Eye gaze cueing facilitates neural processing of objects in 4-month-old infants

Vincent M. Reid, Tricia Striano[CA], Jordy Kaufman[1,2] and Mark H. Johnson[1]

Cultural Ontogeny Group, Max Planck Institute for Evolutionary Anthropology, Deutscher Platz 6, 04103 Leipzig, Germany; [1]Centre for Brain & Cognitive Development, Birkbeck University of London; [2]Department of Psychology, University College, London, UK

[CA]Corresponding Author: striano@eva.mpg.de

Received 28 August 2004; accepted 23 September 2004

A major issue in developmental science is how infants use the direction of other's eye gaze to facilitate the processing of information. Four-month-old infants passively viewed images of an adult face gazing toward or away from objects. When presented with the objects a second time, infants showed differences in a slow wave event-related potential, indicating that uncued objects were perceived as less familiar than objects previously cued by the direction of gaze of another person. This result shows that the direction of eye gaze of another cannot only bias infant attention, but also lead to enhanced information processing of the objects concerned. *NeuroReport* 15:2553–2555 © 2004 Lippincott Williams & Wilkins.

Key words: Event-related potentials; Eye gaze; Infants; Joint attention; Slow wave

INTRODUCTION

By at least 3 months of age, infants can follow the direction of an adult's eye gaze, and they are faster to orient to targets that appear in spatial locations previously cued by another's direction of gaze [1,2]. This ability is thought to lead to shared attention, an important foundation for several aspects of social and cognitive development. What is not currently known is whether infants will apply enhanced information processing to objects when they have recently been the subject of eye gaze by an adult. Thus, our aim in this study was to investigate the effect of gaze direction on infants' neural processing of objects.

Previous ERP research with infants has investigated processing of eye contact [3] and of familiar and unfamiliar objects [4]. However, the consequences of eye gaze for object processing has never been investigated. In the current study, we addressed this question using an ERP component that indicates familiarity of one object compared to another that has previously been associated with the recognition of a familiar object; the positive slow wave. This component is larger for novel than familiar stimuli during the processing of faces and objects by 6-month-old infants [4,5] and in typically developing toddlers [6]. We predicted a larger amplitude positive slow wave in response to objects that were uncued by the direction of gaze of an adult, indicating less familiarity with, and therefore greater processing of, such objects. Further, we predicted a diminished amplitude positive slow wave in response to objects that were cued by the direction of gaze of an adult, thereby indicating greater familiarity with such objects.

SUBJECTS AND METHODS

Participants: The final sample consisted of 12 4-month-old infants (age range 15–17 weeks, median 16 weeks). An additional 20 infants were tested but not included in the final sample due to: excessive ERP artefacts because of eye or body movement (n=6), too few data because of inattentiveness or fussiness (n=13), or a technical error (n=1). This high attrition rate was due to the requirement that infants attend to both phases of the stimuli presentation (see below) and to our requirement that each infant should contribute ≥ 15 trials per condition. All infants were born full-term (37–42 weeks gestation), were of normal birthweight (>2500 g) and were recruited in the UK.

Stimuli and procedure: Each infant was tested individually in an electrically shielded and soundproof room, seated in the mother's lap 70 cm from a computer monitor. For each trial a small, rapidly alternating set of black and white squares served as the fixation display ($3.2 \times 3.2°$), presented at the centre of the screen for 800 ms–1 s, followed by the stimulus presentation sequence described below.

The stimuli were presented on a video screen in two phases. First, a female face posing a neutral facial expression and forward gazing was presented for 1 s, together with an object located either on the left or right hand side of the face, not greater than $4.8 \times 4.8°$ when viewed from a distance of 70 cm from the stimulus monitor. The faces subtended a visual angle of $21.8 \times 14.7°$. The female face gaze then shifted to the left or right using filmed footage of eye movement superimposed on the neutral facial expression. Final gaze was held for 1 s. This generated two conditions – look towards the object and look away from the object, dependent on where the object was located (Fig. 1). Next, a 1 s attractor of alternating, moving squares was presented to attract the infant to the centre of the screen. The object that was presented simultaneously with the face was then centrally presented to the infant, remaining on screen for 1.5 s before a new central attractor appeared to signal the

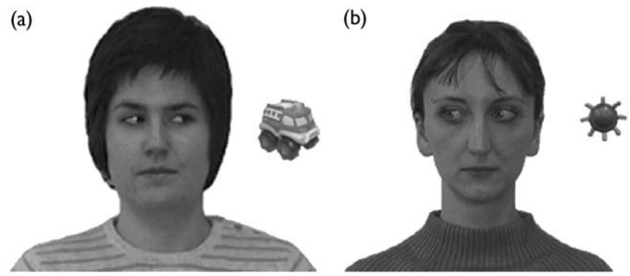

Fig. 1. Final frame of (**a**) Look towards (cued) and (**b**) Look away (uncued) conditions.

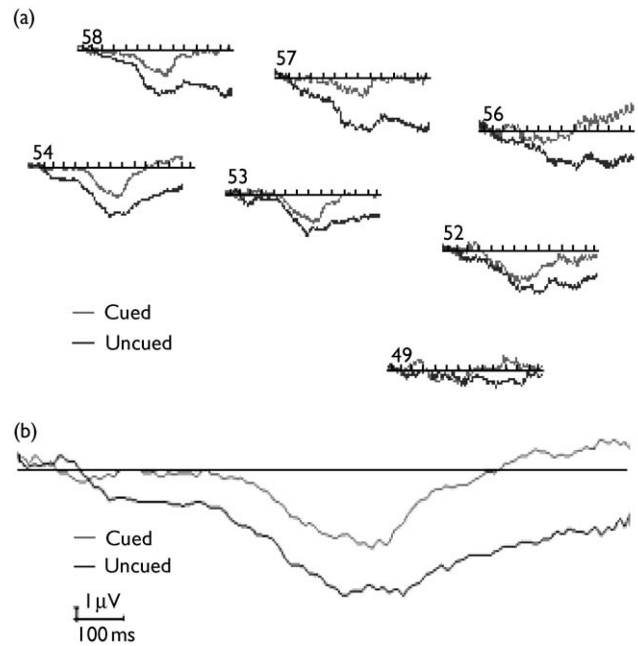

Fig. 2. ERPs in 4-month-old infants, recorded to objects that were previously cued or uncued by eye gaze. (**a**) The electrodes over the fronto-temporal region recorded an enhanced slow wave response to the uncued objects compared to the cued objects. (**b**) Channel 54 enlarged to highlight the slow wave difference between the two conditions.

beginning of the next trial. In total 80 objects were available for presentation, with a novel object presented with each trial.

The two conditions were presented in a random order with two constraints: (a) each of the two conditions was presented with equal probability, but (b) the same condition could not be presented more than three times consecutively. The experimenter monitored the infant's behavior on-line throughout the test session by video camera from the experimental control room adjacent to the test room. If the infant became fussy or failed to attend to the stimuli, the experimenter triggered presentation of a series of sounds to attract the infant's attention back to the monitor, or gave the infant a short break. The session ended when the infant's attention could no longer be attracted to the screen. EEG and video were recorded continuously throughout the session.

EEG recordings: EEG was recorded continuously from 62 channels referenced to the vertex [7] throughout stimulus presentation. A ground electrode was positioned at the rear of the head, and electro-oculogram was recorded from electrodes positioned above both eyes and on the outer canthi. All bioelectrical signals were recorded using Electrical Geodesics Inc. amplifiers (Eugene, OR, USA) with an input impedance of 100 MOhms. Sampling rate was 250 Hz (every 4 ms), band pass was 0.1–100 Hz, and gain was set to $10\,000\times$.

Data reduction: For each trial, EEG recordings were truncated to create an epoch from 200 ms before the second presentation of the object to 1100 ms after stimulus onset. Data were baselined by subtracting the average voltage in the 200 ms baseline period from each post-stimulus data point. ERPs were visually edited offline to remove artefacts related to eye or body movements or poor contacts. For trials in which <7 electrodes contained artefacts, the missing data were interpolated using spherical spline interpolation; trials in which >7 electrodes contained artefacts were discarded. For each participant, a separate average was created for each of the two conditions by averaging across individual trials with good data. Participants required a minimum of 15 trials for each condition in order to be included in further analyses. Following averaging, data were filtered at 35 Hz and referenced to the average reference.

A time window of 700–1000 ms after stimulus onset was defined for the slow wave (SW) based on prior studies that suggest that the SW starts around 600 ms and can continue for several hundred milliseconds [8,9]. This time window was also selected due to inspection of the individual subjects' averages. Our analyses focused on right fronto-temporal electrodes (49,52,53,54,56,57,58; see [7]) because the SW was most prominent over these sites and this scalp location is consistent with effects found in previous SW research [4,10]. One measure of the SW was computed for each condition: Peak Amplitude, by measuring the peak voltage of the SW. Amplitude measures were normalised by dividing each infant's peak amplitude with their average amplitude to minimise variance due to general between-infant differences in ERP amplitude.

RESULTS

We conducted a paired samples *t*-test with condition (gaze cued *vs* uncued object) as dependent variables. There was a significant effect of condition, $t(11)$, $p<0.05$ on the peak SW amplitude (Fig. 2). As predicted, the amplitude was greater for uncued objects ($5.45\pm2.44\,\mu V$) than cued objects ($1.21\pm1.71\,\mu V$); see Fig. 2 for an example.

DISCUSSION

While previous work has demonstrated that infants can be cued to attend to spatial locations as a result of the direction of adult eye gaze, the results of the present study demonstrate that 4-month olds have already encoded aspects of objects that have previously been the subject of adult gaze. For evidence, responses to cued objects produced a diminished SW, whereas the uncued objects produced a larger amplitude SW response.

A review of infant behavior during the presentation of the face and gaze component of the stimulus sequence showed that no infants overtly followed the gaze to the object location. Rather, in the trials used for the analysis all infants remained fixated on the centrally presented face. This suggests that covert attentional shifts initially bias the infants' response to the objects. Further, it allows us to rule out differential looking time as an explanation of the difference seen in the SW component between the conditions. As our results were not related to differences in overt infant behavior, this suggests that ERP data can yield information that cannot be measured by infant behavioral paradigms. It is clear that ERP research utilising paradigms such as that presented here are vital to our understanding of developmental social cognition.

The results of the present study fit well with other evidence of gaze following in early infancy [3], and suggest that the underpinnings of joint attention (i.e. understanding the relevance of the cues others' provide about things) starts in early infancy. It is of note that the ERP finding relates to the SW, which in previous studies relating to object processing has been interpreted as a measure of memory encoding or discrimination [4,5,10]. The present results imply that the skills relating to triadic interactions develop in early ontogeny and involve SW component processes. Clearly well before they engage in more systematic joint attention activities (see [11] for a review), young infants already use other's eye gaze as a cue that facilitates object processing.

CONCLUSION

While infants process and identify others' gaze from the early months, the functional consequences of this skill have been unclear. Here we show that the direction of an adults' gaze facilitates object processing at a neural level in infants as young as 4 months. Future research is needed to assess the development of gaze cueing during ontogeny in order to establish the neurodevelopmental trajectory of joint attention and its relation to object processing.

REFERENCES

1. D'Entremont B, Hains SMJ and Muir DW. A demonstration of gaze following in 3- to 6-month-olds. *Infant Behav Dev* 1997; **20**:569–572.
2. Hood BM, Willen JD and Driver J. Adults eyes trigger shifts of visual attention in human infants. *Psychol Sci* 1998; **9**:131–134.
3. Farroni T, Csibra G, Simion F and Johnson MH. Eye contact detection in humans from birth. *Proc Natl Acad Sci USA* 2002; **99**:9602–9605.
4. de Haan M and Nelson C. Brain activity differentiates faces and object processing in 6-month-old infants. *Dev Psychol* 1999; **35**:1113-–1121.
5. Nelson CA. Electrophysiological correlates of memory development in the first year of life. In: Reese HW and Franzen MD (eds). *Biological and Neuropsychological Mechanisms*. Mahwah NJ: Erlbaum; 1997, pp. 95–131.
6. Dawson G, Carver L, Meltzoff AN, Panagiotides H, McPartland J and Webb SJ. Neural correlates of face and object recognition in young children with autism spectrum disorder, developmental delay and typical development. *Child Dev* 2002; **73**:700–717.
7. Tucker DM. Spatial sampling of head electrical fields: the geodesic sensor net. *Electroencephalogr Clin Neurophysiol* 1993; **87**:154–163.
8. Nelson CA and Collins PF. Neural and behavioral correlates of recognition memory in 4- and 8-month-old infants. *Brain Cogn* 1991; **19**:105–121.
9. Nelson CA and de Haan M. Neural correlates of infants' visual responsiveness to facial expressions of emotion. *Dev Psychobiol* 1996; **29**:577–595.
10. Snyder K, Webb SJ and Nelson CA. Theoretical and methodological implications of variability in infant brain response during a recognition memory paradigm. *Infant Behav Dev* 2002; **25**:466–494.
11. Carpenter M, Nagell K and Tomasello M. Social cognition, joint attention, and communicative competence from 9 to 15 months of age. *Monogr Soc Res Child Dev* 1998; **63** (4, Serial No. 255).

Acknowledgements: We thank the parents and infants for participating in this study, and Dr Gilly Forrester, Agnes Volein and Leslie Tucker for help with testing. Financial support was provided by the MRC (PG 9715587), Birkbeck College, and the Max Planck Institute.