



# Direct gaze facilitates rapid orienting to faces: Evidence from express saccades and saccadic potentials



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## ABSTRACT

Direct gaze is a crucial signal in human social communication, which is known to attract visual attention and modulate a wide range of behaviours. The present study investigated whether direct gaze facilitates rapid orienting to faces, which is important for adaptive on-line communication, and its neural correlates. Fifteen participants performed a rapid orienting task, in which they were instructed to saccade to peripherally presented buildings or faces containing direct or averted gaze as quickly as possible. Electroencephalographic recordings were made during the task. Shorter express saccade latencies were found for faces with direct gaze, compared to averted gaze or buildings, while no significant difference was found between faces with averted gaze and buildings. Furthermore, saccade-locked event-related potential (ERP) amplitudes in parieto-occipital areas discriminated faces with direct gaze from buildings and faces with averted gaze corroborating behavioural results. These results show that detection of direct gaze facilitates rapid orienting to faces.

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## 1. Introduction

One of the hallmarks of social communication is its dynamic and rapidly changing nature. Successful social communication often relies on the immediate detection of social cues and a timely response. For example, missing a quick glance from a social partner can hinder successful communication. Thus, fast detection and orientation to social and communicative signals is crucial for social adaptation. For example, face detection has been reported to occur within 100 ms of a face appearing (Crouzet, Kirchner, & Thorpe, 2010). The optimal stimulus to evoke this type of fast orientation towards faces is thought to consist of the characteristic contrast pattern of the face, three dark areas corresponding to the eye sockets and mouth surrounded by a lighter background (Tomalski, Csibra, & Johnson, 2009), which also generates preferential orienting in newborns (Farroni et al., 2005) and is hypothesized to be supported by a subcortical pathway involving the superior colliculus, pulvinar and amygdala (Johnson, 2005).

Eyes are a major conveyer of communicative signals. Human eyes are unique among primates, being horizontally elongated

and possessing the largest ratio of exposed sclera within primates (Kobayashi & Kohshima, 2001). These two features are thought to have evolved in order to facilitate the detection of another's gaze direction (Emery, 2000), enhancing the communicative value of gaze perception. Direct gaze is a relevant social cue signalling attention and/or intention toward oneself (Frischen, Bayliss, & Tipper, 2007; Senju & Johnson, 2009). It is preferentially detected by newborns (Farroni, Csibra, Simion, & Johnson, 2002) and modulates several concurrent tasks including emotion discrimination (Adams & Kleck, 2005) and identity encoding and retrieval (Conty & Grèzes, 2012; Hood, Macrae, Cole-Davies, & Dias, 2003). Furthermore, direct gaze is a particularly salient visual feature being detected faster than averted gaze in visual search tasks, the so-called "stare-in-the-crowd" effect (Doi & Shinohara, 2013; Senju, Hasegawa, & Tojo, 2005; Von Grünau & Anston, 1995). To account for the neural mechanisms underlying preferential processing of direct gaze, Senju and Johnson (2009) proposed a fast-track modulator model, which hypothesizes that direct gaze is initially detected by a subcortical pathway, which then subsequently modulates the cortical processing of social signals. Enhanced activation of amygdala for direct gaze detection was shown in a patient with total cortical blindness (Burra et al., 2013), which supports the claim that the subcortical pathway is sufficient to detect direct gaze.

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One of the key predictions of the first-track modulator model is that detection of direct gaze facilitates express saccades, which are thought to rely on the superior colliculus (Schiller, Sandell, Maunsell, 1987). More specifically, it is predicted that rapid orienting to faces, as reported in previous studies (e.g. Crouzet & Thorpe, 2010), depends on direct gaze within the target face. To date, no study has directly tested this prediction [but see (Conty, Tijus, Hugueville, Coelho, & George, 2006; Doi and Shinohara, 2013; Palanica & Itier, 2011; Senju et al., 2005; Senju, Kikuchi, Hasegawa, Tojo, & Osanai, 2008; Von Grünau & Anston, 1995) for studies analysing direct gaze saliency with visual search tasks].

Here, we used a rapid orienting gap task to investigate the role of eye gaze in fast face detection. Rapid orienting tasks allow for saccadic responses as fast as 110 ms following the presentation of a face (Crouzet et al., 2010), and therefore should tap into any specialised processes for fast face detection. Moreover, the presence of a gap between the offset of fixation stimuli and the onset of target display has been shown to elicit express saccades (Fischer & Ramsperger, 1984). Express saccades rely on the superior colliculus (SC), being abolished in cases of SC lesion (Schiller et al., 1987). Targets' visual properties have been shown to modulate express saccades, with concomitant modulation of SC activation (Bell, Meredith, Van Opstal, & Munoz, 2006; Marino, Levy, & Munoz, 2015). Significant differences between the detection of direct and averted gaze in this type of fast response would indicate a very fast processing of direct gaze.

Furthermore, significant differences between gaze directions were analysed at the cortical level, through the use of EEG. Saccade related Potentials [Presaccadic Positivity (PSP), the Spike Potential (SP) and the Lambda Wave] were analysed to examine the neural underpinnings of this fast detection and orienting. Compared to the typically used event related Potentials (ERPs) time-locked to stimulus onset, these components that are time locked to the saccade allow us to analyse the timecourse of cortical processing directly linked to fast face orienting. Furthermore the Lambda wave is structurally similar to fixation event-related potentials (fERPs, Dimigen, Kliegl, & Sommer, 2012; Kaunitz et al., 2014), possibly being closely linked with the visually evoked P100, N170, and P200. Faster detection of faces with direct gaze is expected with significant differences between gaze directions observed cortically in saccade locked ERPs during and after the onset of the saccade. Given the proposed role of subcortical structures for a faster detection of direct gaze, we do not expect differences between gaze directions, has measured cortically through the use of EEG, before saccade onset. We also explored a putative left visual field (LVF) bias for this effect since a better discrimination of gaze direction has been observed in the LVF (Ricciardelli, Ro, & Driver, 2002), as well as a more prominent effect of direct gaze (Palanica & Itier, 2011).

## 2. Materials and methods

### 2.1. Participants

Fifteen right handed volunteers (11 female, age range 24–48 years,  $31.87 \pm 9.69$  years) participated in the experiment. All participants reported normal or corrected to normal vision and received payment or course credits. Written informed consent was obtained from all participants. The study was approved by the ethical committee of the Department of Psychological Sciences, Birkbeck, University of London.

### 2.2. Stimuli and procedure

EEG was recorded while participants were asked to rapidly orient to targets that could be faces or buildings presented periph-

erally. Participants sat comfortably in an electrically shielded and soundproofed room at a fixed distance of 60 cm from the computer screen through the use of a chin rest. The experiment consisted of 6 blocks with 96 trials each. Buildings and faces were shown in equal numbers, with the latter balanced between gaze conditions. Each trial started with a fixation cross presented in the centre of the screen for 1000–1400 ms (randomly jittered), after which it disappeared leaving a gap of 200 ms before the stimulus onset (Fig. 1). The use of this gap paradigm allows for faster saccadic initiation (Fischer & Weber, 1993). Stimuli were then presented peripherally to one visual hemifield for 400 ms. Participants were instructed to fixate the centre of the screen until target appearance and then to saccade to the target stimulus as rapidly as possible.

Face stimuli were 12 greyscale digitized photographs of faces in neutral expressions and displaying a deviated head position with a rotation of 30° counterbalanced between right and left directions (George, Driver, & Dolan, 2001). Deviated head positions were used to avoid low level confounds, such as facial symmetry. Gaze condition was manipulated between direct and averted gaze (30°) counterbalanced between right and left gaze direction. Stimuli were cropped excluding hair and other non-facial cues. Twelve greyscale digitized photographs of buildings were also used as a control condition. Face and buildings' stimuli were equated in mean luminance and contrast using the SHINE toolbox (Willenbockel et al., 2010). All images subtended  $7.6^\circ \times 9.5^\circ$  degrees of visual angle and were shown peripherally,  $9.1^\circ$  to the right or to the left of the fixation cross. Stimuli were presented using E-Prime software (Psychology Software Tools, Pittsburgh, PA).

### 2.3. ERP recording and data analyses

EEG was continuously recorded from 60 Ag-AgCl electrodes placed on a fitted cap (EASYCAP) according to the international 10/10 system. EOG electrodes were used to monitor eye-movements, with two electrodes placed on the canthi of right and left eye to detect horizontal movements, and one electrode placed below one eye to monitor vertical movements. Data was acquired at a sampling rate of a 1000 Hz. Electrode impedance was kept below 10 k $\Omega$ . EEG data was online referenced to the mastoids and offline re-referenced to an average reference. Data analysis was performed via the Matlab toolbox EEGLAB (Delorme & Makeig, 2004). Recordings were band pass filtered between 0.1 and 40 Hz, initially epoched (–100 ms to 1000 ms around target stimulus onset) and baseline corrected using the 100 ms prior to stimuli onset. Target locked epochs were used to calculate saccadic reaction time (SRT). This was defined as the time from the target stimulus onset to the execution of a correct saccade towards the target's hemifield. Given the large number of express saccades occurring under 130 ms, which introduce considerable eye-movement artefacts, we do not analyse target locked ERPs here (though their analysis can be found in the Supplementary material, Section 1, and shows smaller amplitudes for direct than averted gaze in P100 in the left hemisphere and right hemifield and larger amplitudes for faces than buildings in the N170). Saccade onsets were automatically identified using the difference between the two horizontal EOG channels, as the beginning of a monotonic slope with more than 1  $\mu$ V/ms in either direction lasting at least 20 ms (Csibra, Tucker, Volein, & Johnson, 2000). Trials with saccades beginning before 80 ms were excluded from further analysis as anticipatory responses. Trials with saccades starting after 500 ms were also rejected. Trials with small corrective saccades were kept while trials which included a switch of gaze direction occurring before 500 ms (i.e. the participant made an initial saccade in one direction followed by a second saccade to the opposite direction), were only kept for the behavioural analysis to obtain a measure of accuracy but excluded from the subsequent ERP analysis due to the

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