Cognition 143 (2015) 108–114

Contents lists available at ScienceDirect

Cognition

journal homepage: www.elsevier.com/locate/COGNIT

Making eye contact without awareness

Marcus Rothkirch [a,*,1], Apoorva Rajiv Madipakkam [a,b,1], Erik Rehn [a,c], Philipp Sterzer [a,c]

[a] Visual Perception Laboratory, Department of Psychiatry, Charité – Universitätsmedizin Berlin, Charitéplatz 1, 10117 Berlin, Germany
[b] International Graduate Program Medical Neurosciences, Charité – Universitätsmedizin Berlin, Luisenstr. 56, 10117 Berlin, Germany
[c] Bernstein Center for Computational Neuroscience, Philippstr. 13, 10115 Berlin, Germany

ARTICLE INFO

Article history:
Received 12 February 2015
Revised 23 June 2015
Accepted 24 June 2015
Available online 29 June 2015

Keywords:
Social cognition
Unconscious processing
Eye movements
Face perception
Gaze direction

ABSTRACT

Direct gaze is a potent non-verbal signal that establishes a communicative connection between two individuals, setting the course for further interactions. Although consciously perceived faces with direct gaze have been shown to capture attention, it is unknown whether an attentional preference for these socially meaningful stimuli exists even in the absence of awareness. In two experiments, we recorded participants' eye movements while they were exposed to faces with direct and averted gaze rendered invisible by interocular suppression. Participants' inability to correctly guess the occurrence of the faces in a manual forced-choice task demonstrated complete unawareness of the faces. However, eye movements were preferentially directed towards faces with direct compared to averted gaze, indicating a specific sensitivity to others' gaze directions even without awareness. This oculomotor preference suggests that a rapid and automatic establishment of mutual eye contact constitutes a biological advantage, which could be mediated by fast subcortical pathways in the human brain.

1. Introduction

Most of us have experienced situations in which our eyes appear to be automatically turned towards another person whose gaze is directed at us, although only subsequently we seem to become aware that this person was looking at us (cf. Titchener, 1898). Indeed, we are highly sensitive to whether someone is staring at us, presumably because this information functions as a meaningful social signal (Kleinke, 1986). When others' faces are clearly visible, our attention is predominantly attracted by people who are looking at us (Senju & Hasegawa, 2005; Von Grünau & Anston, 1995). However, the frequently experienced phenomenon mentioned above further suggests that our sensitivity for direct gaze may extend even beyond our conscious perception.

A frequently adopted technique that has been used by previous studies to investigate face processing in the absence of awareness is continuous flash suppression (CFS; (Tsuchiya & Koch, 2005), in which face stimuli presented to one eye are suppressed from awareness by the concurrent presentation of mask stimuli to the other eye. Manual responses indicating the breakthrough of the face stimuli into participants' awareness were observed to be faster for direct compared to averted gaze (Chen & Yeh, 2012; Stein, Senju, Peelen, & Sterzer, 2011). While such findings indicate that faces with direct gaze enter awareness faster than faces with averted gaze, they cannot provide unequivocal evidence for a preferential processing of direct gaze during the phase in which the face stimuli are still suppressed (Stein & Sterzer, 2014). Instead, they could reflect differences arising from the transition period, that is, the phase during which the stimuli gradually reach awareness (Gayet, Van der Stigchel, & Paffen, 2014). Most critically, such findings cannot clarify whether an unconscious processing of gaze directions can guide the observer's eye movements towards direct gaze, which represents a critical step for establishing mutual eye contact.

In the current study, we therefore sought to test whether faces with direct eye gaze attract observers' eye movements to a greater extent than faces with averted gaze, even when presented outside awareness. Such a bias in eye movements would provide unequivocal evidence for a differential processing of direct and averted gaze during unawareness of the faces. To this aim, we recorded participants' eye movements while they were exposed to faces that were made invisible by CFS, based on the previous finding that the oculomotor system is susceptible to visual information that is presented outside conscious awareness (Rothkirch, Stein, Sekutowicz, & Sterzer, 2012).

* Corresponding author.
E-mail addresses: marcus.rothkirch@charite.de (M. Rothkirch), apoorva-rajiv.madipakkam@charite.de (A.R. Madipakkam), erik.m.rehn@gmail.com (E. Rehn), philipp.sterzer@charite.de (P. Sterzer).
[1] These authors contributed equally.

http://dx.doi.org/10.1016/j.cognition.2015.06.012
0010-0277/

2. Experiment 1

2.1. Materials and methods

2.1.1. Participants

Thirty-four volunteers took part in experiment 1. Five participants from experiment 1 were excluded due to poor eyetracking quality. The data of another three participants were discarded, because they were able to indicate the appearance of the faces with above-chance accuracy and could thus not be considered unaware of the face stimuli (see Section 2.1.4). After applying our exclusion criteria, the final sample consisted of twenty-six participants (21 female; mean age: 24.65 (±0.76 SEM) years). All participants had normal or corrected-to-normal vision and written informed consent was obtained from each participant prior to the start of the experiment. The study was conducted in accordance with the 2008 World Medical Association Declaration of Helsinki and was approved by the local ethics committee.

2.1.2. Stimuli

Face stimuli were photographs of three different female faces that have been used in a series of previous studies (e.g. Senju & Hasegawa, 2005; Stein et al., 2011). There were two versions of each exemplar differing in their eye gaze direction. To avoid low-level stimulus differences between gaze directions, all faces were rotated to the left or the right. The impression of eye gaze being either directed at or away from the observer was achieved by a shift of the pupil to the left or the right. For example, a head rotated to the right together with the pupil shifted to the left resulted in the impression of a face looking at the observer. All faces were cut into oval shapes comprising a size of $3.8^\circ \times 4.5^\circ$ and equalised for global contrast (root mean square (RMS) contrast of 0.05) and luminance. Both face stimuli together covered 18.6% of the whole search field.

2.1.3. Procedure

Participants viewed the screen through a mirror stereoscope, which provided separate visual input to the two eyes. Participant's head was stabilised by a chin rest at a viewing distance of 50 cm. Stimuli were displayed on a 19-in. CRT monitor (resolution: 1024×768 Px; refresh rate: 60 Hz). Participants' eye movements were recorded with a high-speed video-based eyetracker (Cambridge Research Systems, UK; sampling rate: 250 Hz; spatial accuracy: 0.05°).

Prior to the main experiment, each participant's dominant eye was determined using the interocular suppression technique continuous flash suppression (Tsuchiya & Koch, 2005; Yang, Blake, & McDonald, 2010). Briefly, on each trial high-contrast greyscale dynamic mask stimuli (size: $5^\circ \times 5^\circ$) were flashed to one eye at a frequency of 10 Hz while simultaneously a face was presented in one quadrant of the greyscale stimulus to the other eye. Participants had to indicate the location of the face by button press as soon as the face overcame interocular suppression. The eyes viewing the masks and the face stimuli were randomised across trials. Each participant's dominant eye was identified as the eye corresponding to shorter reaction times while viewing the face stimuli.

In the main experiment, each trial started with the presentation of a white frame ($12^\circ \times 12^\circ$) and a central fixation cross ($0.6^\circ \times 0.6^\circ$) to both eyes. A representative trial is depicted in Fig. 1. The white frame and central cross were displayed for 1500 ms, unless participants did not fixate the central cross. In this case, the lines of the cross were thickened and presented until central fixation was established. Two intervals of 800 ms duration followed, during which high-contrast greyscale mask stimuli ($12^\circ \times 12^\circ$) were flashed to the participant's dominant eye at a frequency of 10 Hz to induce continuous flash suppression (Tsuchiya & Koch, 2005). During one of the two intervals, two low-contrast face stimuli (root mean square contrast of 0.03, luminance: 30.06 cd/m^2) were presented simultaneously to the non-dominant eye, one in the left half and one in the right half of the white square (eccentricity of 3.4°). The eye gaze of one face was directed towards the participant while the eye gaze of the other face was averted. Both faces were presented at the same vertical position, that is, either 3° above, below, or at the horizontal meridian. Participants were instructed that their main task was to detect the presence of the faces. They were encouraged to actively search for the faces by making eye movements. Upon the first eye movement that landed on one face, both faces were removed from the screen. The withdrawal of the faces served two purposes. Firstly, it has previously been reported that an attentional prioritisation of visible faces with direct gaze over faces with averted gaze decreases over time: While for short presentation durations spatial attention is specifically captured by faces with direct gaze, the allocation of attention to direct and averted gaze levels out for longer presentations (Senju & Hasegawa, 2005). This indicates that direct gaze primarily influences early, reflexive-like responses, which is why we only focused on initial saccades within trials. Secondly, instantaneous removal of the faces was intended to reduce the risk that the faces might break into participants' awareness. At the end of each interval, mask stimuli were presented to both eyes for 200 ms to prevent afterimages. Both intervals were separated by a fixation period of 750 ms duration. Again, the second interval only started when participants fixated the central cross. After the two intervals, participants performed a manual two-alternative forced-choice (2AFC) task, in which they had to indicate which of the two intervals contained the face stimuli. Finally, participants rated their confidence regarding their 2AFC response on a four-level confidence scale to provide an exhaustive measure for gradual changes in their subjective awareness (Windey, Vermeiren, Atas, & Cleeremans, 2014).

Participants performed five runs, each consisting of 54 trials. Prior to each run, a nine-point calibration of the eyetracker was conducted. Additionally, six 'dummy' trials were randomly interspersed per run, in which the face stimuli were presented to the dominant eye at full contrast. These trials were intended to maintain participants' motivation to search for the face stimuli and were not included in the analyses. The spatial location of the faces as well as their allocation to one of the two intervals was fully randomised and counterbalanced.

2.1.4. Data analyses

Trials were included in the analyses, if they met the following criteria: (i) Participants indicated the lowest level of confidence; (ii) participants made a manual response on both the 2AFC task and the confidence rating; (iii) at least 95% of the eyetracking data collected during one trial were available and not lost due to blinks or other artefacts.

The 2AFC task on each trial was intended to assess participants' awareness of the faces according to objective criteria, since an assessment of awareness solely based on subjective reports is prone to response biases (Kunimoto, Miller, & Pashler, 2001; Sterzer, Stein, Ludwig, Rothkirch, & Hesselmann, 2014). In this context, observers' unawareness of a particular stimulus is demonstrated by their inability to detect or discriminate that stimulus with above-chance accuracy. The following analyses were conducted to probe whether participants' performance exceeded chance level. Firstly, individual 2AFC task performances were subjected to binomial tests, which yielded statistically significant differences from chance level in three participants in both experiments. The data of these participants were excluded from all further analyses. Secondly, we tested whether the group mean of the included participants was at chance level. Since a non-significant result of a one-sample *t*-test cannot provide conclusive evidence for the null hypothesis, we further conducted a

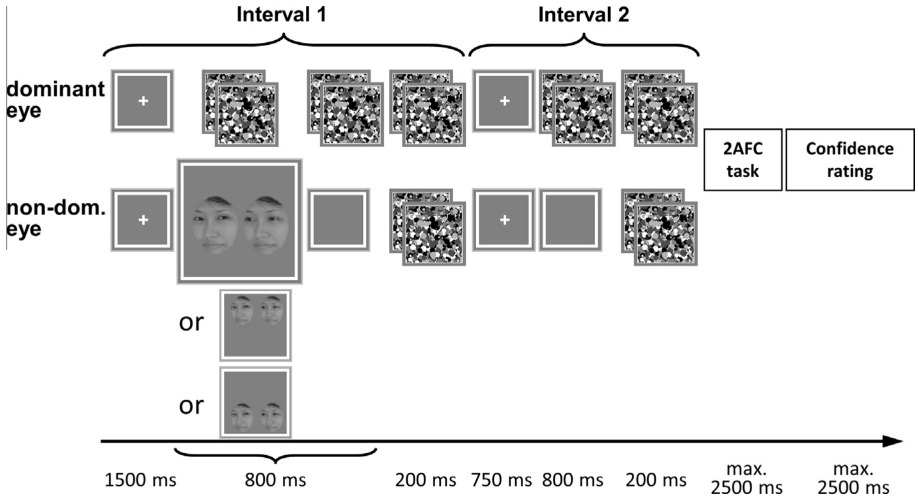

Fig. 1. Depiction of a typical trial in experiment 1 and 2. Each trial consisted of two successive intervals. Before and between the two intervals a white square and a central fixation cross were presented to both eyes. During one of the intervals a face pair was presented with one face in each half of the white square (eccentricity: 3.4°). The figure shows a trial with presentation of the face pair in the first interval. The face pairs could either be presented on the horizontal meridian, above the horizontal meridian, or below the horizontal meridian, as illustrated by the three different frames containing face stimuli in interval 1. The frame with the face pair on the horizontal meridian is enlarged for illustration purposes. Of this pair, one face was looking at the observer, while the gaze of the other face was averted. Faces were only presented to participants' non-dominant eye while concurrently high-contrast grayscale mask stimuli (size: 12° × 12°) were flashed to the dominant eye at a frequency of 10 Hz, leading to a suppression of the faces from awareness. Participants' eye movements were recorded during the two intervals. Finally, participants performed a manual two-alternative forced-choice (2AFC) task, in which they had to indicate the interval containing the face stimuli, and rated their confidence on a four-level confidence scale.

Bayesian analysis (Dienes, 2011). This analysis gives the likelihood of the data given the null hypothesis and the likelihood of the data given the alternative hypothesis and their quotient – the Bayes factor – as an output. While Bayes factors <0.33 provide substantial evidence for the null over the alternative hypothesis, Bayes factors >3 can be interpreted as evidence for the alternative over the null hypothesis (Dienes, 2011). We performed the Bayes analysis on a uniform distribution varying from 0% to 50% and from 50% to 100% to test that the data were neither significantly above or below chance. The Bayes test was carried out with an online Bayes calculator (http://www.lifesci.sussex.ac.uk/home/Zoltan_Dienes/inference/-bayes_factor.swf). Finally, the data from five participants had to be discarded due to poor eyetracking quality, that is, a loss of the eyetracking signal in more than 50% of all trials. Thus, data analyses were performed on a sample of twenty-six participants.

For the analyses of eye movements, we focused on the initial saccades that participants performed within trials. Saccades were defined on the basis of a velocity criterion. To this end, the elapsed time and the distance between consecutive gaze positions of the observer were used to calculate the velocity for each data point recorded by the eyetracking system. Eye movements were considered saccades if the velocity of at least three consecutive data points of the eyetracker (representing >12 ms) exceeded a criterion of 60°/s. The first data point of a detected saccade exceeding this criterion was regarded the onset of this saccade and the last data point exceeding this criterion defined the endpoint of this saccade. Saccades that started earlier than 100 ms after stimulus onset were considered anticipatory saccades and not included in the analyses. To quantify a saccadic preference for one of the two gaze directions, we computed individual saccadic preference indices as $100 * (sd - sa)/(sd + sa)$, based on the number of initial saccades towards faces with direct gaze (sd) and averted gaze (sa) (cf. Farroni, Csibra, Simion, & Johnson, 2002). Positive indices signify a preference for direct over averted gaze.

2.2. Results

On 58.5% (±4.7 SEM) of all trials, on average, participants indicated to be least confident regarding the appearance of the faces. In these trials, participants were unable to correctly guess the presentation of the faces in the manual 2AFC task (M = 50.54% (±0.84 SEM); one-sample t-test against 50%: $t(25) = 0.65$, $p > 0.05$; Fig. 2A), indicating that the faces were effectively suppressed from awareness. In addition, Bayes analysis of participants' task performance yielded Bayes factors of 0.01 and 0.04 for uniform distributions above and below 50%, respectively, providing substantial evidence for the null hypothesis, that is, no difference from a chance level of 50%.

Regarding participants' eye movements at the lowest confidence level, we first probed whether saccades were more frequently directed towards the actual position of the faces in comparison to all possible locations in which the face stimuli could potentially appear. To this end, we computed the proportion of saccadic endpoints landing on the two concurrently presented faces in relation to saccadic endpoints landing within all possible face locations. Saccades were significantly more frequently directed towards the actually presented face stimuli compared to all possible locations of the faces (M = 49.83% (±2.32 SEM); one sample t-test against 40.7% representing the area covered by two faces relative to all possible locations of the faces: $t(25) = 3.93$, $p < 0.001$). Of these face-directed saccades, the mean saccadic preference index across participants was M = 10.41% (±4.95 SEM) (Fig. 2B), which was significantly larger than 0 (one sample t-test: $t(25) = 2.10$; $p = 0.046$; $d = 0.41$). This indicates that relative to all face-directed saccades, saccades were ~10% more often guided towards faces with direct gaze compared to averted gaze. In three participants, saccadic indices were identified as statistical outliers, because they were either 1.5 times the interquartile range above the 75th percentile or below the 25th percentile of the group distribution. After removal of these outliers, the mean saccadic preference index was still significantly above 0 (M = 8.72% (±3.79 SEM); one sample t-test: $t(22) = 2.30$; $p = 0.031$; $d = 0.48$). No difference in saccade latencies between direct (M = 446.94 ms (±9.51 SEM)) and averted gaze (M = 429.96 ms (±9.51 SEM); paired sample t-test: $t(25) = 0.89$; $p = 0.38$; $d = 0.18$) was found.

It has previously been reported that masked faces with averted gaze can trigger attentional shifts in the direction where the face is looking (Sato, Okada, & Toichi, 2007). We therefore directly compared

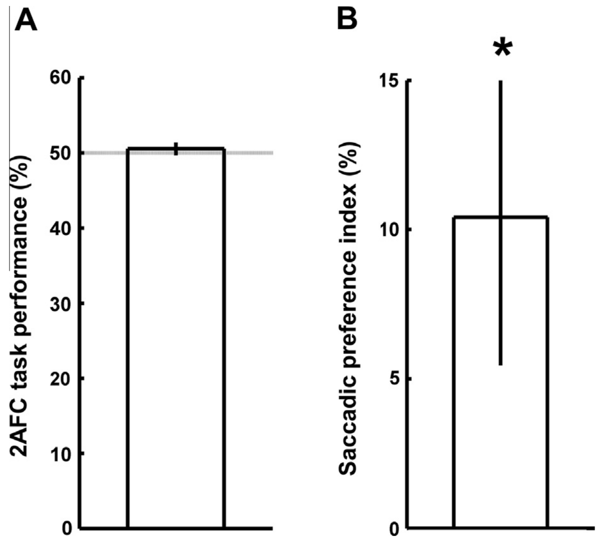

Fig. 2. Manual task performance and saccadic responses in experiment 1. (A) Participants' unawareness of the face stimuli in is demonstrated by their inability to guess the appearance of the faces with above-chance accuracy in the manual 2AFC task. The grey line indicates chance level of 50%. The error bar denotes the standard error of the mean. (B) Depiction of the mean saccadic preference index (in %). The number of initial saccades towards faces with direct and averted gaze was used to compute the individual preference indices as the difference between the two conditions divided by its sum. A positive index reflects saccadic preference for direct over averted gaze. The error bars depicts the standard error of the mean. The asterisk denotes a significant difference from 0 ($p < .05$).

trials in which the averted gaze was looking in the direction of the concurrently presented direct-gaze face to trials in which the eyes of the averted gaze looked away from the direct-gaze face. Saccadic preference indices did not differ between these two stimulus arrangements ($t(25) = -0.55$, $p > 0.5$), indicating that participants' eye movements were attracted by the face with direct gaze, rather than influenced by the gaze direction of the face with averted gaze.

2.3. Discussion

The results of experiment 1 show that despite participants' unawareness of the faces, their eye movements were directed preferentially towards faces looking at them compared to faces looking away. Notably, only 58% of all trials, on average, were available for our analysis, since in the remaining trials the face stimuli overcame suppression from awareness. A possible cause for ineffective suppression in these trials could be that the guidance of overt attention to a particular location facilitates awareness of a suppressed stimulus at that location. Such a role of overt spatial attention for the evocation of awareness under binocular viewing conditions has been suggested by previous research (Dam & Ee, 2006; Ooi & He, 1999). In a second experiment, we therefore aimed at a replication of the effect found in the first experiment and at a more robust suppression of the face stimuli from awareness by removing them from the screen before saccades landed on them.

3. Experiment 2

3.1. Materials and methods

3.1.1. Participants

Thirty-one participants took part in experiment 2. Seven participants were excluded due to poor eyetracking quality. The data of another three participants were discarded, because they were able to indicate the appearance of the faces with above-chance accuracy and could thus not be considered unaware of the face stimuli (see Section 2.1.4). The final sample thus consisted of twenty-one participants (16 female; mean age: 24.85 (±1.09 SEM) years). All participants had normal or corrected-to-normal vision. Prior to the start of the experiment, written informed consent was obtained from each participant. The study was conducted in accordance with the 2008 World Medical Association Declaration of Helsinki and was approved by the local ethics committee.

3.1.2. Stimuli

The stimuli employed in experiment 2 were identical to those used in experiment 1 (see Section 2.1.2).

3.1.3. Procedure

The experimental procedure of experiment 2 was identical to the procedure of experiment 1 (see Section 2.1.3) with the following exceptions. Removal of the face stimuli was carried out upon participants' initiation of the first saccade within a trial. The initiation of the first saccade in each trial was defined as the first eye position after the fixation period exceeding a distance of 1.25° to the centre of the fixation cross. Participants performed 12 runs each consisting of 36 trials. In addition, two 'dummy' trials were randomly interspersed per run, in which the face stimuli were presented to the dominant eye at full contrast. These trials were intended to maintain participants' motivation to search for the face stimuli and were not included in the analyses.

3.1.4. Data analyses

Data collected from experiment 2 were subjected to the same exclusion criteria and analysed analogous to experiment 1 described above (Section 2.1.4). In contrast to experiment 1, faces were removed from the screen before saccades could land on them. Therefore, a saccade was considered as being directed to either face if its landing point was within the region that was covered by the face at the start of the trial.

3.2. Results

As intended, removal of the face stimuli before participants' gaze landed on them increased the proportion of trials in which participants reported no awareness of the face stimuli (on average 68.1% (±4.5 SEM); experiment 1: 58.5% (±4.7 SEM)). Furthermore, accuracy in the manual 2AFC task again did not exceed chance level ($M = 48.94\%$ (±0.51 SEM); one-sample t-test against 50%: $t(21) = -2.0$, $p > 0.05$; Fig. 3A), which was strongly supported by Bayes' factors of 0.00 and 0.22, respectively, for uniform distributions above and below a performance level of 50%.

In contrast to experiment 1, the average proportion of all face-directed saccades did not exceed the chance level of 40.7% ($M = 41.68\%$; $t(20) = 0.62$, $p = 0.54$). As general biases in observers' search behaviour with respect to the vertical screen position have been found in a previous study (Rothkirch et al., 2012), such general biases could have obscured a saccadic preference of the suppressed faces in the current experiment. In a second step, we therefore analysed the proportion of face-directed saccades for each of the three different vertical face positions separately by comparing the number of saccades directed towards a particular vertical position in trials in which the faces were presented at this position vs. trials in which they were presented elsewhere. While the proportion of saccades towards faces in the middle vertical position exceeded chance level ($t(20) = 2.51$, $p = 0.02$), the proportion of saccades towards faces in the upper vertical position was significantly below chance level ($t(20) = -3.50$, $p = 0.002$), indicating a general saccadic bias towards the upper part of the screen. Notably, this bias does not affect our main analysis regarding the influence of gaze direction on participants' eye movements.

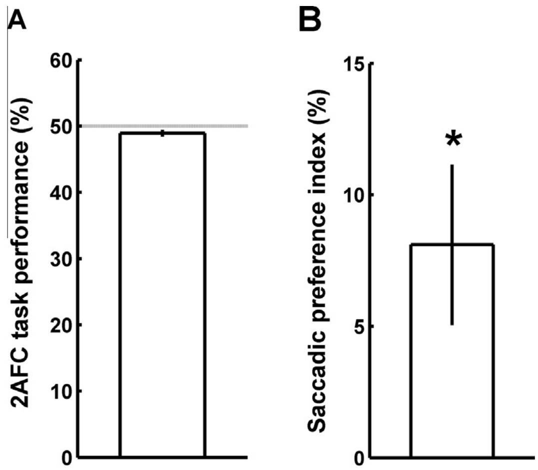

Fig. 3. Manual task performance and saccadic responses in experiment 2. (A) Participants' performance in the 2AFC task was at chance level (indicated by the grey line), demonstrating their unawareness of the face stimuli. The error bar denotes the standard error of the mean. (B) Depiction of the mean saccadic preference index (in %). A positive index reflects saccadic preference for direct over averted gaze. The error bar depicts the standard error of the mean. The asterisk denotes a significant difference from 0 ($p < .05$).

Importantly, in accordance with our findings from experiment 1, saccades were predominantly directed towards faces with direct gaze, indicated by a mean saccadic preference index that was significantly above 0 ($M = 8.10\%$ (±3.05 SEM), see Fig. 3B; one sample t-test: $t(20) = 2.65$; $p = 0.015$; $d = 0.58$). Using the same criteria for the definition of outliers as in experiment 1, no outliers were identified in experiment 2. Moreover, latencies of eye movements towards faces with direct gaze tended to be shorter than latencies of eye movements directed to faces with averted gaze (437.90 ms (±6.68 SEM) vs 462.45 ms (±6.68 SEM); paired sample t-test: $t(20) = -1.83$, $p = 0.08$, $d = 0.42$). Finally, a non-significant t-test between the saccadic preference indices when an averted-gaze was looking at a direct-gaze stimulus and when the averted-gaze stimulus was looking away from the direct-gaze face shows that the current result does indeed indicate a saccadic preference towards direct-gaze faces and not a cuing effect triggered by the averted-gaze stimulus ($t(21) = -1.4$, $p > 0.1$).

3.3. Discussion

Experiment 2 was performed with the aim of replicating the results of experiment 1 under more effective interocular suppression. Still, faces directing their gaze towards the observer were preferentially looked at, although they were presented outside of awareness.

4. General discussion

The results of both experiments consistently demonstrate that humans have a preference towards faces with direct gaze, even when they are completely unaware of these faces: Although participants were unable to correctly guess the presence of faces in the manual 2AFC task, facial gaze directions led to differential behavioural consequences – namely the systematic performance of saccades towards faces with direct gaze.

Our findings raise the question of why it could be useful to preferentially orient ones eyes towards direct gaze in the absence of awareness. The gaze direction of another individual is a salient signal that facilitates and influences a multitude of social processes, such as the interpretation of emotional expressions, face recognition, and the evaluation of the other individual (Adams & Kleck, 2003; Mason, Hood, & Macrae, 2004; Mason, Tatkow, & Macrae, 2005). Most importantly, the establishment of mutual eye contact between two individuals is a precursor to any social interaction and evokes approach tendencies as well as cooperative behaviour (Hietanen, Leppänen, Peltola, Linna-aho, & Ruuhiala, 2008; Kleinke, 1986). As such, a fast and automatic response to direct gaze of other individuals constitutes a biological advantage, which is further underlined by the attentional prioritisation of direct gaze in human neonates and in other species (Emery, 2000; Farroni et al., 2002). Other behavioural responses such as mimicry of emotional expressions in the absence of awareness provide further support for the evolutionary relevance of automatic responses to facial information subserving communicative purposes (Tamietto et al., 2009). In the second experiment of the current study, latencies of saccades guided towards direct gaze tended to be shorter than latencies of saccades towards averted gaze, which is additionally suggestive of a fast orienting response towards direct gaze in the absence of awareness. Since, however, no latency differences between direct and averted gaze were observed in the first experiment, further research is warranted to evaluate the reliability of this effect.

It is important to note that the results of the present study go substantially beyond previous reports of eye contact effects under interocular suppression (Chen & Yeh, 2012; Stein et al., 2011). These earlier findings were based on differences in suppression time, that is, on the time until stimuli enter the observer's awareness. However, from differences in suppression times no conclusions can be drawn about ongoing processes during the time of stimulus suppression and therefore they do not provide unequivocal evidence for differences in unconscious processing (Stein, Hebart, & Sterzer, 2011; Stein & Sterzer, 2014). The online recording of eye movements, in contrast, can reveal behavioural biases for stimuli that are constantly suppressed from awareness, while at the same time participants' (un)awareness of the critical stimuli can be assessed on the basis of manual reports, using objective criteria (Rothkirch et al., 2012). Our current findings provide a clear demonstration that socially relevant information affects ongoing behaviour in the absence of awareness and contributes to the longstanding debate on the question to what extent high-level information can influence behaviour unconsciously (Kouider & Dehaene, 2007). Furthermore, it has to be noted that the findings of the present study do not reflect a classic case of 'blindsight'. Blindsight refers to observers' preserved ability to localise or discriminate visual stimuli that they deny seeing (e.g. see reviews by Cowey (2010), Overgaard (2011), Stoerig and Cowey (2007)). In other words, it describes a dissociation between observers' subjective visual experience and their objective performance in detection or discrimination tasks. In contrast, in the present study participants were unaware of the critical face stimuli with respect to both subjective experience and objective task performance, together demonstrating complete unawareness of the stimuli. Instead, both measures showed a dissociation to participants' eye movements, which were affected by the suppressed stimuli.

Which neural mechanisms may enable a fast attentional orienting towards direct gaze without awareness? Previously, a 'fast-track modulator model' involving subcortical structures, such as the amygdala and superior colliculus (SC) has been proposed (Senju & Johnson, 2009). While the SC is a key structure for the performance of eye movements (Isa & Hall, 2009), direct gaze has recently been found to activate also the amygdala in a cortically blind patient (Burra et al., 2013). Critically, the amygdala combines emotional and spatial information (Peck, Lau, & Salzman, 2013). Anatomical connections between the amygdala and SC (Tamietto, Pullens, de Gelder, Weiskrantz, & Goebel, 2012) could mediate the preferential performance of eye movements towards this socially relevant but unconscious stimulus. Alternatively or complementary, direct gaze may have the status of a ‘social reward’ engaging subcortical reward structures (Kampe, Frith, Dolan, & Frith, 2001), which are also recruited when awareness is strongly limited (Pessiglione et al., 2008; Rothkirch, Schmack, Deserno, Darmohray, & Sterzer, 2014).

The present findings offer a promising starting point both for the investigation of the neural mechanisms underlying unconscious gaze processing and for the understanding of gaze processing in individuals who have been diagnosed with autism or social anxiety disorder, where atypical eye contact is one of the key diagnostic symptoms (Schulze, Renneberg, & Lobmaier, 2013; Senju, Tojo, Yaguchi, & Hasegawa, 2005). Recently, it has been observed that direct gaze does not have preferential access to awareness in adolescents with autism (Akechi et al., 2014). Whether this also indicates a lack of saccadic preferences towards direct gaze in the absence of awareness is currently unknown.

Since social interactions form an integral part of human behaviour, it appears reasonable that behavioural responses to direct gaze – one of the most salient non-verbal social signals – can be performed without or prior to awareness. This may also reflect the phenomenon that the feeling of being looked at often seems to precede conscious perception of another’s face, in line with discrepancies between sensing and seeing that have also been reported within other contexts (Rensink, 2004).

Acknowledgment

This study was supported by the German Research Foundation (STE 1430/2-1 and partly STE 1430/6-1).

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.cognition.2015.06.012.

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