



The neural time course of evaluating self-initiated joint attention bids



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ABSTRACT

Background: During interactions with other people, we constantly evaluate the significance of our social partner's gaze shifts in order to coordinate our behaviour with their perspective. In this study, we used event-related potentials (ERPs) to investigate the neural time course of evaluating gaze shifts that signal the success of self-initiated joint attention bids. **Method:** Nineteen participants were allocated to a "social" condition, in which they played a cooperative game with an anthropomorphic virtual character whom they believed was controlled by a human partner in a nearby laboratory. Participants were required to initiate joint attention towards a target. In response, the virtual partner shifted his gaze congruently towards the target – thus achieving joint attention – or incongruently towards a different location. Another 19 participants completed the same task in a non-social "control" condition, in which arrows, believed to be controlled by a computer program, pointed at a location that was either congruent or incongruent with the participant's target fixation. **Results:** In the social condition, ERPs to the virtual partner's incongruent gaze shifts evoked significantly larger P350 and P500 peaks compared to congruent gaze shifts. This P350 and P500 morphology was absent in both the congruent and incongruent control conditions. **Discussion:** These findings are consistent with previous claims that gaze shifts differing in their social significance modulate central-parietal ERPs 350 ms following the onset of the gaze shift. Our control data highlights the social specificity of the observed P350 effect, ruling out explanations pertaining to attention modulation or error detection.

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1. Introduction

Joint attention – the ability to achieve a common focus of attention with a social partner – supports language development, social communication, and learning (Charman, 2003; Mundy & Newell, 2007). Joint attention is achieved when one individual initiates a bid for joint attention – usually by gazing towards the intended focus of attention – and another individual responds by following their partner's line of regard (Bruner, 1974). Coordinating joint attention with others during dynamic interactions relies on the ability to evaluate the social significance of another's shift in gaze. This involves using the spatial properties of the gaze shift to represent a social partner's attentional, visual and mental perspective (Shepherd, 2010). For instance, to successfully respond to a joint attention bid, one must discriminate gaze shifts that signal

intentional bids for communication (Cary, 1978). Similarly, when initiating joint attention, we must evaluate our partner's responsive gaze to determine whether our bid for joint attention is successful. Despite the importance of this cognitive ability in our daily interactions, there is currently no empirical data elucidating the time course of neural processes involved in evaluating the social significance of gaze shifts in the context of joint attention interactions.

1.1. The second person neuroscience approach

The main challenge associated with investigating the neural processes supporting joint attention is that it can only be experienced during face-to-face interactions. Given that interactions are spontaneous and dynamic, scientific studies of joint attention have had to rise to the challenge of creating ecologically valid paradigms that also provide critical experimental control. In response to this challenge, the field of social neuroscience has seen the emergence of a *Second Person Neuroscience* approach (Schilbach et al., 2013). For example, several functional magnetic resonance

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imaging (fMRI) studies have used interactive virtual reality paradigms to simulate experimentally controlled joint attention interactions (Caruana, Brock, & Woolgar, 2015; Schilbach et al., 2010; Wilms et al., 2010). These studies have pioneered gaze-contingent algorithms that allow participants to engage in a gaze-based interaction with a virtual character whom they believe is being controlled by another person in a nearby laboratory via live infrared eye tracking. This belief is important given the increasing evidence that perceiving agency and intentionality in social stimuli influences subjective experiences and eye movement patterns (Caruana et al., 2015), neural activation (Pfeiffer et al., 2014) and gaze-related ERPs (Pönkänen, Alhoniemi, Leppänen, & Hietanen, 2010; Wykowska, Wiese, Prosser, & Müller, 2014).

In an fMRI study, Schilbach et al. (2010) used a virtual reality paradigm that requested participants to interact with an anthropomorphic character whom – unbeknownst to them – was controlled by a computer. The virtual character was presented in the centre of the screen, surrounded by three squares that were positioned to the left, right, and directly above the animated face. On some trials, participants initiated joint attention by fixating on one of the three squares. A gaze-contingent algorithm was employed so that the virtual character would either respond congruently to achieve joint attention, or incongruently to avoid joint attention. Congruent responses were associated with greater activation in the ventral striatum. This supported claims that evaluating gaze shifts that signal the achievement of joint attention recruits reward-related neurocircuitry. Other gaze-congruency fMRI studies using pre-recorded actors have also found that congruent gaze and head orientation responses that result in joint attention correlate with differential activation in brain regions associated with perspective taking (mPFC, ACC, TPJ; Gordon, Eilbott, Feldman, Pelphrey, & Vander Wyk, 2013; Williams, Waiter, Perra, Perrett, & Whiten, 2005) and social reward (striatum; Gordon et al., 2013).

1.2. Event-related potential (ERP) studies

While fMRI studies have been useful in elucidating the brain structures involved in evaluating self-initiated joint attention bids, they have been unable to reveal the time course of the associated neural processes due to the sluggish nature of the BOLD signal (see Menon & Kim, 1999 for review). In contrast, event-related potentials (ERPs), which represent the average pattern of electrical activity related to a particular stimulus event, can be used to track the time course of neural processes in (practically) real time because electrical activity travels at the speed of light (Luck, 2005). Another advantage of ERPs is that they can be measured “passively” without a person's overt attention. In the context of joint attention, this would allow participants to remain focused on their social partner without disrupting the continuity of the interaction and thus maintaining ecological validity.

Despite the advantages offered by passive ERPs, no study to date has used ERPs to investigate the time course of neural processes involved in evaluating joint attention bids. However, ERPs have been used to investigate the time course of neural processing associated with the evaluation of (1) the perceptual properties of gaze, (2) attention cues from gaze, and (3) the social significance of gaze.

1.2.1. Evaluating the perceptual properties of gaze

A number of studies have used the N170 ERP (a negative peak that occurs around 170 ms after the onset of a stimulus) to explore the timing of neural processes associated with evaluating the perceptual properties of gaze. Most of these studies have measured the N170 during the passive viewing of direct and averted gaze (see Itier & Batty, 2009 for review). The findings have been mixed. Studies employing static stimuli report either no modulation of

the N170 for direct and averted gaze (Grice et al., 2005; Schweinberger, Kloth, & Jenkins, 2007) or small effects in which averted gaze evokes larger (more negative) N170 amplitudes (Watanabe, Miki, & Kakigi, 2002). Larger N170 effects of gaze direction have been found using dynamic gaze stimuli. For example, Puce, Smith, and Allison (2000) reported that ‘direct – averted’ gaze shifts evoked larger N170 amplitudes than ‘averted – direct’ gaze shifts. In contrast, others report that ‘slightly averted – direct’ gaze shifts evoked larger N170 amplitudes than ‘slightly averted – extremely averted’ gaze shifts (Conty, N'Diaye, Tijus, & George, 2007).

These studies have suggested the N170 may be sensitive to the different social signals conveyed by direct and averted gaze. Specifically, direct gaze may signal a readiness to communicate, whilst averted gaze may signal the initiation or response to a joint attention bid (Cary, 1978; Conty, N'Diaye, Tijus, & George, 2007; Kleinke, 1986). However, the outcomes of these studies provide limited insight into the time course of neural processes associated with evaluating self-initiated joint attention bids for three reasons. First, the direction of N170 effects across studies are inconsistent. Second, these studies typically employed passive viewing tasks that did not provide an interactive context. Third, these studies demonstrated that the N170 was affected by manipulating the perceptual properties of gaze (direct versus averted). There currently is no evidence to suggest that the N170 is affected by the evaluation of the social significance of gaze.

1.2.2. Evaluating attention cues from gaze

Studies examining the time course of neural processes associated with the evaluation of attention cues from gaze have often measured the EDAN (early attention direction negativity) and ADAN (anterior directing attention negativity) ERPs (e.g. Feng & Zhang, 2014; Hietanen, Nummenmaa, Nyman, Parkkola, & Hämäläinen, 2006; Holmes, Mogg, Garcia, & Bradley, 2010; Lassalle & Itier, 2013; van Velzen & Eimer, 2003). The EDAN is typically measured over posterior sites (e.g. P7 and P8) 200–300 ms post cue presentation. The ADAN is measured over anterior sites (e.g. C3 and C4) 300–500 ms post gaze cue presentation. These peaks are believed to represent reflexive attention orienting and attentional control mechanisms respectively, and produce maximal responses at electrode sites contralateral to cued locations in gaze-cueing tasks (c.f. Friesen & Kingstone, 1998). In these studies, participants are typically asked to detect a target on the left or right side of the screen following the presentation of a valid or invalid gaze cue (see Frischn, Bayliss, & Tipper, 2007 for review). Using impoverished schematic face stimuli, one study found that the EDAN and ADAN were modulated by arrow cues but not gaze (Hietanen, Leppänen, Nummenmaa, & Astikainen, 2008). A second study using photographic faces reported that gaze cues did not produce a significant EDAN effect, but did result in a significant gaze-congruent ADAN effect (Holmes et al., 2010). A third study using photographic gaze cues reported significant gaze-congruent EDAN and ADAN effects (Feng & Zhang, 2014).

This inconsistent evidence for gaze-congruent EDAN and ADAN effects suggests that these peaks may not be reliable neural markers of gaze processing. Furthermore, whilst studies investigating the EDAN and ADAN attempt to elucidate the effects of gaze on attention orienting – analogous to responding to joint attention bids – they do not inform the time course of neural processing when we evaluate a gaze shift after we have already fixated a peripheral target (analogous to initiating joint attention). As such, it is difficult to determine whether the EDAN or ADAN ERPs represent processes pertaining to the evaluation of attention cues from gaze or the social significance of gaze. Further, gaze cueing tasks used to elicit the EDAN and ADAN ERPs often lack ecological validity since participants are often instructed that the gaze cues do not predict the target's location.

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