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Gaze-cueing requires intact face processing – Insights from acquired prosopagnosia

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ABSTRACT

Gaze-cueing is the automatic spatial orienting of attention in the direction of perceived gaze. Participants respond faster to targets located at positions congruent with the direction of gaze, compared to incongruent ones (gaze cueing effect, GCE). However, it still remains unclear whether its occurrence depends on intact integration of information from the entire eye region or face, rather than simply the presence of the eyes *per se*. To address this question, we investigated the GCE in PS, an extensively studied case of pure acquired prosopagnosia. In our gaze-cueing paradigm, we manipulated the duration at which cues were presented (70 ms vs. 400 ms) and the availability of facial information (full-face vs. eyes-only). For 70 ms cue duration, we found a context-dependent dissociation between PS and controls: PS showed a GCE for eyes-only stimuli, whereas controls showed a GCE only for full-face stimuli. For 400 ms cue duration, PS showed gaze-cueing independently of stimulus context, whereas in healthy controls a GCE again emerged only for full-face stimuli. Our findings suggest that attentional deployment based on the gaze direction of briefly presented faces requires intact processing of facial information, which affords salience to the eye region.

1. Introduction

The human social environment requires an attentional system that is able to rapidly process various sources of social information. One type of information that is critical for engaging in, and maintaining social interactions is the direction of eye gaze. Others' gaze direction can be inferred quickly and with high efficiency, allowing us for example to reliably predict their intentions and actions (Friesen & Kingstone, 1998; Friesen, Moore, & Kingstone, 2005). This socially relevant task has been suggested to be achieved by an innate, domain-specific mechanism for processing eye-gaze (Baron-Cohen, 1994), which ensures that attention is oriented to the eyes as a socially important cue (for a review see : Frischen, Bayliss, & Tipper, 2007; Itier & Batty, 2009).

Experimentally, attention orienting has been typically investigated using the *spatial* cueing paradigm (Posner, 1980). In this paradigm, a central symbolic cue stimulus (e.g. arrow) is presented followed by the presentation of a lateral target stimulus (e.g. a letter or a shape). This cue can be oriented either towards the target (valid cueing) or away from it (invalid cueing). Typically, participants respond faster to validly, as compared to invalidly cued targets. In the endogenous version of the spatial cueing paradigm, the symbolic nature of the cue indicates the probable target location. Conversely, in the exogenous version of the paradigm, a lateral target is preceded by a p*eripherally* flickering cue that automatically or reflexively captures attention (Jonides & Irwin, 1981; Jonides & Yantis, 1988; Yantis & Jonides, 1984).

Similar paradigms have been used involving face stimuli to study attentional deployment based on gaze direction. Interestingly, such gaze-cueing paradigms, where effectively the eyes are used as cues, are considered to convey signals involving endogenous and exogenous attention. Perceived gaze of a centrally presented face elicits attentional orienting irrespective of whether gaze direction is predictive of a target's location (i.e. 50% valid, 50% invalid) (Driver et al., 1999; Friesen et al., 2005; Ristic, Friesen, & Kingstone, 2002), a phenomenon referred to as the gaze-cueing effect (GCE).

The GCE has been interpreted as involving a reflexive, stimulus-driven mechanism that orients attention and is impossible to suppress, which can be observed despite varied task demands (Palanica & Itier, 2012) or counter-predictive cues (Driver et al.,

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1999). Notwithstanding a large body of evidence demonstrating top-down influences on gaze cueing (e.g., Perez-Osorio, Muller, Wiese, & Wykowska, 2015; Teufel, Alexis, Clayton, & Davis, 2010; Teufel et al., 2009; Wiese, Wykowska, Zwickel, & Muller, 2012; Wykowska, Wiese, Prosser, & Muller, 2014), gaze direction is perceived automatically, even when it is completely irrelevant and potentially interferes with the task (Zorzi, Mapelli, Rusconi, & Umilta, 2003). In sum, gaze cues have been shown to elicit involuntary shifts of attention in the direction consistent with gaze (Bayliss & Tipper, 2006; Driver et al., 1999; Friesen & Kingstone, 1998; Friesen, Ristic, & Kingstone, 2004). This GCE is considered to arise from rapid, prioritized processing of the eye region, which is highly diagnostic due to its social relevance (Driver et al., 1999; Friesen & Kingstone, 1998; Hietanen, 1999; Langton & Bruce, 2000; Vuilleumier, 2002).

Concerning the neural underpinnings of gaze-dependent attentional deployment, neuroimaging studies suggest that attentional processing and face/gaze processing depend on similar neural substrates. Perception of gaze leads to increased activation within the superior temporal sulcus (STS), as well as the intraparietal sulcus (IPS), an area associated with attentional orienting (Hoffman & Haxby, 2000; Hooker et al., 2003; Perrett et al., 1985). Similarly, face-preferential regions including the fusiform face area (FFA) (Kanwisher & Yovel, 2006) and occipital face area (OFA) (Gauthier, Skudlarski, Gore, & Anderson, 2000) exhibit increased activity for social cues, as compared to non-social ones (Greene, Mooshagian, Kaplan, Zaidel, & Iacoboni, 2009). Recent findings of functional connectivity between face-preferential regions and the right posterior IPS, STS and inferior frontal gyrus (IFG) during gaze-cueing suggest that face-selective regions are functionally coupled with the attentional network (Callejas, Shulman, & Corbetta, 2014).

Considering this overlap in neural substrates, brain damage or developmental disorders impinging on the functional integrity of the distributed face-processing network (i.e., prosopagnosia) might be associated with abnormal gaze-related attentional orienting. Explicit processing of gaze direction has been investigated in cases of prosopagnosia, albeit with somewhat conflicting results.

Abnormal processing of gaze direction has been reported in both acquired and developmental prosopagnosia in studies that used stimuli with deviated head direction (De Haan & Campbell, 1991; McConachie, 1976; Perrett et al., 1988). Using frontal face stimuli, however, Duchaine and colleagues (Duchaine, Jenkins, Germine, & Calder, 2009) reported that developmental prosopagnosics could accurately judge gaze direction. However, given the use of relatively long stimulus presentation durations (i.e., 1500 ms), 'normal' gaze discrimination reported by Duchaine et al. (2009) could have been achieved through employment of an abnormal (i.e., piecemeal) processing strategy. Therefore, potentially subtle deficits in processing of eye gaze may not be observed in the context of explicit judgements of gaze direction when stimuli are shown for longer durations than cues presented in typical GCE paradigms.

Following this logic, in the present study we addressed the open question of whether the well-established GCE depends on observers' ability to integrate facial information, or process it *holistically*. We investigated gaze-cueing in PS, a case of pure acquired prosopagnosia. PS's underlying impairment of holistic processing (for a review see Rossion, 2014) causes her deficient processing of information conveyed by the eye region, and consequently an overreliance on cues that are less diagnostic for identity processing in healthy observers, such as the mouth region (e.g. Ramon, Busigny, Gosselin, & Rossion, 2017; Ramon, Busigny, & Rossion, 2010; Ramon & Rossion, 2010; Rossion, Kaiser, Bub, & Tanaka, 2009; Xivry, Ramon, Lefevre, & Rossion, 2008). Contrary to healthy controls, who process facial information simultaneously and interdependently, PS treats the various sources of facial information *independently* (Ramon et al., 2017; Van Belle, Lefevre, & Rossion, 2015). In light of her deficiency, investigating GCE in PS represents an ideal means to determine the (potential) relationship between holistic processing and rapid gaze perception.

Here, we used different variations of the classical gaze-cueing paradigm (Hietanen & Yrttimaa, 2005) to assess whether implicit perception of eye gaze depends on the ability to integrate facial information, specifically from the eye region. These variations included manipulations of the type of available facial information (full-face vs. eyes-only). We also varied the cues' presentation duration, which was either 70 ms as used in previous gaze-cueing studies (Hietanen & Yrttimaa, 2005), or 400 ms allowing for comparatively more information sampling. We sought to determine whether attentional deployment as measured with the GCE requires rapid integration of information from the entire face.

Under the assumption of the GCE relying on intact facial information integration, we expected PS to show an abnormal GCE. More specifically, in light of previous findings we hypothesized that when presented with full face stimuli, control subjects would show a GCE, whereas PS would not. Any difference in observers' performance due to removal of contextual information (i.e., given the use of eyes-only cues) would be related to their ability to simultaneously and interdependently perceive facial information, which supports perceived saliency of the eye region in healthy observers (e.g., Ramon & Rossion, 2010; Ramon et al., 2017; Van Belle, De Graef, Verfaillie, Rossion, & Lefevre, 2010; Van Belle et al., 2011, 2015). Any potential dependency of the GCE on cue duration would reflect whether it arises from simultaneous (70 ms) vs. sequential processing (400 ms) of facial information.

2. Methods

2.1. Participants

2.1.1. The patient PS

PS is a 66-year-old woman (65 at the time of testing) who suffered from a closed head injury in 1992. She has been studied and described behaviorally and neurofunctionally in numerous publications (e.g., Busigny & Rossion, 2011; Caldara et al., 2005; Ramon & Rossion, 2010; Ramon et al., 2017; Rossion, 2014; Rossion et al., 2003; Schiltz et al., 2006). Her lesions include the left mid-ventral (mainly fusiform gyrus) and the right inferior occipital cortex, as well as some minor damages to the left posterior cerebellum and the right middle temporal gyrus (for details see Sorger, Goebel, Schiltz, & Rossion, 2007). Her trouble in recognizing faces is the only remaining deficit after successful medical and neuropsychological intervention (Mayer, Fistarol, & Valenza, 1999; Mayer & Rossion, 2007). In everyday interactions, she reports using various non-facial cues (voice, posture, gait, etc.), as well as contextual information and paraphernalia to determine a person's identity. Neuropsychological tests confirmed this deficit, which contrasts with her intact object recognition abilities (Busigny, Joubert, Felician, Ceccaldi, & Rossion, 2010; Rossion et al., 2003; Schiltz et al., 2006). PS is not achromatopsic, has a nearly full visual field (with exception of a small left paracentral scotoma, see Sorger et al., 2007). Importantly, similarly to other brain damaged patients, she is slower than controls on simple reaction time tasks (Benton, 1986).

2.1.2. Age-matched control subjects

Nine female, right-handed subjects (mean age: 64.3 ± 3.1; range: 58–68) recruited via the university mailing list participated as healthy controls for the four gaze-cueing experiments reported here. They all provided written informed consent and were finan-