Developmental Science

Developmental Science 11:1 (2008), pp 10–16 DOI: 10.1111/j.1467-7687.2007.00643.x

# REPORT

# What are you looking at? Infants' neural processing of an adult's object-directed eye gaze

**Stefanie Hoehl,[1] Vincent Reid,[1,2] Jeanette Mooney[1] and Tricia Striano[1,3]**

1. *Neurocognition and Development Group, Center for Advanced Studies, University of Leipzig and Max Planck Institute for Human Cognitive and Brain Sciences, Leipzig, Germany*
2. *Department of Psychology, University of Durham, UK*
3. *Department of Psychology, Hunter College, New York City, USA*

## Abstract

*Previous research suggests that by 4 months of age infants use the eye gaze of adults to guide their attention and facilitate processing of environmental information. Here we address the question of how infants process the relation between another person and an external object. We applied an ERP paradigm to investigate the neural processes underlying the perception of the direction of an adult's eye gaze in 4-month-old infants. Infants showed differential processing of an adult's eye gaze, which was directed at a simultaneously presented object compared to non-object-directed eye gaze. This distinction was evident in two ERP components: The Negative component, reflecting attentional processes, and the positive slow wave, which is involved in memory encoding. The implications of these findings for the development of joint attention and related social cognitive functions are discussed.*

## Introduction

The direction of others' eye gaze is a crucial source of information in social interactions. Eye gaze even triggers attention reflexively to the aimed target or location (see Langton, Watt & Bruce, 2000, for a review). It also provides information about others' communicative intentions and future behavior (Baron-Cohen, 1995).

Recently, developmental research has provided new insights into the relevance and function of the detection of eye gaze direction and gaze following in infancy. For instance, Farroni, Csibra, Simion and Johnson (2002) and Farroni, Massaccesi, Pividori and Johnson (2004) showed that even newborns distinguish direct from averted eye gaze and prefer to look at a face with direct eye contact compared to averted gaze. Farroni *et al.* (2002) also presented evidence for an enhanced neural processing of faces with direct eye gaze in 4-month-olds. At this age infants begin to follow eye gaze and shift their attention to the direction of an adult's eye gaze (D'Entremont, Hains & Muir, 1997; Hood, Willen & Driver, 1998). This ability may be foundational for joint attention, which is considered to be a fundamental achievement in social ontogeny. Joint attention is known to be crucial for language acquisition as well as imitative learning (Baldwin, 1993; see also Brooks & Meltzoff, 2005). It is also considered to be an essential element of social referencing, the ability of infants to use the emotional expressions of familiar adults to regulate behavior in novel situations (Feinman, Roberts, Hsieh, Sawyer & Swanson, 1992).

Recently, the functional relevance of gaze cueing in infancy has been investigated. Reid and Striano (2005) presented 4-month-old infants with videos of a face that was directing eye gaze toward one of two nearby objects. When infants were exposed to both objects again without the face, they looked significantly longer to the previously uncued object, indicating that this was perceived as being more novel. In a similar study applying an event related potentials (ERP) paradigm, Reid, Striano, Kaufman and Johnson (2004) found an enhanced positive slow wave (PSW) at right and central frontal channels for objects that had not been cued by the eye gaze of an adult when compared to the PSW amplitude of eye gaze-cued objects. The PSW in 4- to 6-month-old infants has been related to stimulus updating or encoding (Nelson, Wewerka, Thomas, Tribby-Walbridge, deRegnier & Georgieff, 2000; de Haan & Nelson, 1997, 1999; Webb, Long & Nelson, 2005). In several studies the PSW was observed to be reliably greater for unfamiliar compared to familiar stimuli. It is therefore considered to reflect updating of only partially encoded information. This interpretation of the PSW suggests that the cued objects in the study by Reid *et al.* (2004) were perceived as more familiar and had been more efficiently encoded during the first presentation with the face. Consequently, cued

Address for correspondence: Stefanie Hoehl, Neurocognition and Development Group, University of Leipzig, Otto-Schill-Strasse 1, Leipzig 04109, Germany; e-mail: hoehl@cbs.mpg.de or Tricia Striano, e-mail: striano@cbs.mpg.de

objects elicited a less pronounced PSW when the stimulus was presented for the second time.

An important question, which remains unaddressed, is how infants actually process the relation between another person and an external object. How do infants use the information which is provided by an adult's eye gaze to guide their attention and differentially process environmental information? To explore this question we chose an ERP approach. This method allows for the direct investigation of the neural systems involved in information processing even in the absence of overt behavior. It therefore provides valuable information about the way in which infants process information from their environment. We presented static photographs of faces with eye gaze averted to the left or right side, with one object presented near to the face. The object was either displayed on the same side as the direction of eye gaze, or on the other side. We predicted that infants would form a stronger memory representation for the cued objects. This would be reflected by an enhanced PSW during the observation of stimuli depicting eye gaze-cued objects. Additionally we will explore differences in the earlier occurring mid-latency negative component (Nc), which has been associated with attentional orienting to salient stimuli (Courchesne, Ganz & Norcia, 1981; Nelson, 1994) or a general attentional arousal (Richards, 2003). Striano, Reid and Hoehl (2006) found a significantly enhanced Nc in 9-month-old infants in response to an object that was simultaneously cued by an adult in a live joint attention interaction. This indicates that infants' attention toward external objects is increased in joint attention interactions. However, in our study it is difficult to predict which condition will elicit higher attentional orienting, as we are assessing ERP differences in much younger infants. It may be that infants at 4 months of age pay more attention to the relationship between another person and an object when the person directs their eye gaze towards the object. Alternatively, it might be more unusual for the infant to observe a person averting eye gaze from an object and therefore more attention might be directed in the averted eye gaze condition. This might also account for less pronounced memory encoding of the object in this condition, as attention is then drawn away from the object and to the face. It is important to note that our paradigm does not require infants to perform gaze following. The aim of the present study is to assess how infants process the directedness of an adult's eye gaze in relation to an object which is within the infant's field of view at the same time as the face itself.

## Method

### *Participants*

Seventeen infants (nine males and eight females) were included in the final sample, with an average age of 4 months ± 9 days. All infants were born full term (37–41 weeks) and were in the normal range for birth weight. Another 47 infants were tested but were excluded from the final sample as a result of fussiness ($n$ = 19), failing to reach the minimum requirements for adequate averaging of the ERP data ($n$ = 14). Data from a further 14 subjects were corrupted during saving to the hard drive of the recording computer, due to a defective connection to the amplifier, and could not be analyzed. To be included in the sample an infant had to contribute at least 10 artifact-free trials per condition to their grand average. The experiments were conducted with the understanding and the written consent of each participant's parent.

### *Stimuli*

Stimulus material consisted of portrait photographs of two female actors, whose eyes were directed either to the left or to the right in a horizontal plane. Small pictures of colorful toys were displayed next to the faces either to the left or right side, at the height of the pupils on the face, approximately 2 cm away from the eyes. The eyes were therefore effectively directed at the toys or averted from them (see Figure 1). Stimuli were 25 cm long (from

**Figure 1** *Examples of stimuli for the object-directed eye gaze condition (left) and the non-object-directed eye gaze condition (right).*

the outermost edge of the object to the actor's ear on the opposite side of the picture) and 19.5 cm high.

### *Procedure*

Infants sat on their mother's lap in a dimly lit sound-attenuated and electrically shielded cabin, at a viewing distance of 90 cm away from a 70 Hz 17-inch stimulus monitor. The experiment consisted of one block with 200 trials (100 with object-directed eye gaze, 100 with averted eye gaze).

The two conditions were presented to the infant in a random order with the constraint that the same condition was not presented three times consecutively and that the number of presentations of each set of stimuli was balanced in every 20 trials presented. Each trial was preceded by a small triangular fixation object presented in the middle of the screen for 500 ms. Then a stimulus picture was presented for 1000 ms. After the presentation of every stimulus the screen was blank for a random period of between 800 ms and 1000 ms. In sum the inter-stimulus interval (including the blank screen period and the fixation object) added up to between 1200 and 1500 ms. If the infant became fussy or uninterested in the stimuli, the experimenter gave the infant a short break. The session ended when the infant's attention could no longer be attracted to the screen. EEG was recorded continuously and the behavior of the infants was also video-recorded throughout the session.

### *EEG recording and analyses*

EEG was recorded continuously with Ag-AgCl electrodes from 19 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 electro-oculargrams were recorded bipolarly. The sampling rate was set at 250 Hz. EEG data were re-referenced offline to the linked mastoids.

The EEG recordings were segmented into epochs of waveform that comprised a 200-ms baseline featuring a triangular central fixation object and 1000 ms of one static image featuring a face and object, as described above. For the elimination of electrical artifacts caused by eye and body movements, EEG data were rejected offline whenever the standard deviation within a 200-ms gliding window exceeded 80 V at any electrode. Data were also visually edited offline for artifacts and matched with the infant's recorded behavior. In order to avoid eye movement artifacts in this study, it was important to include only trials in which (1) the infant had looked at the screen during stimulus presentation and (2) the infant did not display any overt gaze following or saccades in the direction of the object, but fixated the face and only peripherally perceived the objects. Infants' looking behavior during stimulus presentation was therefore coded offline based on video-recordings. EOG measures were also assessed. Analyses of these behavioral data revealed that saccades were performed in about 5.37% of the presented trials. Interestingly, 85.8% of those saccades were in the direction of the stimulus object, independent of condition. We found that 49.5% of saccades in the direction of the target object occurred during the direct eye gaze condition and 50.5% during the averted eye gaze condition. This shows that infants occasionally reoriented to the colorful target object at the side of the face, but this behavior was not related to the direction of the adult's eye gaze. In sum, no systematic overt gaze following was observed in the present study.

For the directed eye gaze condition, each infant contributed 12–37 trials (mean of 18.5) to their average from a mean of 69.7 presentations. For the averted eye gaze condition each infant contributed 11–37 trials (mean of 18.4) to their average from a mean of 68.9 presentations.

For statistical analysis of the PSW, a time window was chosen from 700 to 1000 ms after stimulus onset, as this is the typical latency of the onset of an infant PSW (Nelson & de Haan, 1996; Webb *et al.*, 2005). ERPs were evaluated statistically by comparing the mean amplitude at frontal channels.

To assess differences in the Nc, a time window from 400 to 600 ms was chosen on the same channels as in Striano *et al.* (2006), that is, on frontal and central channels. In order to detect differences in the negative peak between the conditions, the minimal amplitude within this window was selected as the dependent variable.

## Results

### *The positive slow wave*

We assessed the ERP difference in object-directed and non-object-directed conditions by considering the mean amplitude in the two conditions between 700 and 1000 ms after stimulus onset. A repeated measures ANOVA was performed in frontal regions with condition (object-directed vs. non-object-directed) and scalp site (right frontal, F4 + FC4 vs. frontocentral, Fz vs. left frontal, F3 + FC3) as independent factors. We chose these regions of interest because previous research suggests that the processing of information obtained by the direction of eye gaze of others is most heavily related to neural responses on frontal channels in an infant population (Reid *et al.*, 2004). Visual inspection of our data also suggested this fact.

The ANOVA indicated that there was a significant main effect of condition on mean amplitude on the selected channel groups, $F(1, 16) = 4.68$, $p = .046$. As expected, the amplitude was substantially larger for the pictures with object-directed eyes ($M = 5.89$ microvolts, $SE$ 2.31) than for the pictures with averted eye gaze ($M = 1.63$ microvolts, $SE$ 1.93) (see Figure 2). No other effects were found in this epoch.

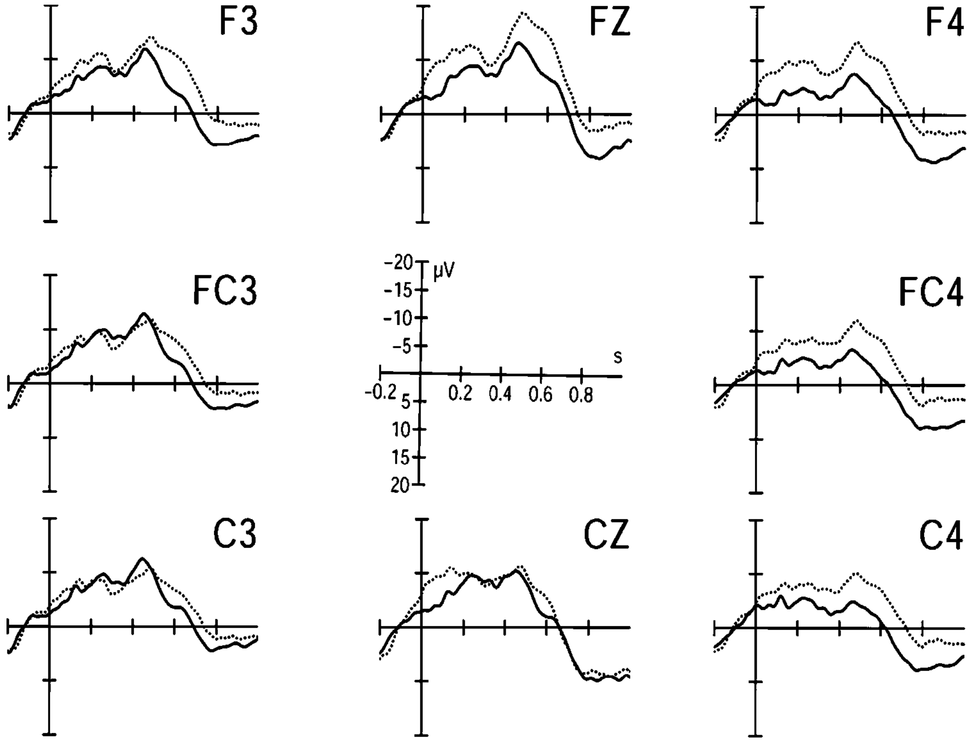


**Figure 2** *Grand averages for the two conditions (dotted line averted eye gaze; solid line object-directed eye gaze) on fronto-central channels. An enhanced PSW is evident for the object-directed eye gaze condition compared to the averted eye gaze condition. Note also differences between both conditions in latency and amplitude of the Nc.*

*The negative component*

To assess differences between the two conditions in this component, the minimal amplitudes between 400 and 600 ms after stimulus onset were compared for the two conditions. A repeated measures ANOVA was performed on the minimal amplitude in frontocentral channels with condition (object-directed vs. non-object-directed) and scalp site (right frontal, F4 + FC4 + C4 vs. frontocentral, Fz + Cz vs. left frontal, F3 + FC3 + C3) as independent factors. The ANOVA indicated that there was a significant main effect of condition on minimal amplitude of the Nc, $F(1, 16) = 4.8$, $p = .044$. The amplitude of this component was larger for pictures with averted eye gaze ($M = -19.6$ microvolts, $SE$ 2.0) than for those with directed eye gaze ($M = -14.3$ microvolts, $SE$ 2.26) (see Figure 3). Additionally there was a significant effect of condition on the latency of this component, $F(1, 16) = 5.52$, $p = .034$. The peak of the Nc occurred significantly later in the averted eye gaze condition ($M = 494$ ms after stimulus onset, $SE$ 12 ms) compared to the directed eye gaze condition ($M = 477$ ms after stimulus onset, $SE$ 8 ms) (see Figure 3). No other effects were found.

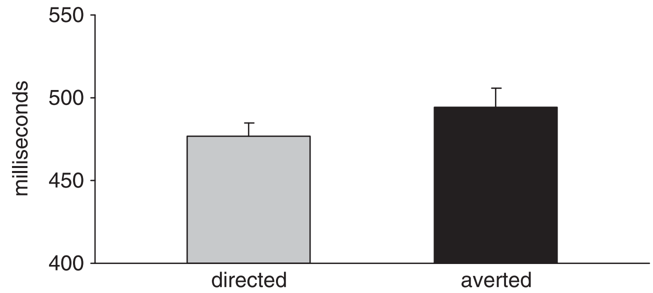


**Figure 3** *The latency of the Nc on right and central frontal channels in both directed and averted conditions. Latencies differ significantly as a function of condition and are substantially shorter in the directed eye gaze condition (gray) compared to the averted eye gaze condition (black).*

## Discussion

In the present study we investigated how infants at the age of 4 months process the direction of an adult's eye gaze in relation to objects. Our findings confirm that infants differentially process whether an adult's eye gaze is directed at an object or averted from an object. Eye gaze directed toward an object led to an enhanced PSW at frontal sites when compared to eyes gazing away from an object. The PSW in infants has previously been related to memory encoding (Nelson *et al.*, 2000; de Haan & Nelson, 1999; Webb *et al.*, 2005). We interpret this finding as evidence that infants form a stronger memory representation for the cued compared to the uncued objects.

Another component in which we found differential neural processing of directed vs. non-directed eye gaze was the Nc. This component is well known in developmental ERP research and has consistently been associated with attentional processes (Courchesne *et al.*, 1981; Nelson, 1994; Richards, 2003). The amplitude of the Nc has usually been interpreted as indicating the degree of visual of attention allocated to the processing of the presented stimulus. A larger amplitude corresponds to a greater allocation of attention (Striano *et al.*, 2006; Webb *et al.*, 2005). In our study a more negative Nc was elicited on frontal and central channels in the averted eye gaze condition. Interestingly, the latency of the Nc was significantly shorter in the directed eye gaze condition. Our stimuli could be processed faster when the adult's eye gaze was directed at the object, but more attentional resources were drawn to the picture when eye gaze was averted from the object. This suggests that the directed eye gaze was probably less complex for the infants, leading to faster and more efficient processing of the target object. Interestingly, we found this pattern of neural responses in the absence of overt saccades. It may be that covert attentional shifts bias the infant's response to the objects prior to overt gaze following behavior (Reid *et al.*, 2004). This might explain why cued objects can consequently be encoded more deeply, as indicated by the enhanced PSW and previous findings by Reid *et al.* (2004) and Reid and Striano (2005). In the averted eye gaze condition the situation between the infant, the person on the screen and the object was more ambiguous and less expected by 4-month-old infants. It took them longer to process the situation; however, they allocated more attention to the scene, as reflected by the amplitude and latency of the Nc component.

This interpretation is supported by findings from functional imaging studies with adults and school age children (Pelphrey, Singermann, Allison & McCarthy, 2003; Mosconi, Mack, McCarthy & Pelphrey, 2005). Activation in the superior temporal suclus (STS) has been related to the processing of biological motion such as shifts in eye gaze. In the above-mentioned studies by Pelphrey *et al.* (2003) and Mosconi *et al.* (2005), activation of the STS is increased when another person's gaze is not directed at a target compared to target-directed shifts in eye gaze. This increase in cerebral flood flow is interpreted as reflecting additional processing when the subject's expectations regarding the other person's intentions are not met. Our data suggest that 4-month-old infants have similar expectations about another person's eye gaze direction. When eye gaze is unexpected, i.e. averted from a target object, additional attentional resources are recruited, as indicated by an enhanced Nc in that condition when compared to the object-directed gaze condition.

Overall, our results suggest that even though the amount of information presented to the infants in this paradigm was high for this age group, and no overt gaze following behavior was displayed in the included trials, infants nonetheless discriminated the two conditions and differentially processed the given information. This finding is in line with previous research suggesting that infants use information from adult eye gaze to guide their limited attentional resources to the most socially relevant targets. These data also suggest that infants as young as 4 months encode object information more deeply when it is cued by an adult's eye gaze. This emphasizes the importance of triadic social interactions and the ability to jointly attend in early infancy (see Striano & Stahl, 2005), as its functional relevance is now better understood. Strikingly, these data also suggest that infants at 4 months of age have expectations regarding others' eye gaze behavior. Infants in our study allocated additional attentional resources to those stimuli where the person was directing eye gaze away from a target object when compared to results from object-directed gaze. These findings contradict theories which state that triadic attention only becomes relevant to social interactions in later infancy (e.g. Tomasello, Carpenter, Call, Behne & Moll, 2005).

As Lavelli and Fogel (2005) reported, infants' interactions with caregivers change within the first three postnatal months. For example, active and emotionally positive forms of attention toward the caregiver and complex sequences of interactive communication are elicited. At the age of 3–4 months, infants increasingly involve external objects in their social interactions (D'Entremont *et al.*, 1997; Hood *et al.*, 1998; Striano & Stahl, 2005). This changes the quality of their interactions with others, and also provides them with a mechanism with which to cope with the enormous informational input that they encounter from the visual world. Socially cued information becomes more important and is therefore more deeply encoded (see also Striano *et al.*, 2006).

There is converging evidence that autistic individuals are impaired in obtaining information from others' eyes (see, e.g. Baron-Cohen, Ring, Bullmore, Wheelwright, Ashwin & Williams, 2000) and that infants who will develop an autistic spectrum disorder (ASD) already show abnormalities in brain development in the first postnatal months (Courchesne & Pierce, 2005). It is possible that infants at risk of developing autism might already show impairments in the very fundamental social skills that were investigated in the current study. This issue, however, remains to be examined.

One considerable restriction on the interpretation of our data is that differences between ERP responses to both conditions can be observed over the whole course of our time window on some of the channels. This means that carry-over effects of earlier components on later components cannot be ruled out. The interpretation of the functional meaning of the Nc and especially of the later occurring PSW should be made with caution. However, our predictions regarding the PSW were clearly based on current understanding of the subsequent processing of the displayed objects.

It would be interesting to further investigate what cues infants utilize to guide their attention toward objects or target locations. For instance, would it be sufficient to display only eyes without the context of a face, or even just a schematic face or eyes? Another open question is whether it is really the eyes that make the difference. Potentially an averted head with occluded eyes would yield similar effects to those presented here. It would be interesting to also look at the influence of non-social cues such as arrows on the direction of an infant's attentional orientation, which has not yet been investigated, though we would predict that infants cannot use cues other than obviously social cues in the same way. It makes sense that information provided by social interactions is more likely to be processed by infants when compared to nonsocial information. This is because infants are highly dependent on other people around them, not only to guarantee care in the form of nutrition or emotion regulation, but also to guide them in learning.

## Conclusion

Infants at the age of 4 months differentially process an adult's eye gaze when it is directed at, or averted from, an object. In the directed eye gaze condition infants displayed an enhanced PSW as well as smaller amplitude and a shorter latency of Nc component. When combined with previous research, the present study suggests that infants are able to process object-directed eye gaze more rapidly than non-object-directed gaze, and encode socially cued information more deeply than information that is not socially cued. Eye gaze that is averted from a target object may contradict the social expectations of infants. Therefore they allocate additional attentional resources to non-object-directed eye gaze compared to object-directed eye gaze.

## Acknowledgements

This research was supported by the Sofja Kovalevskaja Award granted by the Alexander von Humboldt Foundation and donated by the Federal Ministry of Education to T. Striano. We thank Jennifer Landt for assistance with testing. We are grateful to the infants and parents who participated, and to the Universitätsfrauenklinik and the Eitingon Krankenhaus for support and assistance with recruitment.

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Received: 27 June 2006
Accepted: 16 January 2007