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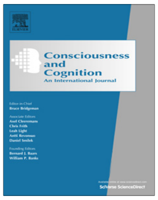

Short Communication

Processing of invisible social cues ☆

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ABSTRACT

Successful interactions between people are dependent on rapid recognition of social cues. We investigated whether head direction – a powerful social signal – is processed in the absence of conscious awareness. We used continuous flash interocular suppression to render stimuli invisible and compared the reaction time for face detection when faces were turned towards the viewer and turned slightly away. We found that faces turned towards the viewer break through suppression faster than faces that are turned away, regardless of eye direction. Our results suggest that detection of a face with attention directed at the viewer occurs even in the absence of awareness of that face. While previous work has demonstrated that stimuli that signal threat are processed without awareness, our data suggest that the social relevance of a face, defined more broadly, is evaluated in the absence of awareness.

1. Introduction

Faces convey a wealth of signals that facilitate social interactions. Through faces we recognize identity and infer the emotional and mental states as well as the direction of attention of others.

Faces are detected even when they are rendered subjectively invisible (i.e. non-conscious) with masking or interocular suppression. Continuous flash interocular suppression is a method to render stimuli invisible using binocular rivalry with a high energy, rapidly changing stimulus presented to one eye (Tong, Meng, & Blake, 2006; Tsuchiya & Koch, 2005). If the stimuli to the two eyes are of equivalent salience, awareness of stimuli fluctuates spontaneously. With continuous flash interocular suppression it is possible to prevent one image to reach awareness for longer periods of time. Because a stimulus is subjectively invisible prior to breakthrough, any factor that facilitates faster breakthrough indicates processing that occurs without conscious awareness. Thus, this technique affords study of unconscious perception and how unconscious perception influences direction of attention to potentially relevant stimuli (Eastwood & Smilek, 2005; Lin & He, 2009). For example, upright faces break through interocular suppression about one-half second faster than do inverted faces, indicating that the upright facial configuration is processed even when the subject is unaware of the image (Jiang, Costello, & He, 2007; Yang, Zald, & Blake, 2007; Zhou, Zhang, Liu, Yang, & Qu, 2010). Facial expressions also appear to be processed when the subject is unaware of the face image, as evidenced by faster breakthrough of interocular suppression by faces with fearful expressions (Jiang & He, 2006; Yang et al., 2007), unconscious imitation of masked facial expressions (Dimberg, Thunberg, & Elmehed, 2000), and amygdala response to masked or suppressed faces (Morris,

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Ohman, & Dolan, 1998; Whalen et al., 1998; Williams, Morris, McGlone, Abbott, & Mattingley, 2004; and for review see Pessoa & Adolphs, 2010; Tamietto & De Gelder, 2010).

Appropriate social interactions depend on correctly interpreting to what others are attending. Head direction and gaze are features that indicate whether another person's attention is directed at oneself or elsewhere in the environment. Attention directed towards oneself can signal interest, the desire to catch one's attention, or the intention to engage in a social interaction (Kampe, Frith, & Frith, 2003). Neurons in the anterior temporal cortex of the monkey that are tuned to direction of others' social attention cues such as head orientation, eye gaze and body movements have been described (Perrett et al., 1985). In humans, fMRI has shown specific regions such as the posterior and anterior superior temporal sulcus, the fusiform gyrus, the medial prefrontal cortex, preferentially engaged by eye gaze and head turns highlighting how dedicated neuronal population are involved in processing relevant social cues (Carlin & Calder, 2012; Carlin, Rowe, Kriegeskorte, Thompson, & Calder, 2012; Engell & Haxby, 2007; Hoffman & Haxby, 2000; Pageler et al., 2003; Pelphrey, Singerman, Allison, & McCarthy, 2003; and for a review Senju & Johnson, 2009).

While the processing of gaze without awareness has been reported (Stein, Shenju, Peelen, & Sterzer, 2011), no specific evidence is yet available as to the processing of head direction, which also represents a powerful cue for directing social attention. We investigated whether head direction is processed in the absence of conscious awareness. Therefore, we rendered faces invisible using continuous flash interocular suppression (Kang & Blake, 2011; Tong et al., 2006; Tsuchiya & Koch, 2005). As mentioned above, because the observer is unaware of a suppressed stimulus prior to breakthrough, processes that facilitate breakthrough happen when it is still invisible.

Our results show that faces turned towards the viewer break through interocular suppression faster than do faces turned away from the viewer, confirming our hypothesis that this social signal is processed in the absence of awareness.

2. Methods

We used continuous flash interocular suppression to render faces invisible and test whether differences in head angle and gaze affected the time for these images to break through interocular suppression.

We conducted three experiments. The first experiment was a pilot study designed to validate our experimental setup. The main experiment tested our hypothesis that images of faces turned towards the viewer would break through interocular suppression faster than faces turned slightly away. The third experiment tested whether faster detection of full view faces in our interocular suppression paradigm could be attributed to faster detection after breakthrough, rather than faster detection prior to breakthrough.

2.1. Subjects

Twenty-six subjects (19 females, mean age = 24 ± 6 yr) participated in a pilot study to validate our experimental setup. 52 subjects (37 females; mean age = 21 ± 3) participated in the main experiment. 10 subjects (5 females, mean age = 24 ± 5) participated in a control experiment to test for an advantage of full-view face detection during conscious perception.

All subjects were healthy with normal or corrected to normal sight and gave written informed consent. The study was approved by the local ethical committee.

2.2. Stimuli

Face images were color pictures of 12 individuals. The 12 individuals (6 actors and 6 actresses) were paid models. To assure consistent image quality, all photographs were made in the same studio with identical equipment and lighting conditions. The head angle was either full view or turned away from the viewer by 23°. At this angle of profile, all facial features, including both eyes, are fully visible (see Fig. 1A and B for examples of stimuli). The eyes were directed either straight ahead or 23° to the side. For faces turned away from the viewer, averted gaze was directed towards the viewer. Face images were presented in an oval mask, subtending 1.6° of visual angle horizontally and 2° vertically. The mask was placed so that for the images with faces turned to the side, the ear towards the viewer was not visible. Thus, the visibility of facial features was equivalent for all face image conditions.

Suppressing stimuli were brightly colored, high contrast collages of different shapes (rectangular and curved figures), subtending 3° of visual angle horizontally and vertically, that changed every 100 ms (Fig. 1A). The dynamic suppressing and target stimuli were presented on different monitors with a mirror haploscope, mounted on a chin rest.

2.3. Procedure

Each trial was preceded by 1 s of a gray screen with a fixation cross. The trial began with 1–2 s of the dynamic suppressing stimuli presented to one eye and a phase-scrambled face image, with the same dimensions as the intact face images, presented to the other eye. Phase-scrambled face images matched the intact faces in terms of spatial frequencies and luminance. The target face was faded in over 1 s by gradually increasing its opacity from 0% to 100%. Beginning one second after the face

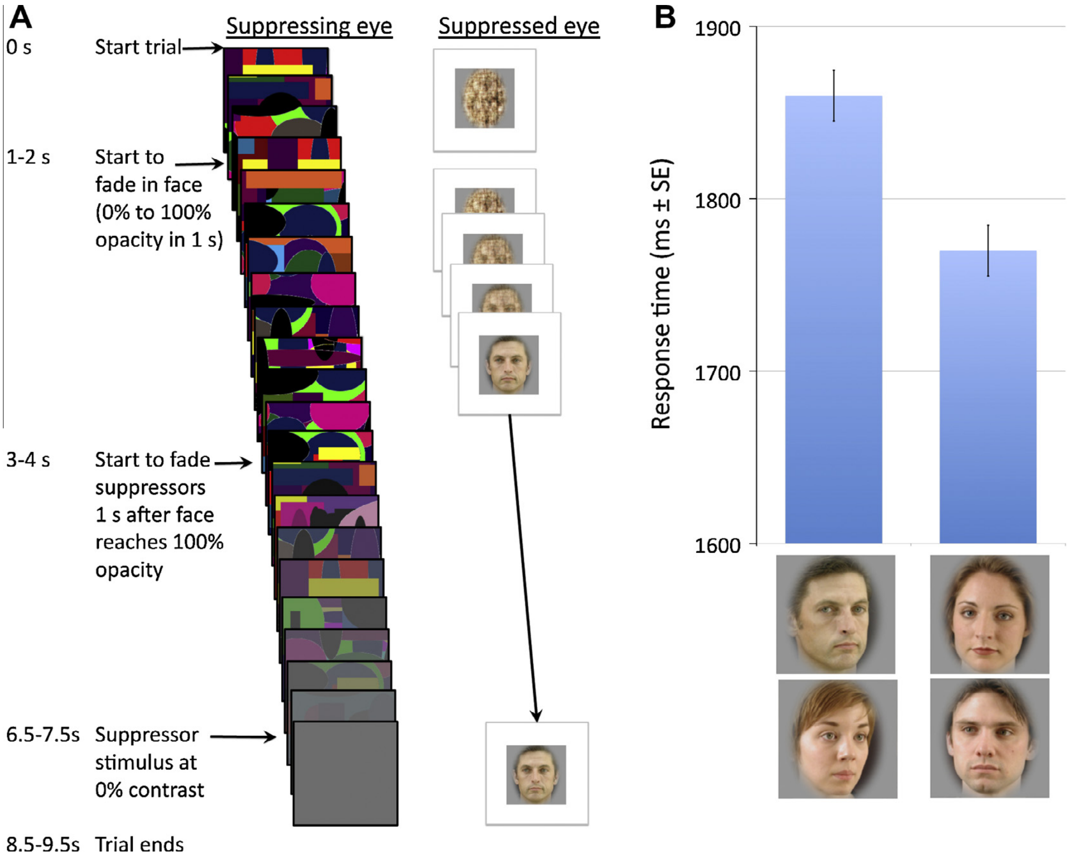

Fig. 1. (A) Experimental design. Different high contrast collages of colored shapes were presented to one eye at 10 Hz. A phase-scrambled image that faded into an intact face image over 1 s, beginning 1–2 s after trial onset, was presented to the other eye. After the intact face was at full opacity for 1 s (3–4 s after trial onset), the suppressing stimuli slowly faded over 3.5 s to a gray square (6.5–7.5 s after trial onset). The trial ended 2 s later (8.5–9.5 s after trial onset). (B) Mean reaction time (± SE) for detecting faces turned 23° and faces turned towards the viewer. Reaction times indicate the time for face images to break through interocular suppression.

image was faded in, the contrast of the suppressing stimuli progressively decreased over 3.5 s to zero (a gray square). Each trial ended with presentation of the face image with no suppressing stimulus for 2 s. On catch trials, the phase-scrambled image was not replaced with an intact face image, and the trial ended with the phase-scrambled image with no suppressing stimulus. Each condition was presented an equal number of times to the right and the left eye. Eye dominance was recorded for each participant.

In all experiments subjects were instructed to respond by pressing the space baron a keyboard as soon as they saw a face or any part of a face. Response times were measured relative to the time when a face began to fade in.

In the pilot study we validated our experimental setup by replicating the finding of faster detection of upright faces, as compared to inverted faces, during continuous flash interocular suppression (Jiang et al., 2007; Yang et al., 2007; Zhou et al., 2010). Stimulus conditions were upright and inverted faces, both in full-view with eyes directed towards the viewer. There were 48 trials for each condition with an additional 48 catch trials.

In the main experiment we tested the effects of head angle and gaze on time to break through continuous flash interocular suppression with a 2 × 2 design with four face image conditions: faces in full view with eye gaze directed (1) towards the viewer and (2) away from the viewer and faces turned 23° with (3) eye gaze averted towards the viewer and (4) direct eye gaze away from the viewer. The experiment consisted of 48 trials for each of four face image conditions and 48 catch trials.

In a control experiment we tested whether faces presented without interocular suppression showed an effect of head angle on response time. We included this experiment to test whether the effect of head angle on time to break through interocular suppression could be attributed to faster reaction time after breakthrough. As in the other experiments, a scrambled face image was presented to one eye and replaced with an intact face image, beginning 1–2 s later, by slowly increasing the opacity of the face image from 0% to 100% over 1 s. No stimulus was presented to the other eye. The head angle and gaze conditions and number of trials were the same as in the experiment with interocular suppression. As in the main experiment, there also were 48 catch trials in which an intact face image did not appear.

2.4. Data analysis

We tested effects of head angle and gaze in the main experiment and the control experiment with repeated measures two-way ANOVAs model. The data collected on three subjects in the main experiment who falsely detected more than 15% of catch trials were removed from the statistical analysis.

3. Results

Results from the pilot study replicated the effect of face inversion on breakthrough time with an effect that was similar in magnitude (mean difference = 514 ms, SE = 95 ms, $t_{25} = 5.4$, $p < .001$) to that reported previously (Jiang et al., 2007; Yang et al., 2007; Zhou et al., 2010). This result shows that our experimental setup produces results that are similar to those reported by others.

The effect of head angle on time to break through continuous flash interocular suppression was significant ($F_{1,144)} = 8.89$, $p < .005$), but the main effect of gaze ($F_{1,144} = 0.01$) and the interaction of gaze with head angle ($F_{1,144} = 0.25$) did not approach significance (Fig. 1B and Table 1). Faces in full view were detected 90 ms faster (SE = 30) than were faces turned 23°. Break through time and the effect of head angle did not vary as a function of the eye to which the suppressed faces were presented, either in terms of left versus right eye or in terms of dominant versus nondominant eye (for main effects of eye – both right versus left and dominant versus nondominant – and interactions between eye and head angle, $F_{1,144} < 1$, $p > 0.4$ in all cases). Detection errors were rare. The mean frequency of false negative responses on face trials was 0.6% (SE = 0.2%), and the mean frequency of false alarms on catch trials was 2.0% (SE = 0.6%).

Results of the control experiment showed no effect of head angle or gaze on the mean detection times without interocular suppression ($F_{1,27} = 0.96$ for head angle; $F_{1,27} = 0.86$ for gaze; $F_{1,27} = 1.47$ for the interaction, n.s.). Mean detection times for full-view faces and faces turned 23° were 660 ms SE = 6 ms and 658 ms SE = 6 ms, respectively (mean difference = 2 ms, SE = 6 ms).

4. Discussion

Our results suggest that detection of a face with attention directed at the viewer occurs even in the absence of awareness of that face. In our experiment, faces turned towards the viewer broke through interocular suppression faster than did faces turned 23° away from the viewer. These results indicate that head angle – a feature that can signal the potential social relevance of a face – is processed automatically. Such facilitated processing may serve to bias attention to individuals whose attention is directed at oneself even before one is aware of their presence.

In the control experiment we found that detection times for the same face images did not vary based on head angle or gaze when they were presented to one eye without interocular suppression and thus fully visible. This result suggests that differential detection times for invisible faces are not due to faster responses after the faces break through interocular suppression and become consciously visible.

Previous reports have shown that time to break through interocular suppression is faster for faces with fearful expressions as compared to neutral and happy expressions (Yang et al., 2007) and that faces with fearful expressions evoke neural activity in the amygdala when they are suppressed and subjectively invisible (Jiang & He, 2006; Williams et al., 2004). These prior results suggest that the expression of a face is processed when the face is rendered invisible with interocular suppression. The expression of fear alters the image of a face with changes in the shapes of the eyes and mouth, raising of the eyebrows, and more exposure of the whites of the eyes. Our images of faces turned away from the viewer differ from faces turned towards the viewer primarily in the locations of the facial features, but the features themselves are similar. Unlike a preconscious detector for facial expression, which may rely on changes in facial features (Whalen et al., 2004), a preconscious detector for head angle may rely more on the location of features in the outline of the face. Both detectors could rely on simple, low-spatial frequency features, e.g. the exposed whites of the eyes in fearful faces (Whalen et al., 2004) and the central placement of facial features in full-view faces. A subcortical route has been proposed as playing a role in processing socially relevant stimuli at a coarse level. The existence of this subcortical route, though, is not universally accepted. Others have suggested that the visual pathway may be sufficient for fast processing of these stimuli – even with reduced attentional resources and awareness – and, further, propose a role for top-down biasing of visual cortex involving frontal–parietal regions (Dehaene & Naccache, 2001; Pessoa, Japee, Sturman, & Ungerleider, 2006; de Jong, Kourtzi, & van Ee, 2012; Rodríguez

Table 1
Response times for the four face image conditions.

Face image condition	RT ± SE (ms)
Full view, gaze towards viewer	1776 ± 28
Full view, gaze away from viewer	1764 ± 27
Turned 23° to side, gaze towards viewer	1851 ± 27
Turned 23° to side, gaze away from viewer	1869 ± 23

et al., 2012). An alternative frontal–occipital direct connection has been proposed also to explain unconscious face processing in normal cognition and covert recognition in prosopagnosics (Valdés-Sosa et al., 2011). Our finding cannot help clarifying any of these hypotheses. Further studies are warranted to investigate the neural basis of unconscious perception.

Processing of expression without awareness has beeninterpreted as evidence for dissociable neural pathways for the representation of expression and identity (Haxby & Gobbini, 2011; Haxby, Hoffman, & Gobbini, 2000; Jiang & He, 2006), expression showing more dependence on neural activity in the superior temporal sulcus (Engell & Haxby, 2007; Winston, Henson, Fine-Goulden, & Dolan, 2004). The representation of head angle also may rely more on face-responsive cortical areas in the superior temporal sulcus (Carlin et al., 2012; Perrett et al., 1985). Processes that operate without awareness for rapid detection of these facial attributes may be associated with engagement of this part of the face processing system. On the other hand, other signals of others' attention directed at oneself, namely hearing one's own name and seeing a direct gaze, automatically engage the Theory of Mind areas, such as the medial prefrontal cortex, (Kampe et al., 2003), providing another candidate for the neural locus of these processes. Our results support the hypothesis that socially-relevant attributes of face stimuli undergo preconscious analysis but do not indicate which brain areas perform this analysis. Further research is necessary to delineate the neural systems that process social signals without awareness.

More recent findings indicate that evaluation of faces on social dimensions happens unconsciously and that the preconscious evaluation of faces is the result of an interaction between the face-stimuli and the observer specific traits (Stewart et al., 2012). These data support further the hypothesis that social information conveyed by faces is processed without awareness.

The effect of head angle on breakthrough time appears to be independent of gaze direction. Another report, however, did find that gaze direction modulated time to break through continuous flash interocular suppression, albeit only for faces turned away from the viewer (Stein et al., 2011). The discrepancy between our results and those of Stein et al. (2011) may be due simply to stimulus image differences. Whereas in Stein et al.'s (2011) study, the faces subtended 3.3° of visual angle horizontally, we restricted our images to 1.6° to minimize the possibility of partial breakthrough, which reduced the visibility of eye gaze direction. The face images in Stein et al. (2011) also had more extreme gaze aversion than did our face images and were presented outside of central vision.

Faster detection of faces that are turned towards oneself may be due to the social salience of these stimuli, but they also have other features that are not social and may also facilitate detection. Low-level visual features differ between faces turned towards the viewer and faces turned slightly away, most notably in terms of symmetry. Symmetry is a feature that the human visual system is highly sensitive to and may play a role in unconscious perception. Inverted upright faces break through interocular suppression faster than inverted faces, as shown earlier by others (Jiang et al., 2007; Yang et al., 2007; Zhou et al., 2010) and replicated here. It is possible that the full-view of a face is more prototypical for face representations than is a partial profile view, in the same way that the upright view is more prototypical than the inverted view. Whereas visual experience of upright faces is more common than of inverted faces, however, full-view faces are not seen more often than faces in various angles of profile. In fact, several lines of evidence suggest that the three-quarter profile of a face is more prototypical than is the full-view. Faces in three-quarter profile, as compared to full-view faces, convey more structural information about faces and tend to be recognized with higher accuracy (O'Toole et al., 2006). Moreover, the three-quarter profile view of faces is preferred in western portraits (Baddeley & Woodhead, 1983) and in cartoons (Perkins, 1975). Thus, faster detection of invisible full-view faces occurs despite the psychophysical advantage and other factors that indicate three-quarter profile faces are more prototypical, suggesting that facilitated detection of the full-view face during unconscious perception is due to other factors, such as social salience or symmetry.

A face turned towards oneself has a different and usually greater social meaning than does a face that is turned away as it can signal interest, the desire to catch one's attention, the intention to engage in a social interaction, or a potential threat. Facilitated processing of faces turned towards the viewer may reflect a detector for this socially salient feature that operates in the absence of visual awareness and selectively biases attention to other individuals in the environment whose attention is directed at oneself – information that is important for social behavior.

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