
Social Neuroscience
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t741771143

# Direct eye contact influences the neural processing of objects in 5-month-old infants

Eugenio Parise [ab]; Vincent M. Reid [c]; Manuela Stets [d]; Tricia Striano [ad]
[a] Max Planck Institute for Human Cognitive and Brain Sciences, Leipzig, Germany
[b] Calabria University, Italy
[c] Durham University, UK
[d] Hunter College, New York, NY, USA

First Published on: 05 February 2008

Psychology Press
Taylor & Francis Group

# Direct eye contact influences the neural processing of objects in 5-month-old infants

**Eugenio Parise**
*Max Planck Institute for Human Cognitive and Brain Sciences, Leipzig, Germany, and Calabria University, Italy*

**Vincent M. Reid**
*Durham University, UK*

**Manuela Stets**
*Hunter College, New York, NY, USA*

**Tricia Striano**
*Hunter College, New York, NY, USA, and Max Planck Institute for Human Cognitive and Brain Sciences, Leipzig, Germany*

Do 5-month-old infants show differences in processing objects as a function of a prior interaction with an adult? Using a live ERP paradigm we assessed this question utilizing a within-subjects design. Infants saw objects during two pretest phases with an adult experimenter. We recorded event-related potentials to the presentation of objects following the interactive pretest phases. Experimental conditions differed only in the nature of eye contact between the infant and the experimenter during the pretests. In one condition the experimenter engaged the infant with direct eye contact. In a second condition the experimenter looked only at the infant's chest. We found that the negative component, related to attentional processes, showed differences between experimental conditions in left fronto-central locations. These data show that 5-month-old infants allocate more attention to objects that have been previously seen during direct eye-contact interaction. In addition, these results clarify the functional nature of the negative component.

## INTRODUCTION

One central issue in early development is the nature of the relationship between the early sensitivity to eye gaze direction in a context of dyadic interaction and the later ability to engage in joint attention interactions involving a third party (object, event, or person). Not only is evidence of infant sensitivity to adult eye gaze direction present from birth, but from at least four months of age the observation of shifting eye gaze following a brief period of mutual gaze facilitates infant

Correspondence should be addressed to: Eugenio Parise, Max Planck Institute for Human Cognitive and Brain Sciences, Stephanstrasse 1a, 04103 Leipzig, Germany. E-mail: eugenioparise@tiscali.it. Or to: Tricia Striano, Hunter College, Department of Psychology, 695 Park Avenue, New York, NY 10065-5024, USA. E-mail: striano@hunter.cuny.edu

The research was supported by the Sofja Kovalevskaja Award granted by the Alexander von Humboldt Foundation, donated by the German Federal Ministry of Education and Research, to T. Striano, and by the Humboldt Research Fellowship granted to E. Parise. We are grateful to the infants and parents who participated, and to the Universitätsfrauenklinik and the Eitingon Krankenhaus for assistance with recruitment.


www.psypress.com/socialneuroscience DOI:10.1080/17470910701865458

attention toward a third object or location (Farroni, Mansfield, Lai, & Johnson, 2003). This sensitivity and rapid understanding of others' eye gaze is thought to be one of the key precursors of the ability to jointly attend. However, it was thought that infants under 9 months of age did not engage in or benefit from joint attention interactions (Carpenter, Nagell, & Tomasello, 1998).

Joint attention is a triadic interaction that involves monitoring: (1) another person's attention in relation to the self; (2) an object; and (3) the other person's attention toward the same object (Striano & Stahl, 2005). This ability is thought to be fundamental in infant development for a variety of cognitive processes. For instance, it is essential in social referencing (Brooks & Meltzoff, 2005; Woodward, 2003) and learning about objects (Striano, Chen, Cleveland, & Bradshaw, 2006a), and it is related to language development and imitative mechanisms (Baldwin, 1995; Tomasello, 1995).

Infant sensitivity to components of joint attention, such as the eye gaze shift towards an object, is present in an elementary form even in newborns (Farroni, Massaccesi, Pividori & Johnson, 2004). Recent behavioral research has provided evidence of components of joint attention in infants younger than 9 months of age. Striano, Stahl, Cleveland and Hoehl (2007) found that 6-week-old infants look more to an experimenter involved in a joint attention interaction than to the same experimenter looking away from the infant and to an object. Further, Striano and Stahl (2005) found that infants from 3 months look longer to an experimenter in a joint attention condition than to the same experimenter when fundamental cues of joint attention are manipulated, i.e. breaking the eye contact prior to shifting the gaze to the object. Reid and Striano (2005) also found that 4-month-old infants processed objects differently depending on whether the objects were cued by a human's eye gaze. Specifically, if the eyes gazed at one of two possible objects, during a second presentation when the two objects were shown alone, infant looking times to the previously uncued object increased. These authors argued that the previously uncued object was perceived as more novel, suggesting that the infant had extracted some information about the cued object in the prior phase of the experiment. These data suggest that even at only 4 months of age, infants are strongly sensitive to specialized features of human social communication. Even if their behavioral performance is poorer compared to older infants, neural processes underlying these abilities could potentially be similar. However, the relationships between the later joint attention manifested by older infants in behavioral studies and these recent data obtained for infants during the first postnatal months are largely unexplored.

Using ERP techniques, we investigated the relationship between observed eye gaze direction and early sensitivity to joint attention interactions in 5-month-old infants. Event-related potentials (ERPs) are recordings of electrical brain activity that are time-locked to the onset of a stimulus (Rugg & Coles, 1995). ERP techniques have proved to be very useful when investigating developmental issues. In some instances, ERPs appear to be more sensitive than behavioral measures due to their ability to provide information on cognitive processes in the absence of overt behavior (see Thierry, 2005, for a review). Consequently, ERPs are appropriate for assessing open questions such as the role of observed eye gaze in object processing in early infant development, requiring only the passive observation of the stimuli by infants rather than behavioral performance. Results can be placed in a well-defined framework of infant cognitive processes and their relation to visual information processing. In the current experiment, ERPs were recorded after live interactions between the experimenter and the infant, with the independent variable being defined as a single feature of the experimenter's behavior.

We focused our investigation on one infant ERP component that is well mapped in terms of its relation to development and cognition: the middle latency negative central component (Nc). It occurs approximately 300–700 ms after stimulus onset and is most prominent at fronto-central electrodes (Webb, Long, & Nelson, 2005). Although the functional properties of the Nc are still not fully known, it has been strongly related to attentional processes. When stimuli have not previously been seen by infants (no familiarization phase), the Nc amplitude is larger for infrequent stimuli (Courchesne, Ganz, & Norcia, 1981). Using the same procedure, but with highly familiar stimuli (i.e., the maternal face, but also objects) infants produce a larger Nc for the familiar stimuli compared to new stimuli (de Haan & Nelson, 1997, 1999). Finally, when a familiarization phase is used before ERP recording, the resulting Nc component is more ambiguous: some studies found no differences in Nc amplitude for new vs. familiar stimuli (Nelson & Collins, 1991, 1992; Richards, 2003); others found this difference (Reynolds & Richards, 2005) with the Nc amplitude being larger for new stimuli.

One possible interpretation of these studies is that the Nc component is related to the amount of attentional resources allocated by an infant in order to process an external stimulus (Reynolds & Richards, 2005). That is, the Nc is greater for the stimulus that elicits the greatest attentional response. It does not strictly reflect frequency/novelty detection *per se* or a general orienting response. However, corroborating evidence for this position would be beneficial from an array of different paradigms.

Recently, the Nc component has demonstrated sensitivity in experiments involving eye gaze or joint attention. For instance, Hoehl, Reid, Mooney, and Striano (2008) found that in 4-month-old infants, the observation of a face gazing toward an object elicited a larger Nc than the Nc induced by observing a face gazing away from an object. In a study with 9-month-old infants, Striano, Reid, and Hoehl (2006b) used a live ERP paradigm involving an experimenter sitting close to a monitor that displayed an object. These authors found that infants produced a larger amplitude Nc when the experimenter looked to the infant and then to the object (“joint attention”) relative to the Nc induced when the experimenter looked only to the object without first looking to the infant (“non-joint attention”).

The paradigm that we used improves on that used by Striano et al. (2006b) with 9-month-olds. Two important differences that are introduced are related to (1) head turn and eye contact and (2) the absence of the experimenter during the test phase. Eye contact was isolated as an independent variable in the current paradigm whereas this was not an isolated variable in Striano et al. (2006b). This is because the head movements by the experimenter were the same in the two conditions in the current experiment, whereas this was not the case in Striano et al. (2006b). Therefore, the present study can offer a stronger conclusion than was previously possible, whereby the eye contact within the context of sharing an object is a fundamental component of joint attention. The second difference relates to the absence of the experimenter in the cabin during stimuli presentation, with EEG recording in two test phases during the current study. In Striano et al. (2006b), the experimenter was always present and the EEG was recorded during the live interaction. Here we separated these phases into two, with a live interaction (pretest) and a shortly delayed stimuli presentation phase (test). As a result of this delay and with no experimenter present in the electrically shielded cabin during the test phase, any differences seen between conditions must relate to the experimenter’s behavior and the resultant impact in the infant’s memory encoding of the objects during the pretest phase. It also serves to investigate the longevity of the memory trace. It is currently unknown whether the effects of joint attention are transient and have no effects in terms of encoding information over longer periods of time; alternatively, joint attention may serve to refine attentional resources and facilitate memory encoding that remains in working memory for more than a few seconds.

The aim of the present study was to investigate neural correlates involved in joint attention in 5-month-old infants. Using a new paradigm, with eye contact as an isolated independent variable, we evaluated the effect of joint attention on object processing following a live interaction. We predicted that even at 5 months, infant ERP measures of the negative component would display a larger negative amplitude when the object had previously been the target of joint attention with mutual gaze when compared to objects displayed without mutual gaze in a joint attention context.

## MATERIALS AND METHODS

### Participants

15 infants were included in the final sample (7 males and 8 females), with an average age of 5 months and 14 days ($SD = 11.31$; range 5 months, 1 day to 6 months, 3 days). All infants were born full term (37–41 weeks) and were in the normal range for birth weight. Another 54 infants were tested but were excluded from the final sample as a result of fussiness ($n = 12$), failing to reach the minimum requirements for adequate averaging of the ERP data ($n = 40$), or technical problems ($n = 2$). Of the 40 that were excluded for failing to reach the minimum requirements, 32 had more good trials in the first block compared to the second block (see “Procedure” below). This group produced a mean of 8.35 good trials in the first block and 4.63 in the second. This relatively large dropout rate compared to other studies with infants using ERP was thus due to task demands related to the paradigm, where infants attended in

two prephase interaction sessions and engaged with stimuli presented in two separate blocks. Of those infants included in the final analysis, each contributed 17–38 (mean 24.7) trials to their average across the two conditions (for Joint Attention condition, mean = 12.53, $SD = 3.38$; for No Joint Attention, mean = 12.20, $SD = 4.07$). The average length of the whole procedure for the final sample, including breaks, was 11.13 min (ranging from 7.5 to 17 min). This experiment was conducted with the understanding and the written consent of each participant's parent.

## Stimuli

The objects presented to infants on the monitor were six colorful pictures of small toys. Each toy was positioned on a white square background. On average, each toy was 106 × 139 pixels (range: from minimum 98 to maximum 258), appearing on the screen at an average size of 3.17 cm × 4.33 cm (range: from minimum 3 to maximum 8).

## Procedure

Infants sat on their mother's lap in a dimly lit sound-attenuated and electrically shielded cabin. Viewing distance was 70 cm from a 70-Hz 17-inch stimulus monitor. The stimuli were presented at minimum 3 cm by maximum 8 cm and were thus a maximum visual angle of 6.54°. The experiment consisted of two blocks, with one subserving each condition. The order of the blocks was balanced across infants and the blocks were conducted sequentially, with the second block immediately following the end of the first. The two blocks were presented to the subject utilizing the software ERTS (BeriSoft Corporation, Germany). Each block consisted of a pretest and a test phase. During the two blocks, three different objects were presented to the subject (three in the first block and three different objects in the second block). During the pretest phases a trained female experimenter sat beside the screen and in front of the infant with her head close to the screen. The three stimuli were displayed at the center of a black screen, for 20 s each. Throughout the presentation of the stimuli in the pretest phase, the experimenter turned her head alternately from the screen to the infant at the rate of approximately one turn every 5 s. During this time, she uttered short phrases such as "Oh, nice!" and "So many colors!", with a friendly face and positive tone of voice. In this way, for all infants included in the final sample, the experimenter was able to capture their attention and gaze.


**Figure 1.** Experimental situation during the pretest phase in the Joint Attention condition (with direct eye contact). Top row: direct eye contact between the infant and the experimenter. Bottom row: the experimenter turns her head toward the screen displaying the stimulus. Note that the stimuli were presented in color.

Each object was preceded by a small white square in the center of the screen. The only difference between the pretest across the two conditions was the eye gaze behavior of the experimenter. In the Joint Attention condition she established mutual eye contact with the infant by gazing directly into the eyes of the infant. In the No Joint Attention condition, she gazed toward the infant but looked at the infant's chest, and did not engage with the eyes. In the Joint Attention condition, mutual eye contact was directly monitored by the experimenter, as in previous behavioral studies (Striano & Stahl, 2005).

At the end of each pretest phase, the experimenter came out of the cabin and the test session started. Each test session was composed of 120 trials. Each trial was one of the three objects displayed in the pretest phase. Objects were presented in a random order with the constraint that the same object was not presented three times consecutively. Each trial was preceded by a small white square (as a central fixation attractor), presented in the middle of the screen for 500 ms, followed by each stimulus presented on the screen for 1 second. Between the presentations of the trials, the screen was blank for a random period of between 1500 ms and 1700 ms. If an infant became fussy or uninterested in the stimuli, the experimenter gave the infant a short break. A block ended when the infant's attention could no longer be attracted to the screen. Electroencephalogram (EEG) was recorded continuously during the two test phases and infant behavior was video-recorded throughout the session for offline trial-by-trial editing of the EEG in order to ensure that the infant was looking at the screen for all trials included in later analysis.

## EEG recording and analysis

EEG was recorded with Ag–AgCl electrodes from 23 scalp locations of the 10–20 system, referenced to the vertex (Cz). Data were amplified via a Twente Medical Systems 32-channel REFA amplifier. Horizontal and vertical electrooculargrams (EOG) were recorded bipolarly. Sampling rate was set at 250 Hz. EEG data was re-referenced offline to the linked mastoids. Filters were set from 0.3 to 20 Hz.

The EEG recordings were segmented into epochs of waveform that comprised a 200 ms baseline and 1000 ms of the image displaying the object. For the elimination of electrical artifacts caused by eye and body movements, the EEG data were rejected offline whenever the standard deviation within a 200 ms gliding window exceeded 50 μV at any electrode (80 μV for EOG). Data were also visually edited offline for artefacts and to ensure that included trials were those where the infant was attending to the screen.

A preliminary analysis on the occipital channels was conducted to ensure that perceptual differences were not present between the two conditions. Out of 15 subjects, 14 were used, due to technical problems at electrode O1 for one subject. The mean amplitude by each condition was calculated on O1 and O2 in the time window 20–170 ms. We chose this time window as it displayed the largest difference between condition on both electrodes. Data were analyzed with a $2 \times 2$ general linear model, condition (Joint Attention–No Joint Attention) and electrode (O1–O2) as within-subject factors. A similar analysis was performed on anterior frontal channels, averaging the amplitude for each condition in the time window 0–400 ms and performing single paired-samples *t*-test in the regions of interest listed below.

To assess differences in the Nc, a time window from 400 to 700 ms was chosen on the same channels that were assessed by Striano et al. (2006b), namely on frontal and central channels. In order to detect differences in the negative peak between conditions, for each included subject the minimum amplitude within this window was selected as the dependent variable in fronto-central left (F3, CF3, C3), central (Fz, Cz) and fronto-central right (F4, FC4, C4) locations. As well as conforming to prior research, these electrodes were included as the effect was most evident across these sites.

Variances of ERPs were analyzed by a $2 \times 3$ general linear model analyzing condition (Joint Attention–No Joint Attention) and location (left–central–right) as within-subject factors.

We also assessed differences in the latency of the peak within the time window 400–700 ms, utilizing the same analyzed factors as reported above.

# RESULTS

## Behavioral results

A paired-sample *t*-test for gazing toward the objects in the pretest phases revealed no significant differences between joint attention and no joint attention condition ($t(14) = 0.46$, $p > .05$). This result ensures that differences observed in ERPs cannot be derived from different amounts of time spent in looking to the objects during the pretest component of the experiment.

As a supplementary behavioral measure we also coded the number of smiles during the pretest phases. No significant difference between conditions was found (McNemar's $\chi^2$ with Edwards' correction for small samples $= 0.00$, $p = 1.000$).

## ERP results

On occipital channels no main effect for condition $F(1,13) = 4.08$, $p > .05$ or electrode $F(1,13) = 0.07$, $p > .05$ and no significant interaction $F(1,13) = 0.06$, $p > .05$ were found.

On anterior frontal channels between 0 and 400 ms no significant results were found in left ($t(14) = -1.82$, $p > .05$), central ($t(14) = 0.27$, $p > .05$) or right location ($t(14) = -0.98$, $p > .05$).

For the Nc peak analysis, the ANOVA indicated an effect of location ($F(2,28) = 4.80$, $p < .02$). A Scheffé post hoc test indicated a significant difference ($p < .02$) between the central ($M = -18.64$ µV, SE 2.85 µV) and the right locations ($-12.30 \pm 2.90$ µV). There was also an interaction between condition and location ($F(2,28) = 4.04$, $p < .03$). A Scheffé post hoc test indicated a significant difference between conditions in the left location ($p < .05$) with the Joint Attention condition ($-20.18 \pm 2.97$ µV) more negative than the No Joint Attention condition ($-12.40 \pm 3.02$ µV). A further assessment, utilizing paired sample *t*-tests within each channel group confirmed greater negative amplitude to the joint attention condition relative to the no joint attention condition in the left electrodes ($t(14) = -2.25$, $p < .05$). No differences were found in the central ($t(14) = 0.09$, $p > .05$) or right locations ($t(14) = -0.41$, $p > .05$). For the grand

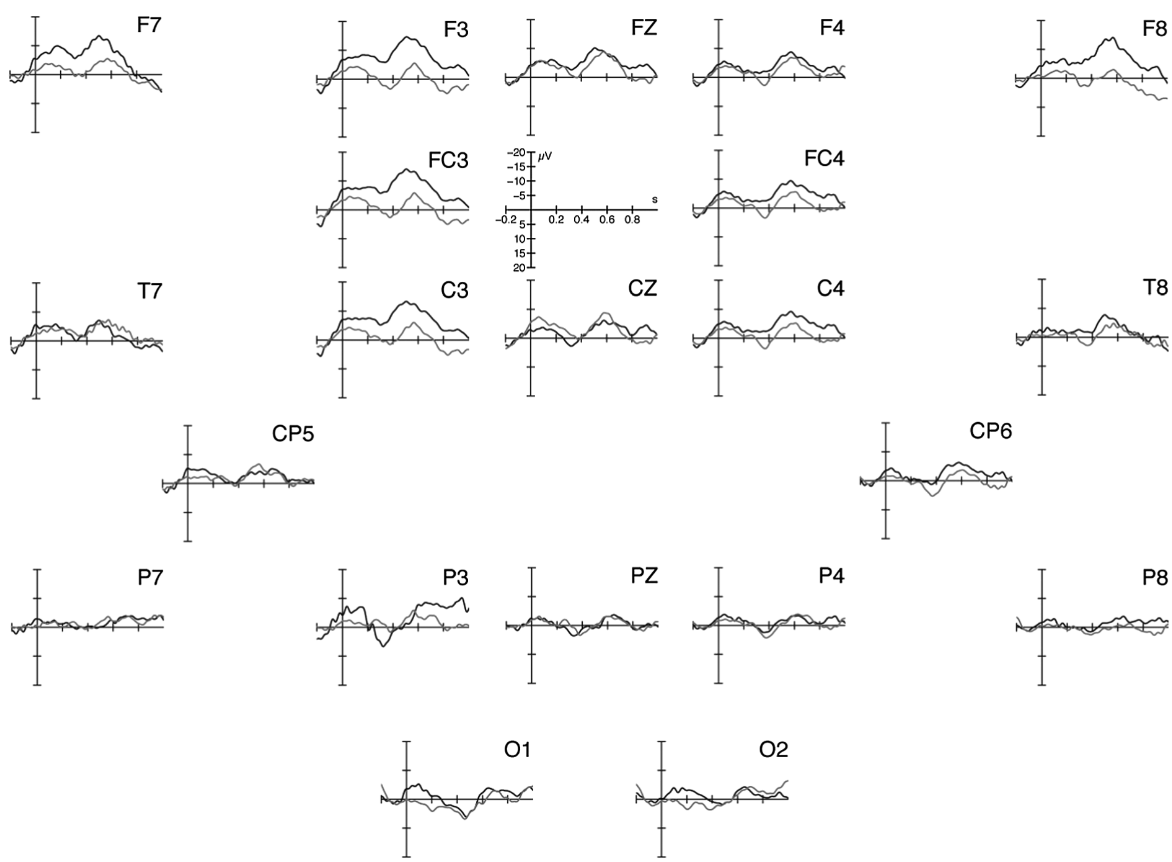


**Figure 2.** Grand average across all electrodes (black = direct eye contact; gray = no direct eye contact) of all subjects included ($n = 15$). The Nc component is maximal in the ERP at 500 ms in the eye contact condition in the left fronto-central (F3, FC3, C3) location. Horizontal tick mark, 0.2 ms; vertical tick mark, 10 µV. Negative is up. Note: O1 is the average of 14 subjects due to technical problems at this electrode.

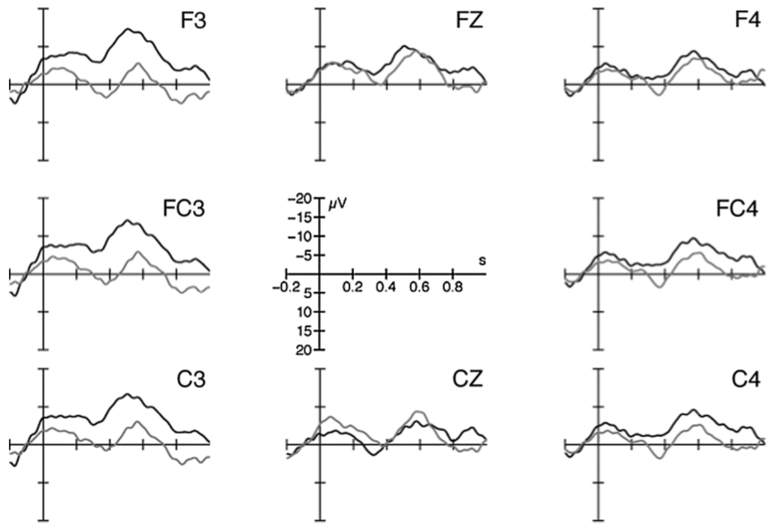


**Figure 3.** Grand average of electrodes used in the analyses (black = direct eye contact; gray = no direct eye contact). The Nc component was analyzed as the negative peak in the ERP between 400 and 700 ms in the frontal location.

average of the Nc effect in the context of all scalp locations, see Figure 2. For the grand average of the Nc effect at the assessed locations, see Figure 3. There were no effects of latency.

A follow-up analysis of whether there were effects of the block design was also performed. It was conceivable that the Nc would be greater in the mutual gaze condition when this condition was conducted first relative to the same condition being performed as the second block. The same is also true for the no mutual gaze condition. The minimum amplitude between left, central and right location was selected separately inside mutual gaze and no mutual gaze condition. Two independent samples *t*-test were performed (one within each condition), using the presentation order (mutual gaze as first block *vs.* no mutual gaze as first block) as categorial predictor. No order effects were found (in mutual gaze condition $t(13) = -0.97$, $p > .05$; and in the no mutual gaze condition $t(13) = -1.29$, $p > .05$).

As a final control, a time course analysis of the Nc amplitude during the sequence of trials was performed. Due to the block design and the task difficulties for the infants present in the paradigm, it was conceivable that a difference in Nc amplitude would be observed between the first and last trials of each block, with later trials displaying a diminished Nc amplitude. Within each test phase the trials that contributed to the participant's grand average were divided into two: the first and second halves of the test phase. ERPs were calculated separately for the first and second halves. The minimum amplitude between the left, central and right locations was selected in the same time window that was previously used. A $2 \times 2$ repeated measure ANOVA was performed with block and first/second half of trials as factors. In this way we segmented the time course of the Nc component in 4 sequential temporal segments, independently from condition (as condition was counterbalanced in the presentation order and was not representative of the Nc time course). No main effects ($F(1,14) = 0.13$, $p > .05$); $F(1,14) = 0.15$ or interaction ($F(1,14) = 0.15$, $p > .05$) were found to be significant. Even considering only the left frontal channels, the same analysis was not significant (all $p > .05$).

## Discussion

We evaluated the effect of direct eye contact (as a fundamental component of joint attention) on object processing in 5-month-old infants. The aim of the present study was to investigate neural correlates involved in joint attention in 5-month-old infants. A two block paradigm was used, with each block including a pretest phase with a live interaction between experimenter and infant, followed by a test phase of stimuli presented during EEG recording. The only difference between the two blocks was the nature of eye contact between the experimenter and the infant during the pretest phase. We performed a peak analyses on the fronto-central electrodes between 400–700 ms. We found a significant effect of location, with amplitude at central electrodes higher than at the right location, and a significant interaction of condition by location, with the amplitude in the Joint Attention condition being higher than in the No Joint Attention condition in the left fronto-central location.

Our results speak to a range of previous studies on the neurobiology of gaze and attention. Senju, Johnson, and Csibra (2006) recorded ERPs from both 9-month-old infants and adults. They used a computer presentation of a face displaying direct eye contact. Then a target appeared beside the face and finally the target disappeared and the face shifted the eyes congruently or incongruently with the previous target location. They found differences in both infants' and adults' ERP. Both groups showed a negative peak at about 300 ms at occipital-temporal locations. More interesting, in infants only two early frontal-anterior components (N200 and N400) were found, and both were more negative for the congruent condition. The authors interpreted the results as detection of communicative cues elicited by the particular experimental setting. Although there were differences in paradigm, EEG recording system and infant age when compared with the current experiment, both Senju et al. (2006) and the present study suggest a strong influence on infant perceptual processing of a period of mutual eye contact.

In one study with 4-month-olds, Reid, Striano, Kaufman, and Johnson (2004) found differences in a late slow wave ERP component during object processing. Infants in that study were initially shown a forward-gazing human face with an object located beside the head. The face then shifted the gaze to the object or away from the object. Finally, the object was displayed alone, to which the ERP was time-locked. The object previously uncued by the eyes elicited a higher amplitude in the late positive slow wave when compared to the ERP for the cued object. The authors interpreted this result as relating to a facilitation of object processing in the encoding of object properties. That is, the previously cued object was more encoded in the infant brain than the uncued one, resulting in a smaller slow wave for the cued object. When compared to this result, our data show a clearer involvement of attentional resources, due to the known properties of the Nc when compared to those of the positive slow wave. This result also suggests that the use of an experimenter in a live paradigm maximizes attentional resources when compared to the presentation of an individual on a computer display. However, both Reid et al. (2004) and the present study clearly demonstrate that eye gaze plays an important role in object processing within the first postnatal months.

The results of the present study shed new light on infants' early social-cognitive capacities. As with Striano et al. (2006b), the present study suggests that mutual eye gaze significantly influences the amount of attentional resources that is allocated by the observing infant during the processing of objects. A higher Nc peak amplitude in both conditions was observed by Striano et al. (2006b) when compared to the amplitudes found in the present study; however, the effect that we have found at 5 months is similar in terms of topography and latency. In both experiments no effect is present in the right anterior locations, with effects found in central and left frontal regions. This suggests an intriguing relationship between 5 and 9 months, with the possibility that the neural systems subserving the extraction of information during social interactions are the same at both ages.

Furthermore, it is of note that we recorded EEG to the presentation of objects once the experimenter had left the cabin. As the results are consistent between the present study and Striano et al. (2006b), this suggests that the formation of the memory trace by the infants was robust enough to withstand the delay between the experimenter leaving the room and the onset of the objects in the test phase. The delay between the end of the interaction and the beginning of the presentation of the object stimuli was anywhere between 20 and 60 s. Further, as we found no differences between the amplitude of the Nc at the beginning and the end of the test phase, this suggests that the manipulation of eye contact had an impact on object processing throughout the test phase. This could have been a period of between 90 and 240 s, depending on the individual infant, with 240 s representing the maximum length of each single test phase. Despite the difficulty of explaining our results without the involvement of memory encoding, it should be noted that we did not explicitly manipulate time as an independent variable. Therefore the issue of memory delay during joint attention is in need of further investigation.

In terms of the functional properties of the Nc, our results support the interpretation of the Nc component as a measure of attentional resources depending on the infant's interest in the stimulus. In our procedure all the stimuli were familiarized, with each EEG recording preceded by a pretest phase. This ensured that all the stimuli had previously been seen by the infants. The difference is in the kind of familiarization and, we can assume, in the nature of the engagement that the infant has with the objects. It is conceivable that objects in the direct eye contact condition were recognized as having more ''social valence'' in terms of being more socially important than those in the other condition. Our results are consistent with previous data on joint attention (both behavioral and ERP). Thus, it is possible to conclude that attention to the object is higher following the interaction with direct eye contact, and that the Nc component actually reflects a larger allocation of attentional resources for stimuli ''familiarized'' during a direct eye contact interaction.

One possible control would be to collapse the two pretest and the two test trials. In a single pretest the experimenter could show different-looking behaviors for different objects and in the test all the objects would be presented in a random order with equal probability. This could significantly improve the effectiveness of the paradigm, avoiding high dropout rates with participants due to the difficulty to attend to two different experimental blocks. Therefore this paradigm would be highly comparable with the method used to study the nature of Nc after stimuli familiarization that has provided inconsistent results in the past (see Reynolds & Richards, 2005).

One caveat to the current research is that the attrition rate of participants was high. It is possible that the demands of the task ensured that only those infants with a large attention span were able to be included in the final analysis. Alternatively, de Haan, Belsky, Reid, Volein, and Johnson (2004) found that it was those infants with high negative temperament that failed to complete an ERP experiment. It is possible that similar effects are present in the current experiment, although it is likely that task demands are the cause of the high attrition rate seen in this study.

The results presented here demonstrate that even 5-month-old infants are sensitive to key components of a joint attention interaction. It is possible to observe an effect of direct eye contact on underlying neural processes in infants of this age. In particular, the difference in the Nc amplitude found in the left fronto-central location suggests that direct eye contact is a fundamental part of a joint attention context that determines, at least in part, the attentional resources that an infant will allocate for processing an object. Due to the young age of the infants tested, these data are particularly relevant. As mentioned in the introduction, joint attention is thought be a fundamental skill for a number of developmental achievements apart from object processing. These skills include social referencing, imitation, and language learning. Therefore, this study also provides information that adds to a growing body of evidence clarifying the complex development of joint attention throughout the first postnatal year. It provides converging evidence with behavioral studies that fundamental components of joint attention are present at a very early age, and that neural systems involved in these tasks are operational well before the manifestation of overt behavior. This study shows that the investigation of joint attention at ages of less than 9 months is warranted in order to produce a robust understanding of the ontogeny of social cognition. This is particularly true given the influence of joint attention on social and cognitive abilities in later life.

Manuscript received 12 September 2007
Manuscript accepted 6 December 2007
First published online 5 February 2008

## REFERENCES

Baldwin, D. A. (1995). Understanding the link between joint attention and language. In C. Moore & P. Dunham (Eds.), *Joint attention: Its origin and role in development* (pp. 131–158). Hillsdale, NJ: Lawrence Erlbaum.

Brooks, R., & Meltzoff, A. N. (2005). The development of gaze following and its relation to language. *Developmental Science*, *8*, 535–543.

Carpenter, M., Nagell, K., & Tomasello, M. (1998). Social cognition, joint attention, and communicative competence. *Monographs of the Society of Research in Child Development*, *36* (4, Serial No. 176).

Courchesne, E., Ganz, L., & Norcia, A. M. (1981). Event-related brain potentials to human faces in infants. *Child Development*, *52*, 804–811.

de Haan, M., Belsky, J., Reid, V., Volein, A., & Johnson, M. H. (2004). Influence of maternal personality on infants' neural and visual responsivity to facial expressions of emotion. *Journal of Child Psychology and Psychiatry*, *45*(7), 1209–1218.

de Haan, M., & Nelson, C. A. (1997). Recognition of the mother's face by six-month-old infants: A neurobehavioural study. *Child Development*, *68*, 187–210.

de Haan, M., & Nelson, C. A. (1999). Brain activity differentiates face and object processing in 6-month-old infants. *Developmental Psychology*, *35*, 1113–1121.

Farroni, T., Mansfield, E. M., Lai, C., & Johnson, M. H. (2003). Infants perceiving and acting on the eyes: Tests of an evolutionary hypothesis. *Journal of Experimental Child Psychology*, *85*, 199–212.

Farroni, T., Massaccesi, S., Pividori, D., & Johnson, M. H. (2004). Gaze following in newborns. *Infancy*, *5*(1), 39–60.

Hoehl, S., Reid, V. M., Mooney, J., & Striano, T. (2008). What are you looking at? Infants' neural processing of an adult's object directed eye gaze. *Developmental Science*, *11*, 10–16.

Nelson, C. A. (1994). Neural correlates of recognition memory in the first postnatal year of life. In G. Dawson & K. Fischer (Eds.), *Human behavior and the developing brain* (pp. 269–313). New York: Guilford Press.

Nelson, C. A., & Collins, P. F. (1991). Event-related potential and looking-time analysis of infants' responses to familiar and novel events: Implications for visual recognition memory. *Developmental Psychology*, *27*, 50–58.

Nelson, C. A., & Collins, P. F. (1992). Neural and behavioural correlates of visual recognition memory in 4- and 8-month-old infants. *Brain and Cognition*, *19*, 105–121.

Reid, V. M., & Striano, T. (2005). Adult gaze influences infant attention and object processing: Implications for cognitive neuroscience. *European Journal of Neuroscience*, *21*, 1763–1766.

Reid, V. M., Striano, T., Kaufman, J., & Johnson, M. H. (2004). Eye gaze cueing facilitates neural processing of objects in 4-month-old infants. *Neuroreport*, *15*(16), 2553–2555.

Reynolds, G. D., & Richards, J. E. (2005). Familiarization, attention and recognition memory in infancy: An event-related potential and cortical source localization study. *Developmental Psychology*, *41*(4), 598–615.

Richards, J. E. (2003). Attention affects the recognition of briefly presented visual stimuli in infants: An ERP study. *Developmental Science*, *6*, 312–328.

Rugg, M. D., & Coles, M. G. H. (1995). *Electrophysiology of mind: Event-related brain potentials and cognition*. London: Oxford University Press.

Senju, A., Johnson, M. H., & Csibra, G. (2006). The development and neural basis of referential gaze perception. *Social Neuroscience*, *1*(3–4), 220–234.

Striano, T., Chen, X., Cleveland, A., & Bradshaw, S. (2006a). Joint attention social cues influence infant learning. *European Journal of Developmental Psychology*, *3*(3), 289–299.

Striano, T., Reid, V. M., & Hoehl, S. (2006b). Neural mechanisms of joint attention in infancy. *European Journal of Neuroscience*, *23*, 2819–2823.

Striano, T., & Stahl, D. (2005). Sensitivity to triadic attention in early infancy. *Developmental Science*, *8*, 333–343.

Striano, T., Stahl, D., Cleveland, A., & Hoehl, S. (2007). Sensitivity to triadic attention between 6 weeks and 3 months of age. *Infant Behavior and Development*, *30*(3), 529–534.

Thierry, G. (2005). The use of event-related potentials in the study of early cognitive development. *Infant and Child Development*, *14*, 99–102.

Tomasello, M. (1995). Joint attention as social cognition. In C. Moore & P. Dunham (Eds.), *Joint attention: Its origin and role in development* (pp. 103–130). Hillsdale, NJ: Lawrence Erlbaum.

Webb, S. J., Long, J. D., & Nelson, C. A. (2005). A longitudinal investigation of visual event-related potentials in the first year of life. *Developmental Science*, *8*, 605–616.

Woodward, A. L. (2003). Infants' developing understanding of the link between looker and object. *Developmental Science*, *6*, 297–311.