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Infant neural sensitivity to eye gaze depends on early experience of gaze communication

Angélina Vernetti[a], Nataşa Ganea[a], Leslie Tucker[a], Tony Charman[b], Mark H. Johnson[a,c], Atsushi Senju[a,*]

[a] Centre for Brain and Cognitive Development, Birkbeck, University of London, Malet Street, London WC1E 7HX, UK
[b] Department of Psychology, Institute of Psychiatry, Psychology & Neuroscience, King's College London, UK
[c] Department of Psychology, University of Cambridge, UK

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ABSTRACT

A fundamental question in functional brain development is how the brain acquires specialised processing optimised for its individual environment. The current study is the first to demonstrate that distinct experience of eye gaze communication, due to the visual impairment of a parent, affects the specificity of brain responses to dynamic gaze shifts in infants. Event-related potentials (ERPs) from 6 to 10 months old sighted infants with blind parents (SIBP group) and control infants with sighted parents (CTRL group) were recorded while they observed a face with gaze shifting *Toward* or *Away* from them. Unlike the CTRL group, ERPs of the SIBP group did not differentiate between the two directions of gaze shift. Thus, selective brain responses to perceived gaze shifts in infants may depend on their eye gaze communication experience with the primary caregiver. This finding highlights the critical role of early communicative experience in the emerging functional specialisation of the human brain.

1. Introduction

From birth, infants show a remarkable capacity to detect and process the eye gaze of others. Newborns preferentially orient to faces making eye contact (Batki et al., 2000; Farroni et al., 2002), and shift their attention to the direction of perceived gaze shift (Farroni et al., 2002). Newborns preference for face-like pattern also involves detecting darker elements against lighter background (Farroni et al., 2005), which could be optimised to detect human eyes, characterised by a darker iris against white sclera (Gliga and Csibra, 2007). As eye gaze is a key channel of non-verbal communication in humans (Kleinke, 1986), such an early-emerging predisposition to process eye gaze is adaptive, preparing infants for social and communicative learning from parents and other adults (Csibra and Gergely, 2009).

Recent evidence suggests that this newborns' predisposition is followed by brain adaptation to the individual's specific sociocultural environment, which may vary in degree of exposure to communicative eye gaze. For example, infants and children developing in different cultures show different patterns of face scanning (Geangu et al., 2016; Kelly et al., 2011; Senju et al., 2013), which are suggested to be adaptive to each of the cultural norms on the use of eye gaze (Argyle and Cook, 1976). Similarly, we recently demonstrated that sighted infants of blind parents (SIBPs), who experience qualitatively different eye gaze communication, show a distinct pattern of face scanning and gaze following, most notably from the second year of life (Senju et al., 2015). Adaptation to an individual's particular social environment is fundamental for effective social learning and communication, as well as the formation of distinct cultural groups (Han et al., 2013). These findings are also consistent with the view that infants are born with initial predispositions to process their species-typical environment, which then also guide the later experience-dependent development of specialized cognition adaptive to the given individual environment (Johnson et al., 2015; Senju and Johnson, 2009). However, to date the evidence on this issue is limited to behavioural measures, and data is lacking on how and when processing in the infant brain is influenced by such variations in experience.

The current study is the first to investigate the role of eye gaze communication experience on the neural sensitivity for gaze processing. We tested 14 SIBPs at the age of 6–10 months of age, all of whose primary caregivers do not use typical forms of eye gaze communication because their visual impairment prevents them from seeing their babies' eyes during face-to-face communication. Electroencephalography was used to record brain activity while SIBPs observed dynamic gaze shifts in a face image that moved either *Toward* or *Away* from the observer,

* Corresponding author.
E-mail address: a.senju@bbk.ac.uk (A. Senju).

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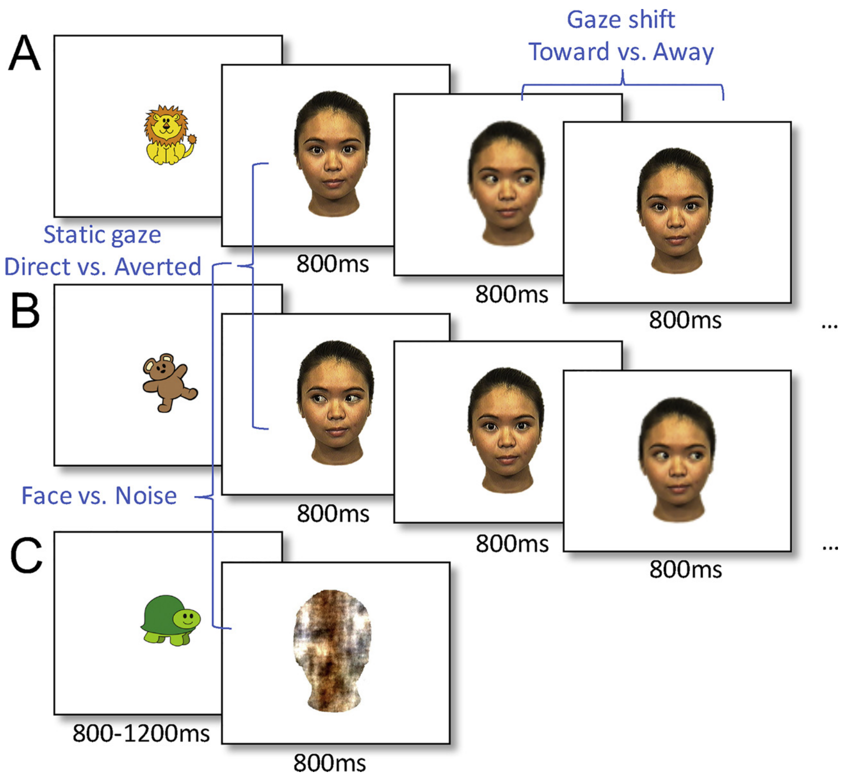

Fig. 1. Schema of the ERP task consisting of three different types of trials (A. *Face* trials starting with direct gaze followed by gaze shifts, B. *Face* trials starting with *Averted* gaze followed by gaze shifts, C. *Noise* trials). The three different contrasts: static gaze (*Direct* vs. *Averted* gaze), gaze-shift (*Toward* vs. *Away* gaze) and *Face* vs. *Noise* are depicted in blue.

presented on a video monitor (Fig. 1). From the recording, event-related potentials (ERPs) were analysed for posterior channels, which are known to show differences for the perception of different directions of gaze (Elsabbagh et al., 2009; Farroni et al., 2002) and gaze shift (Elsabbagh et al., 2012) in young infants. SIBP ERPs were then compared to the ERPs of 45 control infants of sighted parents (CTRLs), who participated in a separate study using the same paradigm, equipment and with experimenters similarly trained within the same research centre (Elsabbagh et al., 2012). The SIBP group also participated in a series of eye-tracking tests and the assessment of general social and cognitive skills at the time of testing (Senju et al., 2015), and was followed-up at 36 months of age to examine whether they show long-term typical development.

2. Methods

2.1. Participants

Fourteen sighted infants (6 males, mean age = 8.84 months; SD = 1.10) of blind parents (SIBP group) participated in the study. An additional SIBP child was excluded from the analyses due to not having a minimum of 10 valid trials in each contrast (see Supplementary information, Section 1 (SI-1), Table S1 for further details). All the blind parents were the primary caregivers of the infants, had visual impairment for at least 15 years prior to the testing, and could not see the infants' eyes and gaze from the distance of 50 cm, based on self report (see SI-2, for more information on the level of visual impairment of the parents and the SIBP's exposure to sighted adults). The ERP data were collected as part of a larger protocol, which also included a series of eye-tracking studies as well as standardised assessments of social and cognitive development (Senju et al., 2015). The data were then compared with the existing dataset of 45 infants with sighted parents (CTRL group, 15 males, mean age = 7.62 months; SD = 1.17), who originally participated in the British Autism Study of Infant Siblings (BASIS, a UK collaborative network examining infants at risk for autism (Elsabbagh et al., 2012)).

Eleven SIBP infants were also followed up at 36 months of age and were administered several behavioural assessments of social communicative and cognitive development: Mullen Scales of Early Learning (MSEL; Mullen, 1995), Vineland Adaptive Behaviour Scale (VABS; Sparrow et al., 2005), Autism Diagnostic Observation Scale-Generic (ADOS-G; Lord et al., 2000), Autism Diagnostic Interview-Revised (ADI-R; Lord et al., 1994) and Social and Communication Questionnaire (SCQ; Rutter et al., 2003) (see the participants characteristics in SI-3, Table S2). All SIBP infants but one obtained ADOS scores below the ADOS cut-off. One child did score above the cut-off for autism spectrum disorder (ASD), and subsequent to the research assessment, received a community clinical diagnosis of ASD.

2.2. Material and procedure

The task consisted in the presentation of four different female faces (face: 21.3° × 13.9°, eye: 1.6° × 2.7°) in the centre of a screen. A trial began with the presentation of a colourful picture of 1.6° × 1.6° for a variable duration of 800–1200 ms to attract infants' attention. Then, a static face with *Direct* or *Averted* gaze was presented for 800 ms, followed by 3–6 gaze shifts from the same face (*Away* or *Toward* the viewer, Fig. 1) presented every 800 ms. As well as static faces and gaze shifts (*Face* trials), scrambled faces (*Noise* trials) were presented for 800 ms. Twelve scrambled faces were constructed from the same face stimuli (*Direct* gaze, left *Averted* gaze, right *Averted* gaze) for each female face, with randomization of the phase spectra while keeping constant the amplitude and colour spectra (Halit et al., 2004). The presentation of *Face* and *Noise* trials was pseudo-random such that 1) the same identity was used within the *Face* trials 2) which consisted in the intermittence of gaze shifts with opposite directions, and 3) the *Noise* trials were set to appear for one third of the total number of trials (Fig. 1). The faces were aligned with the centre of the screen so that the eyes appeared at a location where the fixation stimuli had been presented. All participants sat on their parents' laps in front of a 40 × 29 cm screen at a distance of 60 cm. The infants' gaze and movements were video-recorded.