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Attention holding elicited by direct-gaze faces is reflected in saccadic peak velocity

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Attention holding elicited by direct-gaze faces is reflected in saccadic peak velocity

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Abstract Manual response times to peripherally presented targets have been reported to be greater in the presence of task-irrelevant pictorial faces at fixation which establish an eye contact with the observer. This effect is interpreted as evidence that direct-gaze faces hold attention. In three experiments, we investigated whether this attention-holding effect is also reflected in saccadic response times. Participants were asked to make a saccade towards a symbolic target that could appear rightwards or leftwards, in the presence of a task-irrelevant centrally placed face with either direct gaze or closed eyes. Unexpectedly, saccadic response times did not show any consistent response pattern as a function of whether the faces were presented with direct gaze vs. closed eyes. Interestingly, saccadic peak velocities were found to be lower in the presence of faces with direct gaze rather than closed eyes (Experiment 1). This effect emerged even in the presence of non-human primate faces (Experiment 2), and no differences between direct gaze and closed eyes emerged when the faces were presented inverted rather than upright (Experiment 3). Overall, these findings suggest that eye contact can have an impact on the saccadic generation system.

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Introduction

Inferring the focus of attention of our conspecifics from their gaze direction is crucial both for cognitive development and for navigation within environments and social contexts (e.g., Emery 2000). In the last decades, a bulk of experimental evidence confirmed that eye-gaze stimuli can lead to remarkable effects on visual attention (for reviews, see Emery 2000; Frischen et al. 2007). In particular, the attention effects of eye-gaze stimuli can be divided into three different—but complementary—attention phenomena: attention shifting, attention capture, and attention holding.

On one hand, attention shifting is typically reported in the presence of averted-gaze stimuli presented at fixation. Averted-gaze signals displayed by individuals around us are particularly important to detect the presence of relevant stimuli nearby (e.g., another individual, an object). At the same time, the ability to interpret these signals is essential for the emergence of meaningful and pervasive relationships with our conspecifics (for reviews, see Frischen et al. 2007; Shepherd 2010). Strikingly, averted-gaze stimuli appear to push one's attention in the corresponding direction also in newborns (e.g., Farroni et al. 2004), thus suggesting the innate nature of this ability. Attention shifts in the presence of eye-gaze stimuli have been widely reported for both covert (without eye movements) and overt (with eye movements) orienting of attention. In the case of covert orienting, participants are generally asked to provide a manual response to a peripheral target onset while ignoring a task-irrelevant centrally placed face with averted gaze (e.g., Driver et al. 1999; Friesen and Kingstone 1998). Similarly, in overt orienting tasks, participants are typically asked to perform a saccade towards a rightwards or a leftwards target location while ignoring a task-irrelevant central face with averted gaze (e.g., Kuhn and Benson 2007; Ricciardelli et al.

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2002). When target location corresponds to that indicated by eye-gaze direction, a benefit in performance is generally reported, such as smaller response latencies and a greater accuracy (e.g., Driver et al. 1999; Friesen and Kingstone 1998; Kuhn and Benson 2007; Ricciardelli et al. 2002). Intriguingly, this form of social attention can be deeply shaped by many different social variables that characterize both the cueing face and the participant, such as emotional expressions (e.g., Bayliss et al. 2010), age (e.g., Kuhn et al. 2015), social status (e.g., Dalmaso et al. 2012), social evaluation (Carraro et al. 2017), racial group membership (e.g., Pavan et al. 2011), and even political affiliation (e.g., Carraro et al. 2015; Dodd et al. 2011; Porciello et al. 2016).

On the other hand, both attention capture and holding are typically reported in the presence of direct-gaze faces. Direct-gaze faces play a crucial role in interpersonal perception as they allow individuals to detect approaching behaviours coming from others (e.g., Conty et al. 2016; Hamilton 2016; Senju and Johnson 2009). For this reason, direct-gaze faces likely require to be more rapidly detected in the environment and more thoroughly processed. Similar to gaze-mediated orienting, a preference towards direct-gaze faces is already detectable in newborns (e.g., Farroni et al. 2002), confirming the great relevance of eye contact for our social attention system. On the behavioural side, the majority of studies focused on covert attention capture. For instance, Böckler et al. (2014, 2015) found that participants were faster to discriminate a peripheral target when it appeared in the same spatial location occupied by a direct-gaze face rather than an averted-gaze face. Other studies adopted a visual search task in which several faces appeared simultaneously on peripheral locations, and participants were asked to maintain fixation centrally and to indicate the presence, or not, of a specific target face such as, for instance, a direct-gaze face presented among several other averted-eye faces, or the opposite (e.g., Conty et al. 2006; Doi and Shinohara 2013; Palanica and Itier 2011; Senju et al. 2005; von Grünau and Anston 1995; Yokoyama et al. 2011). In general, lower manual response latencies emerged when the target face displayed direct gaze as compared to both averted gaze and closed eyes (but see Cooper et al. 2013; Framorando et al. 2017). As for overt attention capture, Mares et al. (2016) asked participants to perform a saccade from a central point to a peripheral target. They found lower express saccade latencies when the target was a direct-gaze face as compared to both averted-gaze faces and pictures of buildings. More recently, in Dalmaso et al. (2017), participants were asked to perform a vertical saccade from a central spot to a symbolic target while ignoring a peripheral facial stimulus that acted as distractor. Here, saccadic trajectories deviated more strongly away from direct-gaze faces as compared to both closed-eye faces and scrambled faces, an effect

that can be taken as an indirect evidence of attention capture. Indeed, when a saccade towards a target is performed in the presence of a distractor, it would be necessary to inhibit any potential eye movement towards the distractor. This inhibition would cause, in turn, an imbalance in saccade programming, reflected in a curved trajectory (Van der Stigchel 2010).

Surprisingly, much less is known about attention holding, and intriguingly, the few studies on this topic led to mixed results. In a pioneering study by Senju and Hasegawa (2005) on covert attention holding, participants were asked to maintain fixation on a central spot and to detect a peripheral target that could appear either rightwards or leftwards. Importantly, a task-irrelevant face with direct gaze, averted gaze or closed eyes also appeared at the centre of the screen. Hence, contrary to the studies on attention capture (e.g., Böckler et al. 2014), here, facial stimuli were presented at fixation. The results showed higher manual response latencies in the presence of direct-gaze faces as compared to the other two conditions. Interestingly, an opposite pattern of results has recently been documented by Hietanen et al. (2016), using a similar paradigm as the one employed by Senju and Hasegawa (2005). In more detail, Hietanen et al. (2016) observed that participants were faster in response to a peripheral target when they were looking at a live confederate who established eye contact with the participant (i.e., direct-gaze condition) as compared to a condition in which the confederate looked elsewhere (i.e., averted-gaze condition). Hietanen et al. (2016) explained their results by suggesting that the increased autonomic activation, that is generally observed in the presence of live direct-gaze faces (see Conty et al. 2016), may have predisposed participants to react more readily to target onset. Interestingly, evidence is accumulating showing that real social interactions can shape attention in a peculiar manner as compared to pictorial stimuli (for a review, see Cole et al. 2016). For instance, Gallup et al. (2012) observed that pedestrians tended to shift attention more strongly in response to the spatial cues provided by live individuals observed from behind (i.e., eye-gaze cues were precluded) rather than from the front, a result that contrasts with laboratory-based studies that highlighted the relevance of others' gaze stimuli for guiding attention (e.g., Emery 2000; Frischen et al. 2007). A different strategy to explore the impact of eye contact on attention holding might rely on oculomotor measures which are particularly sensitive to attentional dynamics (e.g., Kristjánsson 2011). To the best of our knowledge, so far, only one study investigated attention holding for direct-gaze faces by employing eye movements in a gap-effect paradigm (Ueda et al. 2014). Specifically, participants made saccades towards a peripheral target in the presence of a central face-like schematic stimulus, displaying higher latencies after the abrupt onset of direct—rather than averted—pupil-like stimuli. However,

the use of the gap-effect paradigm combined with the use of highly schematic stimuli prevents a straightforward comparison with previous studies.

Inspired by Senju and Hasegawa (2005) study, the present work was carried out with the main aim to systematically investigate the impact of direct-gaze pictorial faces on saccadic eye movements. To this end, a modified version of the task devised by Senju and Hasegawa (2005) was employed by presenting, on each trial, one single central pictorial face of real individuals and peripheral targets, in line with the vast majority of overt orienting studies concerning eye-gaze direction (e.g., Ciardo et al. 2014; Dalmaso et al. 2015; Kuhn et al. 2015; Porciello et al. 2016; Ricciardelli et al. 2002). In Experiment 1, participants were asked to make a saccade towards a peripheral target that could appear either rightwards or leftwards with respect to the centre of the screen. At the same time, a task-irrelevant upright picture of a real human face with direct gaze vs. closed eyes appeared at fixation. Overall, we hypothesized that, if eye contact holds attention, this should be reflected in the saccadic generation system. Specifically, higher saccadic latencies were expected in the presence of facial stimuli with direct gaze rather than closed eyes, in line with the hypothesis that direct-gaze faces can hold attention in an observer. We anticipate here that saccadic latency analyses did not show any consistent response pattern as a function of whether the faces were presented with direct gaze vs. closed eyes. However, because saccadic eye movements—like any other ballistic movement—contain a variety of information concerning their development in both time and space, and saccadic reaction times and direction (i.e., accuracy) represent only a part, though highly relevant, of these dynamics (e.g., Gilchrist 2011), we reasoned that the attention-holding effect of eye contact could be reflected also in other saccadic parameters. Of particular interest for the present study, a recent work reported that saccades made towards facial stimuli have higher peak velocities (Xu-Wilson et al. 2009). In more detail, in Xu-Wilson et al. (2009), saccades executed towards a direct-gaze neutral face had higher peak velocities as compared to saccades executed towards a non-facial stimulus, while no differences emerged for saccadic latencies. Interestingly, other previous studies also reported divergent results between peak velocity and latency analyses (e.g., Edelman et al. 2006; Fimm and Blankenheim 2016; Ramchandran et al. 2004), an evidence that would suggest that these two parameters could, at least partially, reflect the operation of different mechanisms. In this regard, Xu-Wilson et al. (2009) explained their main findings in terms of the higher attention capturing power of intrinsically valued stimuli (i.e., direct-gaze faces) which would have specifically increased saccadic velocity. Crucially, in Xu-Wilson et al. (2009), participants were asked to perform a saccade from a central symbolic spot towards a peripheral facial stimulus, while in the current set of experiments, the opposite task was requested, namely, participants performed a saccade away from a central facial stimulus towards a peripheral symbolic target. Consequently, we reasoned that, in the present context, lower peak velocities could be observed when a saccade had to be performed moving away from a face with direct gaze—which is a particularly relevant social stimulus (e.g., Conty et al. 2016; Hamilton 2016; Senju and Johnson 2009)—as compared to a face with closed eyes. We anticipate here that the results of the explorative analyses of saccadic peak velocities were consistent with these additional hypotheses.

Experiment 1: upright human faces

Methods

Participants

Twenty-four naïve students (Mean age = 19.9 years, SD = 2.17, 1 male) took part in the experiment. Their vision was normal or corrected to normal with lenses. The study was approved by the Ethics Committee for Psychological Research at the University of Padova and conducted in accordance with the Declaration of Helsinki. An informed consent was obtained from all participants.

Stimuli and apparatus

Four coloured pictures of real faces were employed to increase the ecological validity of the results. These faces belonged to two adult males and two adult females. For each facial identity, there were two versions: one with open eyes and one with closed eyes (eight stimuli in total). We did not use averted-gaze faces, since it is well known that averted-gaze signals can trigger automatic attention shifts (e.g., Galfano et al. 2012), and in the present context, we wanted to exclude this potentially influential factor. Each face was elliptically cropped, to remove any potential interfering element such as hairs and ears, and stimuli were matched for luminance through Photoshop CS6.

Eye movements were recorded monocularly at 1000 Hz using an EyeLink 1000 Plus (SR Research Ltd, Ottawa, Canada). Participants sat approximately 65 cm away from a 24-inch monitor (1280 × 1024 pixels, 120 Hz) and a chinrest was used to avoid head movements. A display PC running Experiment Builder (SR Research Ltd, Ottawa, Canada) handled timing and stimuli presentation. Background was set to grey (R = 180, G = 180, B = 180).
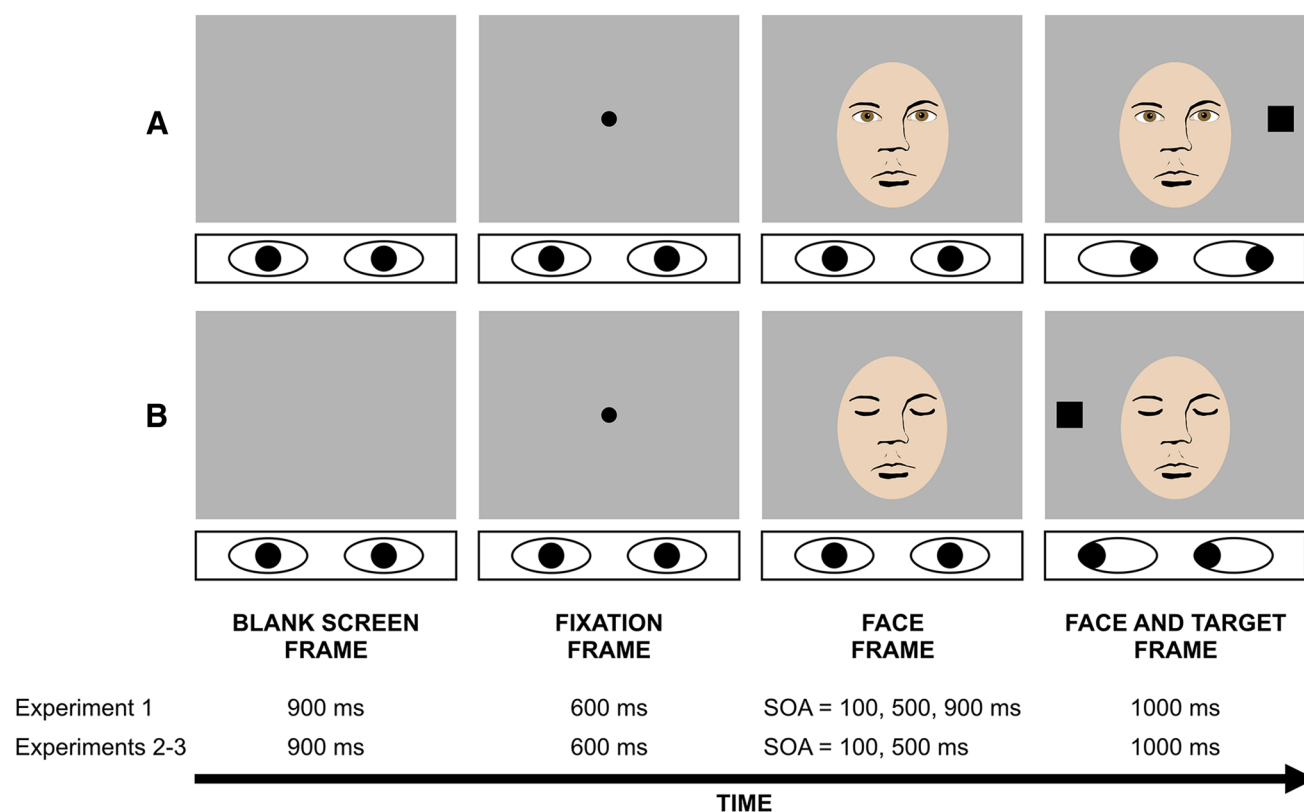
Fig. 1 Illustration of the paradigm employed in the three experiments. In this example, a schematic face with either *direct gaze* (**a**) or *closed eyes* (**b**) is depicted. Stimuli are not drawn to scale. Schematic eyes below each frame illustrate the correct gaze behaviour requested to participants on each trial. Please note that schematic faces were only used for illustrative purposes, whereas real faces were actually used in the three experiments

Procedure

Each experimental session started with a nine-point calibration followed by a validation procedure. Then, each trial started with a blank screen for 900 ms. After that, a centrally placed black circle (diameter 0.45°) appeared (see Fig. 1). The trial continued only if participants maintained their eyes on this spot for 600 ms, assessed through a gaze-contingent trigger (diameter of the invisible boundary 3°). If they failed, after 15 s, a visual feedback appeared for 2000 ms, the trial was aborted and recycled at the end of the experimental blocks, and a new calibration/validation procedure was performed by the experimenter. Otherwise, in case of successful fixation, a face stimulus (7.5° width × 9.8° height) appeared at the centre of the screen. Faces were arranged on the screen, so that their eyes were at the same height of the black circle (i.e., the area occupied by the face was slightly bigger on the lower part of the screen). After either 100, 500, or 900 ms (Stimulus Onset Asynchrony, SOA), a black square (0.7°) appeared 12° on the right or on the left with the same probability. Participants were instructed to move their eyes away from the central location and to reach the target square as fast and accurate as possible. The trial

ended after 1000 ms. Three different SOAs were employed to explore the time course of attention holding. In particular, we expected to observe stronger attention holding in the presence of direct-gaze faces at the two shorter SOAs (i.e., 100 and 500 ms), in line with Senju and Hasegawa (2005).

Each condition defined by eyes (open vs. closed) and SOA (100 vs. 500 vs. 900 ms) was presented for an equal number of times. There was a practice block composed of ten randomly selected trials, followed by 4 experimental blocks each composed of 120 randomly-selected trials (i.e., 480 experimental trials in total; 80 trials for each combination of the two factors). The whole procedure lasted about 40 min.

Results

Data handling

One participant did not complete the experiment due to a technical failure, leaving the sample composed of 23 individuals (mean age = 20 years, SD = 2.17, 1 male).

Eye movements with a velocity and acceleration exceeding 30°/s and 8000°/s², respectively, and with a

Table 1 Mean saccadic reaction times (SRTs), observed in Experiment 1, in response to faces with direct gaze and closed eyes as a function of SOA

	100-ms SOA		500-ms SOA		900-ms SOA	
	Direct gaze	Closed eyes	Direct gaze	Closed eyes	Direct gaze	Closed eyes
SRTs (ms)	238	240	215	215	199	199
SE	10.42	10.3	6.83	7.52	5.72	5.5

SE standard error

minimum amplitude of 1°, were defined as saccades. On each trial, we extracted the first saccade performed after the target onset. Saccades were discarded if they contained a blink (2.5% of trials) and their latencies were smaller than 80 ms or greater than 3 SD above the mean of each participant (6% of trials).

Data were analysed using ANOVAs and Bonferroni-corrected *t* tests. Moreover, Bayes factor scores (BF_{10}) were also computed. Indeed, BF_{10} scores can indicate which model (H0 vs. H1) is more likely supported by the data by calculating the ratio between the Bayesian probabilities of H1 against H0 (e.g., Jarosz and Wiley 2014; Wagenmakers 2007).

Saccadic directional errors

Saccadic directional errors (i.e., saccades performed in the opposite direction with respect to the target location) were low (1.1% of trials), and therefore, they were not analysed further.

Saccadic latencies

Mean saccadic latencies of correct saccade responses were submitted to a repeated-measures ANOVA with eyes (2: open vs. closed) and SOA (3: 100 vs. 500 vs. 900 ms) as within-participant factors. The main effect of SOA was significant, $F(2, 44) = 16.662$, $p < .001$, $\eta_p^2 = .431$, indicating that latencies were higher at the 100-ms SOA ($M = 239$ ms, SE = 10.3), halfway at the 500-ms SOA ($M = 215$ ms, SE = 7.1), and smaller at the 900-ms SOA ($M = 199$ ms, SE = 5.6), a result in line with the well-known foreperiod effect (e.g., Niemi and Näätänen 1981). No other significant results emerged ($Fs < 1$, $ps > .414$; see also Table 1).[1]

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[1] For completeness, Bonferroni-corrected *t* tests confirmed that no significant differences emerged between open vs. closed eyes at each SOA ($ts < 1.2$, $ps > .755$). Bayes Factor scores (BF_{10}) were also computed through JASP software (JASP Team 2017), in order to provide further support to this pattern. The results indicated that H1 (a difference between open and closed eyes) was never preferable over H0 (no difference between open and closed eyes) in any of these comparisons (all $BF_{10} < 1$).

Saccadic peak velocities

Mean saccadic peak velocities of correct saccade responses were submitted to a repeated-measures ANOVA with eyes (2: open vs. closed) and SOA (3: 100 vs. 500 vs. 900 ms) as within-participant factors. The eyes × SOA interaction was significant, $F(2, 44) = 3.407$, $p = .042$, $\eta_p^2 = .134$. No other significant results emerged ($Fs < 2.459$, $ps > .131$). To further explore the two-way interaction, Bonferroni-corrected *t* tests were performed. At the 100-ms SOA, a significant difference emerged, $t(22) = 2.692$, $p = .039$, $d = .561$, $BF_{10} = 3.864$, indicating that peak velocity was lower in the presence of a face with open eyes ($M = 347°/s$, SE = 9.4) than closed eyes ($M = 356°/s$, SE = 8.9). At the longer SOAs, no significant results emerged ($ts < 1$, $ps > .999$, $BF_{10}s < 1$; see also Fig. 2).

Discussion

Two main results emerged from Experiment 1. First, saccadic latencies in the presence of faces with open and closed eyes were—unexpectedly—virtually the same, an evidence also supported within a Bayesian framework. This result clearly does not help clarifying the available mixed
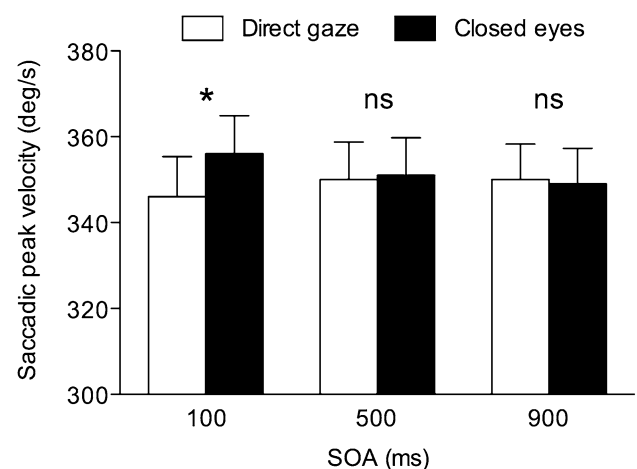
Fig. 2 Mean saccadic peak velocities, observed in Experiment 1, in the presence of faces with *direct gaze* and *closed eyes* as a function of SOA. *Asterisk* denotes $p < .05$; *ns* non-significant difference. *Error bars* are SEM

evidence stemming from studies using manual responses (i.e., Hietanen et al. 2016; Senju and Hasegawa 2005). Second, explorative analyses of saccadic peak velocities revealed that, at the 100-ms SOA, these were lower when participants performed a saccade away from a face with open eyes as compared to a face with closed eyes. This latter evidence seems to be complementary with previous studies that reported greater peak velocities for saccades executed from a central spot towards a peripheral facial stimulus (Xu-Wilson et al. 2009), which is exactly the opposite oculomotor behaviour as that requested in the present experiment.

In Experiment 2, two main changes were adopted to uncover attention holding for direct-gaze faces through saccadic latency analyses. First, we varied the social relevance of the facial stimuli by presenting participants with both open- and closed-eye faces of human as well as non-human primates. Indeed, there are both behavioural and electrophysiological evidences that human faces, as compared to non-human primate faces, are processed more efficiently by humans (e.g., de Haan et al. 2002; Mondloch et al. 2006; Pascalis et al. 2002), and these species-specific effects seem to be also reflected in oculomotor parameters (e.g., Conway et al. 2008). Second, all facial stimuli were submitted to a more rigorous procedure aimed to further attenuate any potential low-level perceptual confounds that could have interfered with the attention-holding mechanism in Experiment 1. In more detail, each face was made perfectly symmetrical and both luminosity and spatial frequency were matched among faces using a dedicated image-processing algorithm (see the method section of Experiment 2 for more details). Similar to Experiment 1, a greater attention-holding effect—inferred by comparing saccadic reaction times for open- and closed-eye faces—was expected for human rather than for non-human primate faces. Finally, saccadic peak velocities were analysed as well, to further explore the dynamics concerning this saccadic parameter.

Experiment 2: upright human and non-human primate faces

Methods

Participants

Twenty-six naïve students (Mean age = 23.03 years, SD = 1.4, 1 male) took part in the experiment. Their vision was normal or corrected to normal with lenses. The study was approved by the Ethics Committee for Psychological Research at the University of Padova and conducted in accordance with the Declaration of Helsinki. An informed consent was obtained from all participants.

Stimuli and apparatus

Human faces were the same as those employed in Experiment 1. Four coloured pictures of non-human primates (i.e., *Macaca mulatta*) were taken from the PrimFace database (http://visiome.neuroinf.jp/primface) and elliptically cropped. Furthermore, all stimuli were modified through a photo-editing procedure aimed to increase the control on their perceptual features. First, to eliminate any potential spatial asymmetry, the symmetrical version of each face was created by mirroring the right side of the face on the left side. Second, luminosity and spatial frequency were matched using the SHINE toolbox (Willenbockel et al. 2010) for Matlab, which also automatically converted pictures from full-colour to greyscale. Hence, participants were presented with greyscale facial pictures.

Eye movements were recorded in the same way as in Experiment 1.

Procedure

The procedure was identical to that used in Experiment 1, with the only exception that only two SOAs were employed (i.e., 100 and 500 ms; see Fig. 1), since in Experiment 1, the main results observed at the two longer SOAs (500 and 900 ms) were virtually identical. Each condition defined by eyes (open vs. closed), SOA (100 vs. 500 ms), and species (human vs. non-human primate) was presented for an equal number of times. A practice block composed of ten randomly selected trials was followed by four experimental blocks each composed of 120 randomly selected trials (i.e., 480 experimental trials in total; 60 trials for each combination of the three factors).

Results

Data handling

One participant did not complete the task due to difficulties in both calibration and tracking. The final sample was, therefore, composed of 25 participants (Mean age = 23.04 years, SD = 1.4, 1 male).

Saccades were extracted in the same way as in Experiment 1. Trials with blinks (1.5% of trials) and with latencies below 80 ms and 3 SD above the mean of each participant (5.4% of trials) were discarded from the analyses.

Data were analysed in the same way as in Experiment 1.

Saccadic errors

Saccadic directional errors were low (1.3% of trials), and therefore, they were not analysed further.
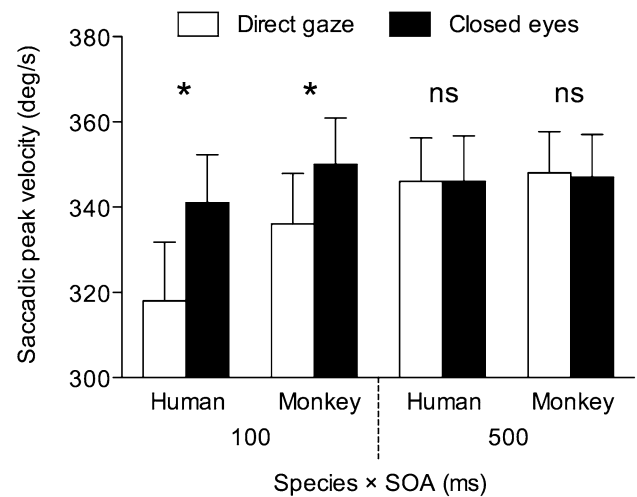
Saccadic latencies

Mean latencies of correct saccade responses were submitted to a repeated-measures ANOVA with eyes (2: open vs. closed), SOA (2: 100 vs. 500 ms), and species (2: human vs. non-human primate) as within-participant factors. The main effect of SOA was significant, $F(1, 24) = 8.337$, $p = .008$, $\eta_p^2 = .258$, due to higher latencies at the 100-ms SOA ($M = 203$ ms, SE = 7.6) than at the 500-ms SOA ($M = 189$ ms, SE = 5.9), as well as the main effect of species, $F(1, 24) = 15.616$, $p = .001$, $\eta_p^2 = .394$, due to higher latencies in the presence of non-human primates ($M = 199$ ms, SE = 6.3) than to human faces ($M = 193$ ms, SE = 6.4). The eyes × SOA × species interaction was also significant, $F(1, 24) = 9.049$, $p = .006$, $\eta_p^2 = .274$. No other significant results emerged ($Fs < 1.054$, $ps > .315$). The significant three-way interaction was further explored through Bonferroni-corrected *t* tests. At the 500-ms SOA, a significant difference was observed for human faces, $t(24) = 2.951$, $p = .028$, $d = .590$, $BF_{10} = 6.482$, indicating that latency was higher in the presence of a face with open eyes ($M = 189$ ms, SE = 6.1) than closed eyes ($M = 185$ ms, SE = 6). No other significant results emerged ($ts < 1.950$, $ps > .251$, $BF_{10}s < 1$; see also Table 2).

Saccadic peak velocities

Mean peak velocities of correct saccade responses were submitted to a repeated-measures ANOVA with eyes (2: open vs. closed), SOA (2: 100 vs. 500 ms), and species (2: human vs. non-human primate) as within-participant factors. The main effect of eyes was significant, $F(1, 24) = 16.360$, $p < .001$, $\eta_p^2 = .405$, due to a lower peak velocity in the presence of a face with open eyes ($M = 337°/s$, SE = 10.8) than closed eyes ($M = 346°/s$, SE = 10.5). The main effect of species was also significant, $F(1, 24) = 10.268$, $p = .004$, $\eta_p^2 = .300$, due a lower peak velocity in the presence of human faces ($M = 338°/s$, SE = 11) than to non-human primate faces ($M = 345°/s$, SE = 10.3). The species × SOA interaction was significant, $F(1, 24) = 11.016$, $p = .003$, $\eta_p^2 = .315$, and more importantly, also the eyes × SOA interaction was significant, $F(1, 24) = 18.359$, $p < .001$, $\eta_p^2 = .433$. No other significant results emerged ($Fs < 4.081$, $ps > .055$).[2] The latter two-way interaction was further explored through Bonferroni-corrected *t* tests. A significant effect emerged at the 100-ms SOA, $t(24) = 4.393$, $p < .001$, $d = .879$, $BF_{10} = 147.961$, indicating that peak velocity was

Fig. 3 Mean saccadic peak velocities, observed in Experiment 2, in the presence of faces with *direct gaze* and *closed eyes* as a function of SOA and species. *Asterisks* denote $p < .05$; *ns* non-significant difference. *Error bars* are SEM

lower in the presence of a face with open eyes ($M = 327°/s$, SE = 12.6) than closed eyes ($M = 345°/s$, SE = 11). At the 500-ms SOA, no differences emerged in the presence of direct-gaze faces ($M = 347°/s$, SE = 9.9) and closed-eye faces ($M = 347°/s$, SE = 10.3; $t(24) = .067$, $p = .999$, $d = .013$, $BF_{10} < 1$).[3]

Discussion

In this second experiment, while no significant differences emerged in saccadic latencies when participants were presented with non-human faces, a significant effect was observed for human faces. In more detail, at the 500-ms SOA, but not at the 100-ms SOA, latencies were significantly lower for closed-eye faces as compared to direct-gaze faces, an evidence in line with Senju and Hasegawa (2005) and with the view that direct-gaze human faces can hold attention.

As for saccadic peak velocity, the analyses led to a pattern of results which closely resembled that reported in Experiment 1. Indeed, lower peak velocities emerged

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[2] For completeness, we report here that the main effect of SOA approached significance, $F(1, 24) = 4.081$, $p = .055$, $\eta_p^2 = .145$, in line with a foreperiod effect.

[3] Even if the eyes × SOA × species interaction was non-significant, $F(1, 24) = 2.306$, $p = .142$, $\eta_p^2 = .088$, for completeness Bonferroni-corrected *t* tests were also carried out. The only significant results emerged at the 100-ms SOA, indicating that peak velocity was smaller in the presence of a face with open eyes than closed eyes, for both humans, $t(24) = 4.282$, $p = .001$, $d = .858$, $BF_{10} = 116.893$, and non-human primate faces, $t(24) = 3.057$, $p = .02$, $d = .611$, $BF_{10} = 8.042$. No other significant results emerged ($ts < 1$, $ps > .999$, $BF_{10}s < 1$; see also Fig. 3).

at the 100-ms SOA when participants moved their eyes from a direct-gaze face as compared to a face with closed eyes, irrespective of the species of the facial stimulus. Although the effect of direct gaze was not modulated by species, as it might have been expected on the basis of the documented greater sensitivity of human observers to human faces (e.g., de Haan et al. 2002; Mondloch et al. 2006; Pascalis et al. 2002), this latter factor led to a significant main effect, with lower peak velocities in the presence of human faces, in line with the idea that smaller velocities can emerge when individuals have to perform a saccade away from a comparatively more relevant social stimulus. Nevertheless, the lack of a modulatory role of species on attention holding for direct-gaze vs. closed-eye faces is quite surprising. Intriguingly, some recent evidence observed comparable attention shifts in human adults in response to cues provided by both human and non-human primate pictures (Hattori et al. 2010; Kano and Call 2014), while infants responded only to human cues (Kano and Call 2014). Hence, it seems plausible that a higher degree of face processing skills—as typically possessed by adults—could predispose individuals to respond to a wider range of facial stimuli, including non-human primate faces. The same rationale could also be applied to the present context, since only human adults were tested. To sum up, in Experiment 1, exploratory analyses were performed on saccadic peak velocities and Experiment 2 provided converging evidence suggesting the possibility to employ peak velocity as a reliable index to uncover the impact of direct-gaze stimuli on saccadic eye movements.

In Experiment 3, we decided to compare saccadic eye movements in the presence of upright vs. inverted (i.e., rotated 180°) human faces. This choice was made to take advantage of two opportunities provided by the combined use of both upright and inverted faces. First, several studies reported that face inversion can impair both face processing (for a review, see Maurer et al. 2002) and attention mechanisms (e.g., Senju et al. 2008). Therefore, it could be predicted that any effect of direct gaze would be disrupted or at least reduced in the presence of inverted faces. Second, inverted faces are perfect control stimuli, because participants are presented with the same perceptual stimulation in both conditions (i.e., upright vs. inverted faces). This approach could, therefore, provide a solid piece of evidence that the expected differences between faces with open and closed eyes, if any, could be attributed to social attention mechanisms rather than to mere low-level perceptual differences between the two stimuli (e.g., the presence vs. the absence of both pupil and sclera). Importantly, the potential role of low-level confounds was also controlled by employing the same human faces used in Experiment 2 (i.e., faces perfectly symmetrical and matched for both luminosity and spatial frequency).

In relation with saccadic latencies, the goal was to further test whether a reliable pattern, if any, would emerge as a function of the open vs. closed eyes of the presented stimuli. As for saccadic peak velocities, on the basis of both Experiments 1 and 2, at the 100-ms SOA, we predicted lower velocities in the presence of direct-gaze faces, especially when faces were presented upright rather than inverted.

Experiment 3: upright and inverted human faces

Methods

Participants

Twenty-six naïve students (Mean age = 22.77 years, SD = 1.31, 1 male) took part in the experiment. Their vision was normal or corrected to normal with lens. The study was approved by the Ethics Committee for Psychological Research at the University of Padova and conducted in accordance with the Declaration of Helsinki. An informed consent was obtained from all participants.

Stimuli and apparatus

Stimuli were the human faces employed in Experiment 2 with only one exception: For each face, there were two versions, namely, one in which the face was presented upright and another one in which the face was rotated 180°. Each condition defined by eyes (open vs. closed), SOA (100 vs. 500 ms), and face orientation (upright vs. inverted) was presented for an equal number of times. A practice block composed of ten randomly-selected trials was followed by four experimental blocks each composed of 120 randomly selected trials (i.e., 480 experimental trials in total; 60 trials for each combination of the three factors).

Eye movements were recorded in the same way as in the previous experiments.

Procedure

The procedure was identical to that employed in Experiment 2 (see Fig. 1). There was only one exception: Contrary to both Experiments 1 and 2, here, faces were perfectly centred on the screen, namely, the area occupied by facial stimuli was exactly the same both in the upper and in the lower part of the screen. This was done to avoid any perceptual differences due to face rotation.

Results

Data handling

Saccades were extracted in the same way as in previous experiments. Trials with blinks (1.7% of trials) and with latencies below 80 ms and 3 SD above the mean of each participant (4.3% of trials) were discarded from the analyses.

Data were analysed in the same way as in previous experiments.

Saccadic errors

Saccadic directional errors were low (1.1% of trials), and therefore, they were not analysed further.
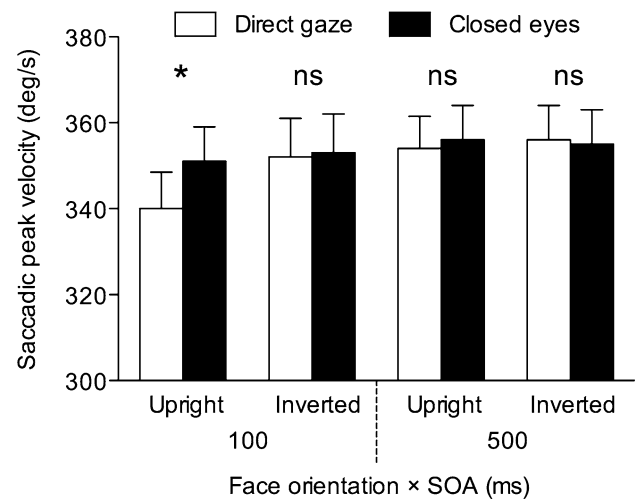
Saccadic latencies

Mean latencies of correct saccade responses were submitted to a repeated-measures ANOVA with eyes (2: open vs. closed), SOA (2: 100 vs. 500 ms), and face orientation (2: upright vs. inverted) as within-participant factors. The main effect of SOA was significant, $F(1, 25) = 20.351$, $p = .001$, $\eta_p^2 = .449$, due to higher latencies at the 100-ms SOA ($M = 221$ ms, SE = 9.4) than at the 500-ms SOA ($M = 190$ ms, SE = 5.5). No other significant results emerged ($Fs < 2.422$, $ps > .132$; see also Table 3).[4]

Saccadic peak velocities

Mean peak velocities of correct saccade responses were submitted to a repeated-measures ANOVA with eyes (2: open vs. closed), SOA (2: 100 vs. 500 ms), and face orientation (2: upright vs. inverted) as within-participant factors. The eyes × face orientation interaction was significant, $F(1, 25) = 4.534$, $p = .043$, $\eta_p^2 = .154$. No other significant results emerged ($Fs < 3.374$, $ps > .078$).[5] The significant two-way interaction was further explored through t tests.

Fig. 4 Mean saccadic peak velocities, observed in Experiment 3, in the presence of *direct gaze* and *closed eyes* as a function of SOA and face orientation. *Asterisk* denotes $p < .05$; *ns* non-significant difference. *Error bars* are SEM

The only significant result emerged for the upright faces, $t(25) = 2.279$, $p = .031$, $d = .447$, $BF_{10} = 1.832$, due to slower peak velocity in the presence of a face with open eyes ($M = 347°/s$, SE = 7.2) than closed eyes ($M = 353°/s$, SE = 7.9). For inverted faces, the comparison was non-significant, $t(25) = .136$, $p = .893$, $d = .027$, $BF_{10} < 1$, as virtually the same velocity emerged in the presence of both open eyes ($M = 354°/s$, SE = 8.2) and closed eyes ($M = 354°/s$, SE = 8.5).[6]

Discussion

Experiment 3 provided both a replication and an extension of the pattern of results reported in the previous experiments. First, in line with Experiment 1, saccadic latencies were virtually identical in the presence of both faces with open and closed eyes, and no difference also emerged between upright and inverted faces. Second, consistent with both Experiments 1 and 2, at the 100-ms SOA, saccadic peak velocities were lower for direct-gaze faces as compared to closed-eye faces, and this difference emerged only when faces were presented upright rather than inverted.

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[4] For completeness, t tests were performed between open and closed eyes for each face orientation and at each SOA. No significant results emerged ($ts < 1.049$, $ps > .304$, $BF_{10}s < 1$). Because we hypothesized a null effect in the case of inverted faces, no Bonferroni correction was applied as this would have resulted in an increased likelihood of detecting exactly such null effect. In so doing, we followed a more conservative approach.

[5] For completeness, we report here that the main effect of eyes approached significance, $F(1, 25) = 3.374$, $p = .078$, $\eta_p^2 = .119$, suggesting a trend towards lower velocities in the presence of faces with open eyes than closed eyes. The main effect of face orientation also approached significance, $F(1, 25) = 3.037$, $p = .094$, $\eta_p^2 = .108$, suggesting a trend towards lower velocities in the presence of upright faces than inverted faces.

[6] Even if the eyes × SOA × face orientation interaction was non-significant, $F(1, 25) = 2.161$, $p = .154$, $\eta_p^2 = .080$, for completeness t tests were conducted. The only significant result emerged at the 100-ms SOA for upright faces, $t(25) = 2.451$, $p = .022$, $d = .481$, $BF_{10} = 2.490$, indicating that peak velocity was smaller in the presence of a face with open eyes than closed eyes. No other comparisons were significant ($ts < 1$, $ps > .475$, $BF_{10}s < 1$; see also Fig. 4).

Table 2 Mean saccadic reaction times (SRTs), observed in Experiment 2, in response to faces with direct gaze and closed eyes as a function of SOA and species

	100-ms SOA				500-ms SOA			
	Human		Non-human		Human		Non-human	
	Direct gaze	Closed eyes	Direct gaze	Closed eyes	Direct gaze	Closed eyes	Direct gaze	Closed eyes
SRTs (ms)	197	202	209	205	189	185	190	191
SE	7.88	7.96	7.9	7.5	6.07	6.02	5.96	6.09

SE standard error

Table 3 Mean saccadic reaction times (SRTs), observed in Experiment 3, in response to faces with direct gaze and closed eyes as a function of SOA and face orientation

	100-ms SOA				500-ms SOA			
	Upright		Inverted		Upright		Inverted	
	Direct gaze	Closed eyes	Direct gaze	Closed eyes	Direct gaze	Closed eyes	Direct gaze	Closed eyes
SRTs (ms)	220	223	220	222	189	190	191	191
SE	9.56	9.39	9.24	9.89	5.71	5.62	5.52	5. 8 3

SE standard error

The comparison between upright and inverted faces was important to rule out the role of potential low-level perceptual confounds in shaping the results of the previous experiments. Indeed, in both Experiments 1 and 2, it was not possible to exclude that the significant results were affected by the presence of both pupils and sclera in the case of open-eye faces, but not in the case of closed-eye faces. However, here, we observed that the differences in saccadic peak velocities, detected when faces were presented upright, completely disappeared when participants were presented with exactly the same visual stimuli rotated of 180°. This evidence aligns with the bulk of studies that showed that a simple rotation of the facial stimuli can strongly interfere with face processing mechanisms (see Maurer et al. 2002) and suggests that our results are likely due to genuine social attention mechanisms.

General discussion

The aim of the present study was to address whether eye contact can hold overt attention in an observer. To reach this goal, in three experiments, we employed a modified version of the paradigm devised by Senju and Hasegawa (2005), who recorded manual responses to a symbolic target in the presence of a centrally placed face with either a direct-gaze or not. In the present study, instead of manual responses, participants had to perform rightwards or leftwards saccades towards a symbolic target. Overall, lower latencies were expected when participants were presented with direct-gaze faces as compared to closed-eye faces, in line with the idea that

direct-gaze stimuli can hold attention in an observer. However, in both Experiments 1 (upright human faces) and 3 (upright vs. inverted human faces), saccadic latency analyses did not lead to any significant result as concerns the attention-holding effect exerted by direct-gaze faces, and the adoption of a Bayesian framework further indicated that the null hypothesis was more supported by the available evidence. However, in Experiment 2, higher latencies emerged at the 500-ms SOA in response to human faces with direct-gaze as compared to human faces with closed eyes, a pattern that aligns with the notion that direct-gaze stimuli can hold attention in an observer. The present set of experiments seems to suggest that when only human faces were presented (Experiments 1 and 3), saccadic latencies were not able to reveal attention holding for direct-gaze stimuli. When human faces were presented intermixed with non-human primate faces (Experiment 2), a difference between direct-gaze faces and closed-eye faces emerged. Even so, the overall picture stemming from the present experiments does not seem to highlight any unambiguous and systematic pattern of findings about the effects of direct gaze at the level of saccadic latencies. Nevertheless, it is important to remark that a straightforward comparison with the study of Senju and Hasegawa (2005) cannot be carried out because of the differences involving both stimuli and the procedural aspects we have employed. Future studies are, therefore, needed to further explore the relationship between the attention-holding effect and overt orienting as assessed through saccadic latency analyses.

Contrarily to saccadic latencies, a significant difference between direct-gaze faces and closed-eye faces consistently emerged in saccadic peak velocity analyses. Indeed,

direct-gaze faces led to slower peak velocities as compared to closed-eye faces (Experiment 1), an effect that emerged also in the presence of non-human primate faces (Experiment 2) and that disappeared when the face was presented inverted (i.e., 180° rotated) rather than upright (Experiment 3). Importantly, the difference between open- and closed-eye faces on peak velocities emerged only at the 100-ms SOA, which is consistent with the idea that when a longer time interval occurs between the onset of the central face and the onset of the target, the features of the face no longer affect peak velocities, because they are task-irrelevant and their processing likely decays with time (see also Dalmaso et al. 2014; Jones et al. 2010).

This overall pattern of results, though unexpected, seems to be complementary with what reported in a previous study that found greater peak velocities when saccades were performed from a central symbolic spot to a peripheral face (Xu-Wilson et al. 2009), that is exactly the opposite oculomotor behaviour as that requested in the present study. Intriguingly, Xu-Wilson et al. (2009) pushed forward the idea that the link between facial stimuli and peak velocity could be associated with the reward system. Indeed, studies conducted both on human (Montagnini and Chelazzi 2005) and non-human primates (Takikawa et al. 2002) reported higher saccadic velocities towards peripheral targets associated with a reward (e.g., food or a positive feedback). Moreover, there is neuroimaging evidence of a greater activation of the reward system in response to direct-gaze faces as compared to averted-gaze faces (Kampe et al. 2001). Hence, variations in saccadic peak velocities could be the expression of a mechanism devoted to the processing of rewarding stimuli, such as human faces. At the neural level, this mechanism could involve the basal ganglia, which are known to shape saccades in response to reward signals through inhibitory connections towards the Superior Colliculus (SC; e.g., Hikosaka et al. 2006), a subcortical structure highly implicated in saccade generation (e.g., Lee et al. 1988). Hence, it seems plausible that basal ganglia activity in the presence of a direct-gaze face may have reduced the predisposition to perform a saccade—reflected in lower peak velocities—because that implied removing the eyes from a more relevant stimulus as compared to a closed-eye face. Moreover, according to some studies, saccadic peak velocity would be mainly modulated by SC activity (e.g., Segraves and Park 1993; Sommer and Tehovnik 1997), while saccadic latency would also be influenced by the activity in some cortical regions such as the frontal eye fields (e.g., Everling and Munoz 2000; Quaia et al. 1999). Hence, this hypothesized involvement of different neural regions could tentatively explain the dissociation that emerged in the present set of studies between these oculomotor metrics. Furthermore, it is important to note that, as mentioned in the introduction, also some previous studies reported divergent results

between peak velocity and latency analyses (e.g., Edelman et al. 2006; Fimm and Blankenheim 2016; Ramchandran et al. 2004; Xu-Wilson et al. 2009), strengthening the view that these two saccadic parameters could, at least partially, reflect the operation of different mechanisms. Interestingly, according to a recent theoretical framework, saccadic peak velocity could also be linked to autonomic activation, but this would be particularly evident in ergonomics and naturalistic settings in which, for instance, individuals perform everyday activities (e.g., driving; Di Stasi et al. 2013). Overall, the present set of experiments invites to consider saccadic peak velocity as a parameter that could work together with saccadic latency and accuracy to uncover attention mechanisms in social contexts.

During the last decades, a flourishing literature has investigated the effect of eye-gaze direction on attention mechanisms (e.g., Böckler et al. 2014; Senju and Hasegawa 2005; for a review see Frischen et al. 2007). Intriguingly, direct-gaze faces have been shown to modulate other cognitive mechanisms. For instance, direct-gaze faces, as compared to averted-gaze faces, are better encoded in memory (e.g., Mason et al. 2004; Sessa and Dalmaso 2016) and facilitate social categorization (e.g., Macrae et al. 2002). To account for the special salience of direct-gaze stimuli, Senju and Johnson (2009) proposed the "fast-track modulator" model, according to which perceived eye contact with another individual would be first processed by a fast-subcortical pathway—formed by the SC, pulvinar, and amygdala—and then the acquired information would be passed to a broader social brain network involved in face and gaze processing, as well as in evaluating emotions and intentions (the "eye contact" effect; see also Conty et al. 2016; Hamilton 2016; Johnson et al. 2015). The present data observed for saccadic peak velocity seem to be consistent with the view that direct-gaze faces are processed in a rapid and prioritized manner. This peculiar processing of direct-gaze faces could be aligned with the potential involvement of the subcortical pathway proposed by Senju and Johnson (2009). However, the lack of a significant pattern of results in saccadic latency analyses invites caution.

To conclude, in three experiments, we observed lower saccadic peak velocities in the presence of faces with open rather than closed eyes, while saccadic latency analyses led to less consistent results. Overall, this work could provide new insights concerning the impact of eye contact on oculomotor dynamics and invites to consider saccadic peak velocities as an index to uncover attention mechanisms in social contexts. Nevertheless, additional studies are necessary to further explore the link between attention holding for eye-gaze stimuli and oculomotor dynamics. This could be done through paradigms that employ gaze-based interactions with pictorial faces and avatars (for reviews, see Hamilton 2016; Pfeiffer et al. 2013; see also Dalmaso et al. 2016; Edwards et al. 2015; Pfeiffer et al. 2012; Vernetti et al. 2017) or even

with live confederates (see Cole et al. 2016; Hietanen et al. 2016; Lachat et al. 2012), to increase the ecological validity which is crucial for a full comprehension of social attention abilities (see Risko et al. 2016).

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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