finally, we expected that attachment quality would moderate effects of the type of response on frontal asymmetry. However, we did not find a significant difference in FA response between the comforting and ignoring behavior overall or in interaction with attachment. First we will discuss some methodological caveats and then turn to conceptual considerations regarding this finding.

Frontal asymmetry to the behavior of the parent figure was based on the entire response section. However, the actual outcome of the comforting behavior (proximity and contact of the parent figure with the child character) is only shown in the last 2.4 s of the section. This period may not have been long enough to elicit a significant change in FA compared to the ignoring behavior. The lack of difference in FA response might also be due to the fact that the blocks of the two types of behavior were alternating, which might have created an impression of an overall inconsistent behavior. Furthermore, uncertainties about the exact timing of frontal activation changes to stimulation, particularly in the infant brain (Saby and Marshall, 2012), and the ways in which various factors can influence frontal asymmetry could also contribute to the null result. As we cautioned earlier (see also Harmon-Jones, and Gable, 2018), for example, in case of the insecure infants the familiarity with and the reward value attached to certain interactions (e.g., an unresponsive parent) may have opposing directional effects on emotional-motivational tendencies. Finally, although there is some evidence that infants can evaluate interactions between abstractly depicted characters, showing social interactions between characters with human features in future studies may lead to a stronger recruitment of neural circuits involved in emotion and motivation and may thus create a potentially better starting point for studying individual differences.

Putting methodological issues aside, the lack of an overall difference between the two types of responses is particularly interesting in the light of the Cowell and Decety study (2015) in which infants responded with relative left-sided, approach related asymmetry to helping and with relative right-sided, withdrawal related asymmetry to hindering behavior in animations involving abstract figures similar to ours. As helping and comforting are both forms of prosocial behavior, our finding is also relevant to the theoretical accounts on the development of processing and performing prosocial behavior. There is a debate in the literature whether different types of prosocial behavior develop at the same time and whether they share the same underlying cognitive mechanisms and neural underpinnings (Dunfield et al., 2011; Paulus et al., 2013). To understand helping, one needs to figure out what the goal of the other individual is and what action needs to be taken to attain that goal, which is a change of state in the observable world. Comforting, however, requires recognition of the internal emotional state of another individual and inferences about the ways in which it could be altered. Furthermore, distress of others typically evokes negative arousal in the observing individual (which is often interpreted not only as emotional contagion but also as empathic concern, the latter being claimed as a prerequisite for the development of comforting). It has been proposed

that the reason why infants perform comforting behavior later than helping is because they are not yet able to transform self-distress to solutions (Zahn-Waxler et al., 1992; Paulus et al., 2013). In our study, although actual comforting behavior was not required from the infants, the lack of difference in FA between ignoring and comforting might be due to the fact that the frontal activation during the response section reflected infants' difficulties with overcoming self-distress inflicted by the observation of separation and the sound of crying. Finally, the contrast between helping and hindering behaviors might be larger than that of between comforting and ignoring, as hindering is a form of active hurting while ignoring is not.

Recall, however, that cognitive and attentional measures do indicate that before their first birthday, infants are already able to evaluate comforting and ignoring differently (Jin et al., 2018) and that attachment quality influences infants' expectations about these behaviors (Johnson et al., 2007, 2010). The lack of FA differences between comforting and ignoring might therefore suggest, while keeping the methodological and theoretical considerations mentioned above in mind, that infants' neural responses reflecting emotional-motivational tendencies are not necessarily in unison with infants' cognitive competence.

In conclusion, we found evidence that neural responses to abstractly depicted distressed social interactions are moderated by attachment quality. Disorganized infants showed a lack of right-sided frontal asymmetry during the animations, possibly indicating dysregulation, and only avoidant infants showed a reduced right-sided FA response following separation. Frontal asymmetry patterns and attachment were, however, not related to whether the interactions ended with comforting or ignoring. Our study, being the first to examine the association of infants' attachment with approach-withdrawal-related neural responses to observed social interactions, calls for future studies replicating and further investigating our findings with a larger sample. Note, however, that within infant neurophysiology research, in which technical and data quality issues typically result in high attrition rates, our sample size is relatively large (Button et al., 2013).

Infants' attachment quality predicts a wide variety of social skills later in life such as peer relations, behavioral problems, self-image, social competence, emotion regulation, coping and social attributions (Fearon et al., 2010; Groh et al., 2012; Sroufe et al., 2005). Identifying the nature of early biases in social-emotional neurocognitive processing has the potential to provide insight into the mechanisms that govern how early infant-caregiver experiences can bring about later developmental outcomes.

Data statement

Raw or processed anonym EEG and questionnaire data are available upon request. Due to its sensitive nature, video material will not be shared but processed and anonym data is available for our observational measure upon request.

Declaration of Competing Interest

The authors report no declarations of interest.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:<https://doi.org/10.1016/j.dcn.2021.100941>.

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