

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.

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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 : Frischi, 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 *peripherally* 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, & Umiltà, 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 inter-

dependently, 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-

cially compensated for their participation. Additionally, PS and a subset of these control subjects ($n = 4$, strictly age-matched) completed an identity matching task developed to replicate PS's face processing impairment with the stimuli used for the gaze-cueing experiments (see below).

2.1.3. Young control subjects

Seventeen female right-handed students (mean age: 20.58 ± 4.1 ; range: 18–35) participated in the *delayed matching task*, which was developed to replicate PS's face processing impairment at processing facial information with the stimuli created for the *gaze-cueing experiments* (see below).

2.2. Stimuli

As in previous studies of gaze perception (e.g., Burra, Kerzel, de Gelder, & Pegna, 2014; Burra et al., 2013; Ethofer, Gschwind, & Vuilleumier, 2011), FaceGen Modeller 3.4 was used to create a database of stimuli (7 males, 7 females for the initial identity and gaze matching experiment; 15 females, 15 males for gaze-cueing experiments). The avatars were desaturated and equalized for their overall luminance. The full-frontal face stimuli were presented on a black background and subtended $11^\circ \times 16^\circ$ of visual angle. Per identity we created five versions as a function of gaze direction: both eyes facing to the front, both deviated to the right, or left side, as well as two versions in which the left or right eye deviated outwards while the other was front facing (for examples see Fig. 1). For the eyes-only experiments, we created stimuli by masking the external features in order to display only the eyes without the eyebrows ($\sim 8^\circ \times 3^\circ$ of visual angle), as also in our recent work with the patient PS using “real” face stimuli taken from personally familiar individuals (Ramon et al., 2017).

2.3. Procedure

For all experiments, subjects were positioned 54 cm from a 53.1×29.9 cm computer screen (1920×1080 pixel resolution). Stimulus presentation and response registration was controlled using Psychtoolbox in a Matlab environment. Participants were tested in a dimly lit, sound controlled environment. PS and control subjects completed six experiments: three different paradigms, each conducted with cue presentation durations of 70 ms and 400 ms. The first two experiments served to establish that PS was capable of discerning gaze direction in general; details and results of these *Explicit gaze discrimination* experiments are reported in [Supplementary Material 1](#). Two ‘*delayed matching tasks*’ were designed to replicate PS's face processing deficit with the stimuli described above; here participants were required to match consecutively presented face stimuli (see below). Finally, two ‘*gaze-cueing experiments*’ were completed to address the present research question. Both versions of the *delayed matching tasks*, as well as the *gaze-cueing experiments* differed with respect to the presentation duration of target or cue stimuli, as detailed below. The procedures were approved by the ethics committee of the University of Geneva.

2.3.1. Delayed matching task

On each trial, a target face was presented for 70 ms or 400 ms in the center of the screen. After a 1000 ms inter-stimulus interval (ISI), the target and a foil face were presented side by side in the probe display until a response was provided. Participants indicated which of the two faces was the target face by pressing one of two keys (left, right) as rapidly as possible (see Fig. 1a for an illustration of the paradigm). The delayed matching task involved 560 trials, and comprised three different trial-types: those involving changes in identity, direction of one eye and direction of both eyes (see

below). These different types of trials were included to minimize the potential of PS using a specific strategy or switching between strategies throughout the experiment. Therefore, we included both identity and various gaze manipulations presented at random. Although these served to avoid PS detecting any specific manipulation (e.g., purely focusing on the mouth to distinguish identity changes), the results across conditions also demonstrate how PS's impairment affects processing of different types of manipulations, which are immediately evident for healthy observers (see Section 2).

Participants were instructed to respond as accurately and rapidly as possible. Note that participants performed image matching throughout this task, irrespective of the trial types which differ with respect to the nature of change between target and probe stimuli.

On *identity* trials (see Fig. 1), the probe display showed the target stimulus together with a foil depicting a different identity. Target and probe stimuli had the same gender and gaze direction and the target stimulus was the same in the target and probe display. The probe display depicted one of seven gender-specific identity pairs (i.e., Female 1 – Female 2, Female 3 – Female 4, ..., Female 13 – Female 14; same procedure for male faces.). The gaze direction of the target varied randomly among the five possible gaze directions (frontal, left, right, strabismus right, strabismus left). Per identity and gaze direction there were four trials, with the location of the matching probe stimulus (left vs. right) counterbalanced. Thus, there were 280 *identity trials* in total (2 genders \times 7 pairs \times 5 gaze directions \times 4 trials).

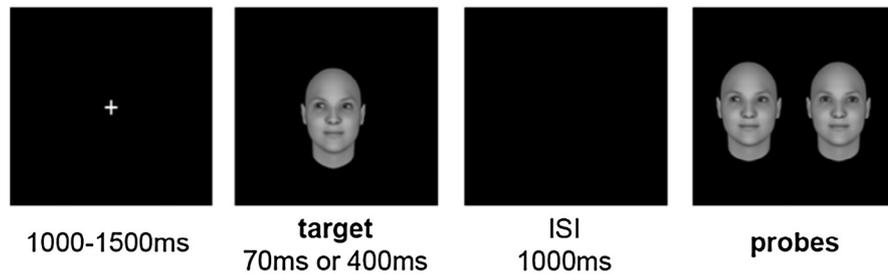
On trials involving changes in direction of one eye (*deviant-by-1*) and direction of both eyes (*deviant-by-2*), the probe display showed the target face and a foil, which depicted the same identity, but with a different gaze direction. *Deviant-by-1* trials depend on subjects' ability to integrate information from *both* eyes to match targets and probes accurately. These *deviant-by-1* trials could involve one of four possible types of pairs (right - strabismus right, left - strabismus left, frontal - strabismus right, frontal - strabismus left), and target stimuli could depict either of the comprising face stimuli. This led to a total of 112 *deviant-by-1* trials (2 genders \times 7 identities \times 4 gaze pairs \times 2 target types), with a response side counterbalanced across trials.

Deviant-by-2 trials on the other hand could be discriminated based on a single eye, since both eyes never shared direction of gaze across either of the six trial types (left - strabismus right, right - strabismus left, frontal - left, frontal - right, right - left, strabismus right - strabismus left). Targets could depict either of the face stimuli comprising a trial type. Response side was counterbalanced across the 168 trials (2 genders \times 7 identities \times 6 trial types \times 2 target types).

2.3.2. Gaze-cueing task

Participants were required to indicate the location of a target letter presented simultaneously with a distractor letter that was shown on the opposite side. The target letter was specified before each of the 10 blocks (each block comprised 60 trials); the letters T and L were used equally often as targets and distractors. On each trial a central fixation cross was presented for 1000–1500 ms, followed by a full-face stimulus or a pair of eyes displayed in the center. Full-face and eyes-only stimuli were run in separate blocks of trials. The eyes were always centered relative to the fixation cross. The full-face or eyes-only stimuli were presented for 70 ms or 400 ms. After a 200 ms ISI, the target and distractor letters were presented at 6° from the center. Participants had to indicate the location of the target letter by keypress, using two fingers of their right hand. Relative to target location, the direction of the gaze cue could be congruent, incongruent or neutral (33%; i.e. non-predictive cueing). See Fig. 1b for an illustration of the paradigm.

a. Delayed matching experiments



b. Gaze-cueing experiments

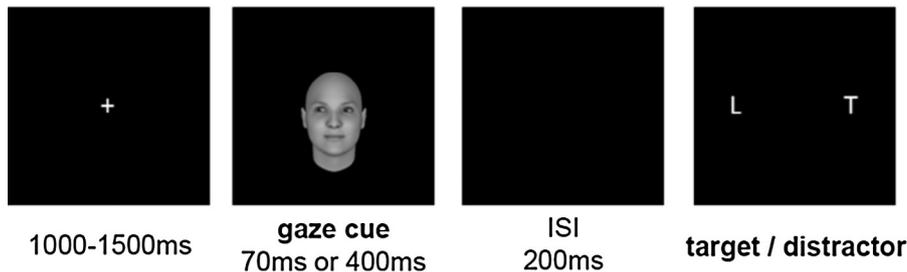


Fig. 1. Examples of stimuli and paradigms used. The (a) delayed matching and (b) gaze-cueing tasks were run with two different durations (70 ms, 400 ms) of the target stimulus or gaze cue, respectively.

2.4. Analyses

All analyses were performed using SPSS version 23. Across tasks, one-tailed binomial tests were performed to determine whether PS's performance exceeded chance level. For the *delayed matching tasks*, analyses involved comparisons (Crawford & Howell, 1998) between PS's and controls' performance (accuracy and correct reaction times; RTs). This was done separately for each trial type (*deviant-by-2*, *deviant-by-1* and *identity trials*) in order to take into account the difference in the number of trials per trial type. For the *gaze-cueing experiments*, analyses were performed on subjects' median RTs for congruent and incongruent conditions; their difference was measured and is referred to as the GCE. Confidence intervals (CI) for controls' GCEs were computed by means of resampling (bootstrapping) techniques performed with 1000 iterations. Accuracy was also measured but not reported due to subjects performing at ceiling. First, a repeated-measures analysis of variance (rANOVA) was performed on controls' data, in order to ascertain the occurrence of a GCE. We also compared PS's and controls' GCE using a *t*-test for case-control comparisons (Crawford & Howell, 1998). Additionally, potential differences in performance across tasks between PS and controls were assessed using the Revised Standardized Difference Test (RSDT) (Crawford & Garthwaite, 2005). These measures control Type I error rate irrespective of the control sample size and the magnitude of the correlation between tasks, and highlight potential dissociation(s) between PS and controls.

3. Results

3.1. Matching of identity and gaze with full-face stimuli

As evident from Fig. 2 and summarized in Supplementary Material 2, irrespective of cue duration, PS's performance did not differ from chance level for neither *deviant-by-2*, nor *deviant-by-1* trials ($ps > 0.29$). Contrariwise, for identity trials her performance was significantly better than chance for both cue durations

($ps > 0.001$). Importantly, for these identity change trials, she was more accurate for 400 ms cues ($p < 0.001$). However, PS's RTs did not differ significantly as a function of cue duration ($t(401,8) = 1.04$, $p = 0.29$) (see Supplementary Material 2 for a detailed account of PS's and controls' behavioral performance).

Comparing PS's accuracy scores to those of controls using the procedure proposed by Crawford and Howell (1998) revealed that her performance was significantly lower irrespective of condition (age-matched controls: $ts(3) > 3.87$, $ps < 0.03$, young controls: $ts(16) > 2.18$, $ps < 0.05$, two-tailed probability tests). Analyses of RTs revealed no significant difference between PS and age-matched controls' RTs ($ts(3) > 2.5$, $ps < 0.09$), but young controls were significantly faster than PS ($ts(16) > 4.4$, $ps < 0.05$).

3.2. Gaze-cueing experiments

3.2.1. Full-face stimuli

The mean GCE (RT incongruent – RT congruent) for full-face stimuli are shown in the left column of Fig. 3 (see also Supplementary Material 3). As predicted, the control group exhibited a significant GCE for both cue durations, reflecting shorter response times for congruent as compared to incongruent conditions ($ts(8) > 3.01$, $ps < 0.017$, 95% CI [5, 22]). Conversely, PS did not demonstrate a GCE for 70 ms cue durations, which was significantly different from controls' performance ($t(8) = -5.01$, $p < 0.001$). However, for 400 ms cue durations PS's performance did not differ from that of controls ($t(8) = 0.76$, *ns*).

3.2.2. Eyes-only stimuli

Mean GCE for eyes-only stimuli are shown in the right column of Fig. 3 (see also Supplementary Material 3). For controls, no significant GCE was observed when cues displayed only the eyes; this was found irrespective of cue duration ($ts(8) < 1.1$, $ps > 0.3$, 95% CI [-15, 6]). Contrariwise, PS demonstrated a GCE for both cue durations, which differed significantly from controls ($ts(8) > 2.41$, $ps < 0.03$) (see Fig. 3).

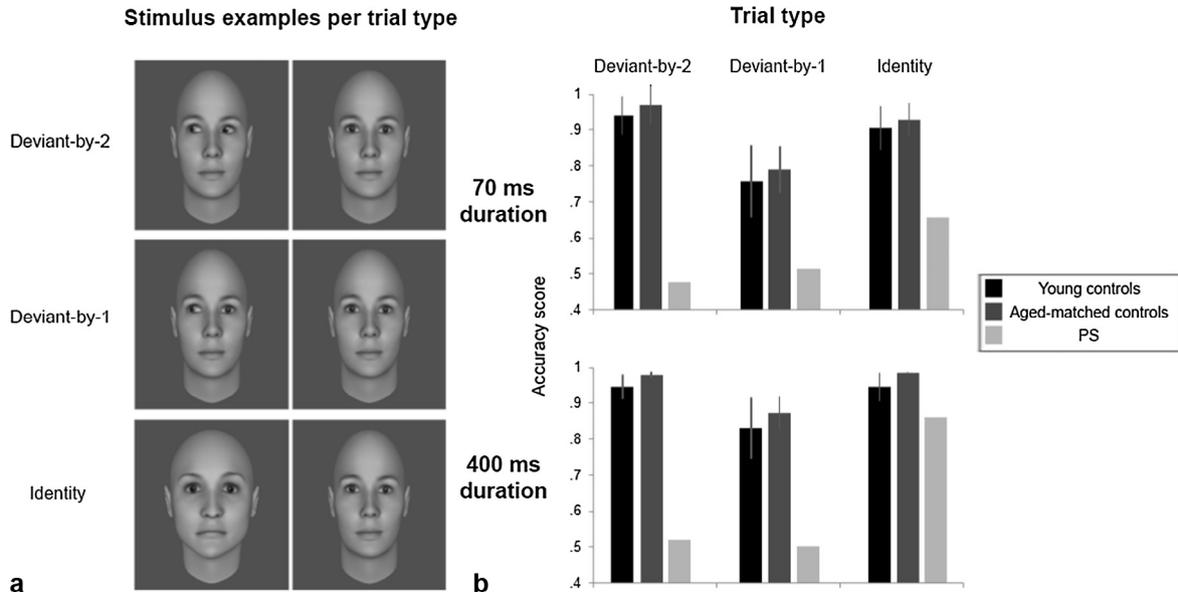


Fig. 2. Stimuli used and results obtained for matching of identity and gaze with full-face stimuli. (a) Examples of stimuli shown per trial type. (b) Young (black) and aged-matched controls' (dark grey) and PS's (light gray) average accuracy scores are displayed for trials involving changes in gaze (deviant-by-2 and deviant-by-1 trials; see Section 2) or identity, for cues presented for 70 ms and 400 ms; error bars represent 95% confidence intervals.

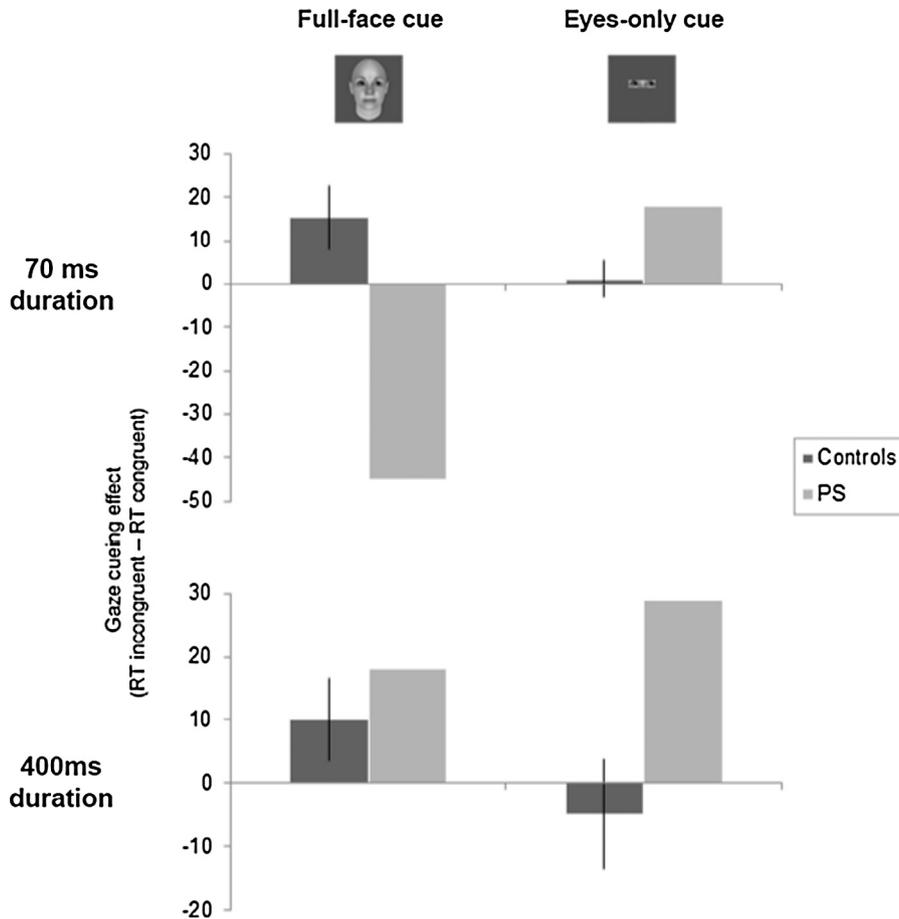


Fig. 3. Results observed for the gaze-cueing experiments. Displayed are the RT differences between incongruent and congruent conditions, for controls (dark grey) and PS (light gray) as a function of cue durations (70 and 400 ms), and cue type (full-face on the left; eyes-only on the right). Positive scores (with 95% confidence intervals not including zero) indicate the presence of a significant GCE.

3.2.3. Effect of stimulus format

We also determined whether changing the stimulus format (full-face vs. eyes-only stimuli) affected controls and PS differently using Crawford and Garthwaite's (2005) Revised Standardized Difference Test (RSDT). For cues presented for 70 ms, we observed a significant dissociation between PS's and controls' performance ($t(8) = 4.26, p < 0.005$); for 400 ms cues no significant dissociation was found ($t(8) = 0.90, ns$).

3.2.4. Effect of cue duration

Investigating the effect of cue duration (70 ms vs. 400 ms) on controls' and PS's performance by means of Crawford and Garthwaite's (2005) RSDT revealed a significant dissociation for full-face cues ($t(8) = 3.87, p < 0.005$), but not for eyes-only cues ($t(8) = 0.06, ns$).

4. Discussion

The ability to orient attention in response to social signals such as faces and gaze is critical for human beings (e.g., Baron-Cohen, 1994). When eyes are perceived as oriented towards a particular direction, efficient gaze perception results in attentional allocation towards the gazed-at location, leading to the observation of the GCE. Since gaze and face processing have been shown to involve overlapping neural substrates, it seems plausible that individuals presenting disorders of face processing might also demonstrate abnormal or absent gaze-related attentional orienting. Although some studies have addressed explicit processing of gaze in developmental and acquired prosopagnosia (De Haan & Campbell, 1991; Duchaine et al., 2009; McConachie, 1976; Perrett et al., 1988), to our knowledge, it remains unclear whether intact face processing skills are required for the observation of the GCE.¹ To this end we tested PS, a case of pure prosopagnosia with deficient holistic face processing due to rOFA damage (Ramon et al., 2017; Rossion, 2014; Rossion et al., 2003).

4.1. Processing of gaze during delayed face matching

In a first set of delayed matching experiments, we aimed to replicate PS's impairment in processing facial identity using FaceGen stimuli we created for our gaze-cueing experiments. The to-be-matched stimuli presented in this context could differ with respect to either identity or gaze direction. Here, in line with previous observations, we observed impaired, but above-chance performance for PS when target/probe stimuli differed in terms of facial identity. On the other hand, she performed at chance when target/probes involved changes in gaze direction, indicating that she did not efficiently integrate information from the eyes (see Rossion, 2014), which needed to be appreciated simultaneously for accurate performance.

Interestingly, PS's post-experimental debriefing upon completion of this task revealed that she was entirely unaware that some of the stimuli presented showed "strabismus" faces, in which the direction of gaze was different for both eyes. This confirms findings from gaze-contingent paradigms (Van Belle et al., 2010, 2011, 2015) and recent behavioural experiments (Ramon et al., 2017; Experiment 9) that suggest that PS's narrowed perceptual field prevents her from processing the eye region as an ensemble.

¹ Note that although the GCE cannot be regarded as a purely reflexive phenomenon (Teufel et al., 2009, 2010; Wiese et al., 2012, 2014; Perez-Osorio et al., 2015; Wykowska et al., 2014), we believe that the longer stimulus presentation durations used in investigations of explicit gaze processing will have increased the relative contribution of voluntary over reflexive mechanisms.

4.2. Abnormal GCE in acquired prosopagnosia

Having established the utility of the stimuli to study face processing in PS, our gaze-cueing experiments aimed to determine whether the normally observed GCE relies on intact holistic processing. These experiments involved a gaze-cueing paradigm (Hietanen & Yrttimaa, 2005), known to demonstrate automatic attentional allocation towards the gazed-at direction in healthy observers (Driver et al., 1999; Friesen & Kingstone, 1998; Hietanen, 1999; Langton & Bruce, 2000). These experiments involved two critical manipulations: information available (full face, eyes only) on the one hand, and cue duration (70 ms, 400 ms) on the other.

In line with previous studies, when full face stimuli were presented, healthy controls exhibited the GCE regardless of cue duration (Driver et al., 1999; Hietanen & Yrttimaa, 2005). In stark contrast and in line with our predictions, PS's performance pattern for full face stimuli varied as a function of cue duration, as she displayed a GCE only for cues presented for 400, but not 70 ms. For eyes-only cues on the other hand, controls did not show a GCE irrespective of cue duration. Here again, PS's performance deviated from that of controls: she exhibited a GCE for both types of eyes-only cues (70 ms and 400 ms).

We suggest that our findings of abnormal CGE in this case of acquired prosopagnosia do not contradict previous reports of normal judgment of gaze direction in developmental prosopagnosia (Duchaine et al., 2009). Such explicit judgements may be performed based on the relative contrast in luminance between scleral regions – a physically salient signal that can be processed locally, especially if its location is predictable (Kobayashi & Kohshima, 2001). This is in line with the observation of PS exhibiting a CGE for eyes only stimuli, which we interpret as reflecting such a general cueing mechanism acting upon the low-level information conveyed by an eye.

Additionally, tasks of explicit gaze judgments usually involve stimulus presentation durations exceeding those of our cues (e.g., 1500 ms by Duchaine et al., 2009). In line with this reasoning PS's performance for explicit gaze discrimination (Supplementary Material 1) revealed reliable judgments despite comparatively shorter stimulus durations (70 ms and 400 ms), where longer durations were associated with increased performance. Based on the findings of our gaze cueing experiments we propose that the GCE as measured here may represent a more sensitive measure to uncover deficits in gaze processing.

4.3. Information-dependency of the GCE in healthy controls

Our finding of controls exhibiting no GCE when cues comprised only the eyes suggest that normal gaze-cueing as measured in our paradigm is dependent on intact perception of the eyes embedded within the context of the face. How can we reconcile our controls' complete lack of GCE with such eye only stimuli, which have in fact been reported by others (e.g., Greene et al., 2011)? We believe that this apparent discrepancy can be readily accounted for when considering more closely the differences in the stimulus material used. In our study our eyes-only stimuli genuinely showed no other information. Greene et al. (2011) used (schematic) full face stimuli, as well as "eyes-only" stimuli. Note, however, that their "eyes only" stimuli actually comprised eyes presented within the context of a schematic facial contour. Previous studies have demonstrated that processing of facial contour or shape based information involves holistic processing (e.g., Jiang, Blanz, & Rossion, 2011; see Rossion, 2013 for a review), even when schematic faces are used. Thus, Greene et al.'s (2011) observation of a GCE does not seem surprising, if not to be expected.

Similarly, one could hypothesize that the involvement of holistic processing and hence likelihood of observing a GCE increases with information presented together with the eye gaze cues (e.g., adding eye brows, facial contour, or texture) which are involuntarily perceived inter-dependently. It is plausible that a mechanism enabling rapid attention orienting should require some type of additional information integrated with gaze cues, rather than engaging given any visual input resembling a pair of eyes (i.e., false positive). Future studies are required to determine which specific types of additional facial information (e.g., contour, texture, availability of eye brows) presented together with gaze information lead to GCE.

5. Conclusion

The results reported here demonstrate that attentional deployment depending on perceived gaze direction requires intact integration of facial information. The ability to rapidly derive information from the entire face is a necessary condition for the observation of a GCE in healthy subjects. The observed dissociation between PS and controls, which varied as a function of available information and cue duration, is in line with her previously reported inability to rapidly integrate and derive information from the entire face. She is particularly impaired at processing information conveyed by the eyes (Busigny and Rossion, 2011; Caldara et al., 2005; Ramon & Rossion, 2010; Ramon et al., 2017; Rossion, 2014; Rossion et al., 2003; Schiltz et al., 2006; Sorger et al., 2007) but can discriminate faces based on the eyes, when instructed to attend this region (Ramon & Rossion, 2010). The observed lack of a GCE for full-face cues and cues presented for 70 ms is in line with recent studies suggesting that PS's impairment at rapidly deriving salient facial information results from her restricted perceptual field (e.g., Van Belle et al., 2015).

Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at <http://dx.doi.org/10.1016/j.bandc.2017.01.008>.

References

- Baron-Cohen, S. (1994). How to build a baby that can read minds: Cognitive mechanisms in mindreading. *Cahiers de Psychologie Cognitive* (13), 513–552.
- Bayliss, A. P., & Tipper, S. P. (2006). Gaze cues evoke both spatial and object-centered shifts of attention. *Perception and Psychophysics*, 68(2), 310–318.
- Benton, A. (1986). Reaction-time in brain disease – Some reflections. *Cortex*, 22(1), 129–140.
- Burra, N., Hervais-Adelman, A., Kerzel, D., Tamietto, M., de Gelder, B., & Pegna, A. J. (2013). Amygdala activation for eye contact despite complete cortical blindness. *The Journal of Neuroscience: The Official Journal of the Society for Neuroscience*, 33(25), 10483–10489. <http://dx.doi.org/10.1523/JNEUROSCI.3994-12.2013>.
- Burra, N., Kerzel, D., de Gelder, B., & Pegna, A. J. (2014). Lack of automatic attentional orienting by gaze cues following a bilateral loss of visual cortex. *Neuropsychologia*, 58, 75–80. <http://dx.doi.org/10.1016/j.neuropsychologia.2014.04.003>.
- Busigny, T., Joubert, S., Felician, O., Ceccaldi, M., & Rossion, B. (2010). Holistic perception of the individual face is specific and necessary: Evidence from an extensive case study of acquired prosopagnosia. *Neuropsychologia*, 48(14), 4057–4092. <http://dx.doi.org/10.1016/j.neuropsychologia.2010.09.017>.
- Busigny, T., & Rossion, B. (2011). Holistic processing impairment can be restricted to faces in acquired prosopagnosia: Evidence from the global/local Navon effect. *Journal of Neuropsychology*, 5(Pt 1), 1–14. <http://dx.doi.org/10.1348/174866410X500116>.
- Caldara, R., Schyns, P., Mayer, E., Smith, M. L., Gosselin, F., & Rossion, B. (2005). Does prosopagnosia take the eyes out of face representations? Evidence for a defect in representing diagnostic facial information following brain damage. *Journal of Cognitive Neuroscience*, 17(10), 1652–1666.
- Callejas, A., Shulman, G. L., & Corbetta, M. (2014). Dorsal and ventral attention systems underlie social and symbolic cueing. *Journal of Cognitive Neuroscience*, 26(1), 63–80. http://dx.doi.org/10.1162/jocn_a_00461.
- Crawford, J. R., & Garthwaite, P. H. (2005). Testing for suspected impairments and dissociations in single-case studies in neuropsychology: Evaluation of alternatives using monte carlo simulations and revised tests for dissociations. *Neuropsychology*, 19(3), 318–331. <http://dx.doi.org/10.1037/0894-4105.19.3.318>.
- Crawford, J. R., & Howell, D. C. (1998). Comparing an individual's test score against norms derived from small samples. *Clinical Neuropsychologist*, 12(4), 482–486. <http://dx.doi.org/10.1076/clin.12.4.482.7241>.
- De Haan, E. H., & Campbell, R. (1991). A fifteen year follow-up of a case of developmental prosopagnosia. *Cortex*, 27(4), 489–509.
- Driver, J., Davis, G., Ricciardelli, P., Kidd, P., Maxwell, E., & Baron-Cohen, S. (1999). Gaze perception triggers reflexive visuospatial orienting. *Visual Cognition*, 6(5), 509–540. <http://dx.doi.org/10.1080/135062899394920>.
- Duchaine, B., Jenkins, R., Germine, L., & Calder, A. J. (2009). Normal gaze discrimination and adaptation in seven prosopagnosics. *Neuropsychologia*, 47(10), 2029–2036. <http://dx.doi.org/10.1016/j.neuropsychologia.2009.03.011>.
- Ethofer, T., Gschwind, M., & Vuilleumier, P. (2011). Processing social aspects of human gaze: A combined fMRI-DTI study. *NeuroImage*, 55(1), 411–419. <http://dx.doi.org/10.1016/j.neuroimage.2010.11.033>.
- Friesen, C. K., & Kingstone, A. (1998). The eyes have it! Reflexive orienting is triggered by nonpredictive gaze. *Psychonomic Bulletin & Review*, 5(3), 490–495. <http://dx.doi.org/10.3758/BF03208827>.
- Friesen, C. K., Moore, C., & Kingstone, A. (2005). Does gaze direction really trigger a reflexive shift of spatial attention? *Brain and Cognition*, 57(1), 66–69. <http://dx.doi.org/10.1016/j.bandc.2004.08.025>.
- Friesen, C. K., Ristic, J., & Kingstone, A. (2004). Attentional effects of counterpredictive gaze and arrow cues. *Journal of Experimental Psychology: Human Perception and Performance*, 30(2), 319–329. <http://dx.doi.org/10.1037/0096-1523.30.2.319>.
- Frischen, A., Bayliss, A. P., & Tipper, S. P. (2007). Gaze cueing of attention: Visual attention, social cognition, and individual differences. *Psychological Bulletin*, 133(4), 694–724. <http://dx.doi.org/10.1037/0033-2909.133.4.694>.
- Gauthier, I., Skudlarski, P., Gore, J. C., & Anderson, A. W. (2000). Expertise for cars and birds recruits brain areas involved in face recognition. *Nature Neuroscience*, 3(2), 191–197. <http://dx.doi.org/10.1038/72140>.
- Greene, D. J., Colich, N., Iacoboni, M., Zaidel, E., Bookheimer, S. Y., & Dapretto, M. (2011). Atypical neural networks for social orienting in autism spectrum disorders. *NeuroImage*, 56(1), 354–362. <http://dx.doi.org/10.1016/j.neuroimage.2011.02.031>.
- Greene, D. J., Mooshagian, E., Kaplan, J. T., Zaidel, E., & Iacoboni, M. (2009). The neural correlates of social attention: Automatic orienting to social and nonsocial cues. *Psychological Research Psychologische Forschung*, 73(4), 499–511. <http://dx.doi.org/10.1007/s00426-009-0233-3>.
- Hietanen, J. K. (1999). Does your gaze direction and head orientation shift my visual attention? *NeuroReport*, 10(16), 3443–3447.
- Hietanen, J. K., & Yrttimaa, K. (2005). Where a person with a squint is actually looking: Gaze-cued orienting in crossed eyes. *Visual Cognition*, 12(1), 117–126. <http://dx.doi.org/10.1080/13506280444000184>.
- Hoffman, E. A., & Haxby, J. V. (2000). Distinct representations of eye gaze and identity in the distributed human neural system for face perception. *Nature Neuroscience*, 3(1), 80–84. <http://dx.doi.org/10.1038/71152>.
- Hooker, C. I., Paller, K. A., Gitelman, D. R., Parrish, T. B., Mesulam, M. M., & Reber, P. J. (2003). Brain networks for analyzing eye gaze. *Brain Research: Cognitive Brain Research*, 17(2), 406–418.
- Itier, R. J., & Batty, M. (2009). Neural bases of eye and gaze processing: The core of social cognition. *Neuroscience and Biobehavioral Reviews*, 33(6), 843–863. <http://dx.doi.org/10.1016/j.neubiorev.2009.02.004>.
- Jiang, F., Blanz, V., & Rossion, B. (2011). Holistic processing of shape cues in face identification: Evidence from face inversion, composite faces, and acquired prosopagnosia. *Visual Cognition*, 19(8), 1003–1034. <http://dx.doi.org/10.1080/13506285.2011.604360>.
- Jonides, J., & Irwin, D. E. (1981). Capturing attention. *Cognition*, 10(1–3), 145–150.
- Jonides, J., & Yantis, S. (1988). Uniqueness of abrupt visual onset in capturing attention. *Perception and Psychophysics*, 43(4), 346–354.
- Kanwisher, N., & Yovel, G. (2006). The fusiform face area: A cortical region specialized for the perception of faces. *Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences*, 361(1476), 2109–2128. <http://dx.doi.org/10.1098/rstb.2006.1934>.
- Kobayashi, H., & Kohshima, S. (2001). Unique morphology of the human eye and its adaptive meaning: Comparative studies on external morphology of the primate eye. *Journal of Human Evolution*, 40(5), 419–435. <http://dx.doi.org/10.1006/jhev.2001.0468>.
- Langton, S. R., & Bruce, V. (2000). You must see the point: Automatic processing of cues to the direction of social attention. *Journal of Experimental Psychology: Human Perception and Performance*, 26(2), 747–757.
- Mayer, E., Fistarol, P., & Valenza, N. (1999). *Prise en charge neuropsychologique d'une patiente prosopagnosique. La reeducation en neuropsychologie: Etudes de cas*. Marseille: Solal.
- Mayer, E., & Rossion, B. (2007). *Prosopagnosia (s. E. The behavioral cognitive neurology of stroke ed.)*. Cambridge: Cambridge University Press.
- McConachie, H. R. (1976). Developmental prosopagnosia. A single case report. *Cortex*, 12(1), 76–82.
- Palanica, A., & Itier, R. J. (2012). Attention capture by direct gaze is robust to context and task demands. *Journal of Nonverbal Behavior*, 36(2), 123–134. <http://dx.doi.org/10.1007/s10919-011-0128-z>.

- Perez-Osorio, J., Muller, H. J., Wiese, E., & Wykowska, A. (2015). Gaze following is modulated by expectations regarding others' action goals. *PLoS ONE*, *10*(11), e0143614. <http://dx.doi.org/10.1371/journal.pone.0143614>.
- Perrett, D. I., Mistlin, A., Chitty, A., Harries, M., Newcombe, F., & De Haan, E. (1988). Neuronal mechanisms of face perception and their pathology. *Physiological Aspects of Clinical Neuro-Ophthalmology*, 137–154.
- Perrett, D. I., Smith, P. A., Potter, D. D., Mistlin, A. J., Head, A. S., Milner, A. D., & Jeeves, M. A. (1985). Visual cells in the temporal cortex sensitive to face view and gaze direction. *Proceedings of the Royal Society of London. Series B: Biological Sciences*, *223*(1232), 293–317.
- Posner, M. I. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology*, *32*(1), 3–25.
- Ramon, M., Busigny, T., Gosselin, F., & Rossion, B. (2017). All new kids on the block? Impaired holistic processing of personally familiar faces in a kindergarten teacher with acquired prosopagnosia. *Visual Cognition*, 1–35. <http://dx.doi.org/10.1080/13506285.2016.1273985>.
- Ramon, M., Busigny, T., & Rossion, B. (2010). Impaired holistic processing of unfamiliar individual faces in acquired prosopagnosia. *Neuropsychologia*, *48*(4), 933–944. <http://dx.doi.org/10.1016/j.neuropsychologia.2009.11.014>.
- Ramon, M., & Rossion, B. (2010). Impaired processing of relative distances between features and of the eye region in acquired prosopagnosia – Two sides of the same holistic coin? *Cortex*, *46*(3), 374–389.
- Ristic, J., Friesen, C. K., & Kingstone, A. (2002). Are eyes special? It depends on how you look at it. *Psychonomic Bulletin & Review*, *9*(3), 507–513.
- Rossion, B. (2013). The composite face illusion: A whole window into our understanding of holistic face perception. *Visual Cognition*, *21*(2), 139–253. <http://dx.doi.org/10.1080/13506285.2013.772929>.
- Rossion, B. (2014). Understanding face perception by means of human electrophysiology. *Trends in Cognitive Sciences*, *18*(6), 310–318. <http://dx.doi.org/10.1016/j.tics.2014.02.013>.
- Rossion, B., Caldara, R., Seghier, M., Schuller, A. M., Lazeyras, F., & Mayer, E. (2003). A network of occipito-temporal face-sensitive areas besides the right middle fusiform gyrus is necessary for normal face processing. *Brain*, *126*(11), 2381–2395.
- Rossion, B., Kaiser, M. D., Bub, D., & Tanaka, J. W. (2009). Is the loss of diagnosticity of the eye region of the face a common aspect of acquired prosopagnosia? *Journal of Neuropsychology*, *3*(1), 69–78.
- Schiltz, C., Sorger, B., Caldara, R., Ahmed, F., Mayer, E., Goebel, R., & Rossion, B. (2006). Impaired face discrimination in acquired prosopagnosia is associated with abnormal response to individual faces in the right middle fusiform gyrus. *Cerebral Cortex*, *16*(4), 574–586. <http://dx.doi.org/10.1093/cercor/bhj005>.
- Sorger, B., Goebel, R., Schiltz, C., & Rossion, B. (2007). Understanding the functional neuroanatomy of acquired prosopagnosia. *NeuroImage*, *35*(2), 836–852. <http://dx.doi.org/10.1016/j.neuroimage.2006.09.051>.
- Teufel, C., Alexis, D. M., Clayton, N. S., & Davis, G. (2010). Mental-state attribution drives rapid, reflexive gaze following. *Atten Percept Psychophys*, *72*(3), 695–705. <http://dx.doi.org/10.3758/APP.72.3.695>.
- Teufel, C., Alexis, D. M., Todd, H., Lawrance-Owen, A. J., Clayton, N. S., & Davis, G. (2009). Social cognition modulates the sensory coding of observed gaze direction. *Current Biology: CB*, *19*(15), 1274–1277. <http://dx.doi.org/10.1016/j.cub.2009.05.069>.
- Van Belle, G., Busigny, T., Lefevre, P., Joubert, S., Felician, O., Gentile, F., & Rossion, B. (2011). Impairment of holistic face perception following right occipito-temporal damage in prosopagnosia: Converging evidence from gaze-contingency. *Neuropsychologia*, *49*(11), 3145–3150. <http://dx.doi.org/10.1016/j.neuropsychologia.2011.07.010>.
- Van Belle, G., De Graef, P., Verfaillie, K., Rossion, B., & Lefevre, P. (2010). Face inversion impairs holistic perception: Evidence from gaze-contingent stimulation. *Journal of Vision*, *10*(5), 10. <http://dx.doi.org/10.1167/10.5.10>.
- Van Belle, G., Lefevre, P., & Rossion, B. (2015). Face inversion and acquired prosopagnosia reduce the size of the perceptual field of view. *Cognition*, *136*, 403–408. <http://dx.doi.org/10.1016/j.cognition.2014.11.037>.
- Vuilleumier, P. (2002). Perceived gaze direction in faces and spatial attention: A study in patients with parietal damage and unilateral neglect. *Neuropsychologia*, *40*(7), 1013–1026.
- Wiese, E., Wykowska, A., Zwickel, J., & Muller, H. J. (2012). I see what you mean: How attentional selection is shaped by ascribing intentions to others. *PLoS ONE*, *7*(9), e45391. <http://dx.doi.org/10.1371/journal.pone.0045391>.
- Wykowska, A., Wiese, E., Prosser, A., & Muller, H. J. (2014). Beliefs about the minds of others influence how we process sensory information. *PLoS ONE*, *9*(4), e94339. <http://dx.doi.org/10.1371/journal.pone.0094339>.
- Xivry, J. J. O., Ramon, M., Lefevre, P., & Rossion, B. (2008). Reduced fixation on the upper area of personally familiar faces following acquired prosopagnosia. *Journal of Neuropsychology*, *2*(1), 245–268.
- Yantis, S., & Jonides, J. (1984). Abrupt visual onsets and selective attention: Evidence from visual search. *Journal of Experimental Psychology. Human Perception and Performance*, *10*(5), 601–621.
- Zorzi, M., Mapelli, D., Rusconi, E., & Umiltà, C. (2003). Automatic spatial coding of perceived gaze direction is revealed by the Simon effect. *Psychonomic Bulletin & Review*, *10*(2), 423–429.