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Trajectories of social vision: Eye contact increases saccadic curvature

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ABSTRACT
Saccades are known to deviate away from distractors, and the amplitude of this deviation seems to reflect the salience of these stimuli, as in the case of human faces. Here, we investigated whether eye contact can modulate attention allocation by examining saccadic curvature when faces with closed vs. open eyes act as distractors. In two experiments, participants were asked to perform a vertical saccade towards a symbolic target. At the same time, task-irrelevant faces with open or closed eyes (Experiments 1 and 2) and scrambled faces (Experiment 2) could appear leftwards or rightwards with respect to the ideal trajectory towards the target. Overall, a greater saccadic curvature was observed in response to faces with open eyes, as compared to the other two conditions. These results confirm that eye contact plays an important role in shaping attentional mechanisms and provide further evidence concerning the link between social vision and eye movements.

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Visual attention is deeply modulated by social stimuli (e.g., Frischen, Bayliss, & Tipper, 2007; Sui & Humphreys, 2016). For instance, averted-gaze stimuli can elicit both covert (e.g., Driver et al., 1999) and overt (e.g., Kuhn & Benson, 2007) orienting, whose magnitude is sensitive to the social salience of these stimuli (e.g., Bayliss, Schuch, & Tipper, 2010; Dalmaso, Galfano, & Castelli, 2015). On the other hand, it is known that direct-gaze stimuli can impact onto several cognitive and attentional mechanisms (i.e., the "eye contact effect"; Senju & Johnson, 2009). In this regard, behavioural studies showed that direct-gaze stimuli capture attention in both infants (e.g., Farroni, Csibra, Simion, & Johnson, 2002) and adults (e.g., Böckler, van der Wel, & Welsh, 2014; Senju & Hasegawa, 2005; see also Hietanen, Myllyneva, Helminen, & Lyyra, 2016), and atypical eye contact effects have been reported in clinical populations (e.g., autism; Senju, Yaguchi, Tojo, & Hasegawa, 2003).

Here, we focused on the potential effects of eye contact on saccadic trajectories. Saccades provide a variety of information concerning ongoing cognitive mechanisms and, importantly, they represent a direct measure of attention allocation over space. In particular, it is known that saccades curve away from covertly attended locations (e.g., Sheliga, Riggio, & Rizzolatti, 1995). Interestingly, saccades curve away even from visual distractors (e.g., Doyle & Walker, 2001), and the magnitude of such curvature is shaped by the salience of the distractor. For instance, greater curvatures have been observed when target and distractor are similar (e.g., Ludwig & Gilchrist, 2003). Curvatures away from distractors are typically explained in terms of inhibitory mechanisms. When a saccade is required towards a certain location but a task-irrelevant object is presented in the visual field, it is necessary to inhibit the spatial location occupied by the distractor-object. This inhibitory processing, in turn, would cause an imbalance in the programming of the saccade, leading to a curved trajectory (Van der Stigchel, 2010). According to this view, the greater the salience of the distractor, the greater the inhibition required and, in turn, the greater the reported curvature. Moreover, evidence suggested that curvatures away from distractors are more likely at relatively long saccadic latencies, while at short latencies saccades would tend to deviate towards the distractors (e.g., Walker, McSorley, & Haggard, 2006). So far, most of the studies concerning saccadic curvature employed symbolic distractors (Van der Stigchel, 2010). Much less is known about the impact of social distractors. The few studies on this topic reported greater curvatures in the presence of upright faces as compared to both scrambled faces (Laidlaw,

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Badiudeen, Zhu, & Kingstone, 2015) and inverted faces (Qian, Gao, & Wang, 2015), and when upright faces carried relevant emotional information (Petrova & Wentura, 2012; Schmidt, Belopolsky, & Theeuwes, 2012).

Here, two experiments investigated the impact of eye contact on saccadic curvature. In Experiment 1, participants performed vertical saccades towards a symbolic target that could appear in either the upper or the lower visual hemifield. At the same time, a peripheral task-irrelevant face, with either open or closed eyes, could also appear close to the target. In Experiment 2, the same procedure was adopted, but scrambled faces were also added as control stimuli. If faces with open eyes do capture attention more strongly, as compared to both faces with closed eyes and scrambled faces, they should also elicit larger saccadic curvatures, in line with the so called "eye contact effect".

Experiment 1

Method

Participants

Twenty-two undergraduates (mean age = 24.8 years, *SD* = 5.13, four male) participated.

Apparatus

An EyeLink 1000-Plus (SR Research) recorded eye movements (1000 Hz, monocular). A chinrest was placed 65 cm away from a 24-inch monitor (1280 × 1024 pixels, 120 Hz). Experiment Builder (SR Research) handled timing and stimulus presentation.

Stimuli and procedure

Coloured pictures of faces of four adults (two males) were used. There were two versions for each face: one with open eyes and one with closed eyes. Stimuli were elliptically cropped (distracting elements such as hair and ears were removed) and matched for luminance (100 cd/m^2; OptiCAL luminance metre device, Cambridge Research Systems), to eliminate potential low-level confounds.

Colour background was grey. Each session started with a nine-point calibration followed by a validation procedure. Before each trial, participants fixated a central black circle (diameter: 0.5°) and then the trial was initiated by the experimenter through the host PC. This procedure ensured that participants fixated the centre of the screen and allowed us to perform a drift checking (Figure 1). A successful drift checking was accompanied by a brief tone that informed the participant of the imminent start of the trial. Each trial started with a central black circle (diameter: 0.5°). The trial continued only if participants fixated this spot for a variable duration of 800–1300 ms (100 ms steps), assessed through a gaze-contingent trigger (diameter of the invisible boundary: 2°). This procedure ensured that participants continued to maintain their eyes at fixation. On 80% of the trials, a distractor face (3.9° width × 5° height) appeared in one of the four corners of a virtual square (side: 14°) centred on the fixational spot. The distractor face was centred around the vertex of one of these corners. On the remaining 20% of the trials, no distractor face appeared. After either 0 or 100 ms (i.e., Stimulus Onset Asynchrony, SOA), a black target cross (side:

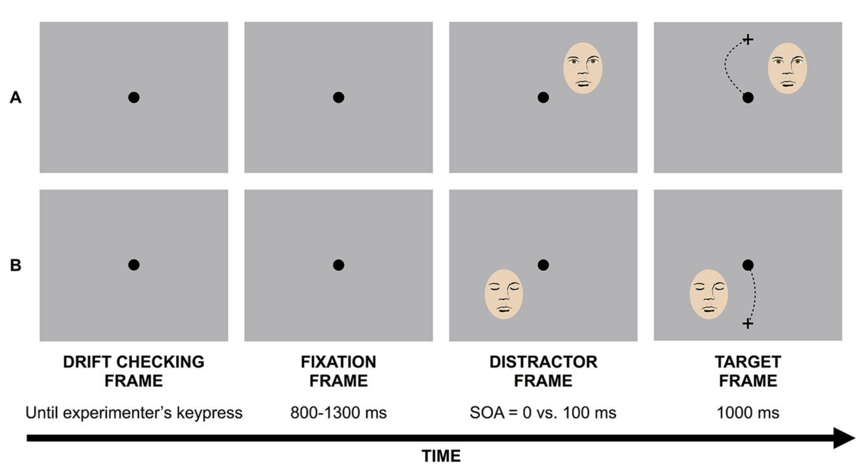

Figure 1. Illustration of stimuli (not drawn to scale) and events employed in both experiments. Schematic faces with (A) open and (B) closed eyes are depicted. Dotted lines show hypothetical saccadic curvatures.

0.6°) appeared 9° above or below the fixation spot, and always in the same (upper vs. lower) hemifield as the distractor face, if any. More specifically, at the 0 ms SOA, both the distractor face and the target appeared simultaneously while, at the 100 ms SOA, the distractor face appeared 100 ms before the target. Two different SOAs between distractor and target were employed to explore the time course of the "eye contact effect" on saccadic trajectories. The mechanisms that promote curvature away from the distractor are known to require time to emerge (Walker et al., 2006). We expected that the impact of our manipulation on saccadic curvatures would be more likely detected at the longer SOA, but we also included a 0 ms SOA to test the extent to which the hypothesized modulation exerted by the eye-contact effect was early rising. Participants were asked to maintain fixation on the central spot until target onset and, after that, to make a saccade towards the target as fast and accurately as possible. They were also asked to ignore the distractor face, if any, as it was completely irrelevant for the task. After 1000 ms, the trial ended. Ten practice trials were followed by 480 randomly-selected experimental trials divided into three blocks.

Finally, given the potential link between autism and eye-gaze processing (see Senju et al., 2003), the Autism-spectrum Quotient (AQ) was also administered (Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001). An AQ score greater than 32 (i.e., within the clinical range) would have excluded the participant from the analyses. The whole experiment lasted about an hour.

Results and discussion

Data handling

Eye movements with a velocity and acceleration exceeding 30°/sec and 8000°/sec^2, respectively, were classified as saccades. On each trial, we extracted the first saccade performed after target onset. Similar to previous studies (e.g., Doyle & Walker, 2001; Laidlaw et al., 2015), saccades with blinks (2.5%), latencies outside the 100–500 ms range (9.3%), and amplitudes outside the 6–12° range (5.9%) were discarded. Directional errors, namely saccades that landed within the area occupied by the distractor (see Stimuli and procedure for more detail about the spatial properties of the distractor), were rare (0.3%) and not further analysed.

Saccadic curvature was computed using the curve-fitting method proposed by Ludwig and Gilchrist (2002). In more detail, a quadratic polynomial was fitted on normalized saccades and then the quadratic coefficients were extracted as a measure of saccadic curvature. Negative and positive values (in degrees of visual angle) were assigned to saccades deviating away from and towards the distractor, respectively.

Mean saccadic latencies and curvatures of distractor-present trials were analysed through two identical repeated-measures ANOVAs with Face (open vs. closed eyes) and SOA (0 vs 100 ms) as within-participant factors. Furthermore, because some evidence suggests that faces could exert an influence on saccadic curvature especially at long Saccadic Reaction Times (SRTs; see Laidlaw et al., 2015; Qian et al., 2015), SRT Bin (1 vs. 2 vs. 3) was also included as within-participant factor. Each Bin, calculated separately for each participant and experimental condition (i.e., Face, SOA), contained one-third of the trials, and ranged from the fastest (Bin 1) to the slowest (Bin 3) SRT. Tertiles were chosen in order to ensure enough observations in each Bin. Distractor-absent trials were analysed separately through *t*-tests comparing responses as a function of SOA.

No participant was excluded based on AQ scores (range: 5–26; mean = 16, *SD* = 5.8).

Saccadic reaction times

The main effect of SOA was significant, $F(1, 21) = 261.168$, $p < .001$, $\eta_p^2 = .926$, due to shorter SRTs at the 100 ms ($M = 191$ ms, SE = 7.2) than at the 0 ms SOA ($M = 241$ ms, SE = 6.6), likely reflecting a foreperiod effect, as well as the main effect of bin, $F(2, 42) = 258.039$, $p < .001$, $\eta_p^2 = .925$. The main effect of Face approached significance, $F(1, 21) = 3.138$, $p = .091$, $\eta_p^2 = .130$, reflecting shorter SRTs for faces with open ($M = 215$ ms, SE = 6.6) than closed ($M = 217$ ms, SE = 7) eyes. No other significant results emerged (*F*s < 1.332, *p*s $> .275$; see Table 1). In distractor-absent

Table 1. Mean SRTs (ms) as a function of face (Open vs. Closed eyes), SOA (0 vs. 100 ms) and Bin (1 vs. 2 vs. 3).

	0 ms SOA			100 ms SOA		
Face	Bin 1	Bin 2	Bin 3	Bin 1	Bin 2	Bin 3
Open	184.4 (24.15)	233.0 (34.92)	300.1 (46.29)	137.4 (18.56)	179.4 (34.62)	253.1 (47.41)
Closed	188.5 (21.48)	235.4 (34.85)	303.0 (43.71)	141.1 (23.12)	181.3 (37.01)	253.2 (50.66)

Values in parentheses are SEM.

trials the main effect of SOA was significant, $t(21) = 2.819$, $p = .01$, $d = .601$, due to shorter SRTs at the 100 ms SOA ($M = 256$ ms, SE = 7) than at the 0 ms SOA ($M = 264$ ms, SE = 7.5).

Saccadic curvatures

The main effect of SOA was significant, $F(1, 21) = 25.441$, $p < .001$, $\eta_p^2 = .548$, due to greater curvatures at the longer than at the shorter SOA, as well as the main effect of Bin, $F(2, 42) = 6.401$, $p = .004$, $\eta_p^2 = .234$, as saccadic curvatures increased with Bin. The SOA × Bin interaction approached significance, $F(2, 42) = 3.212$, $p = .05$, $\eta_p^2 = .133$. More importantly, the main effect of Face was significant, $F(1, 21) = 6.251$, $p = .021$, $\eta_p^2 = .229$. In line with the hypothesis, a larger saccadic curvature emerged in response to faces with open eyes ($M = -.168°$, SE = .0319) as compared to faces with closed eyes ($M = -.15°$, SE = .0293). Neither the Face × Bin nor the Face × Bin × SOA interactions were significant ($Fs < 1$, $ps > .515$). No other significant results emerged ($Fs < 1.425$, $ps > .252$; Figure 2). Moreover, no significant results emerged from correlational analyses between AQ scores and the magnitude of saccadic curvatures for the faces (false discovery rate (fdr) corrected $ps > .5$). Finally, in distractor-absent trials no significant result emerged ($p = .4$).

Overall, the main results of Experiment 1 are in line with the "eye contact effect". The larger curvature reported in response to faces with open eyes can be interpreted as the consequence of the greater attentional capture likely exerted by these social stimuli. In Experiment 2, we aimed to replicate this pattern of results and scrambled faces were also included as control stimuli. Indeed, scrambled faces maintain all the low-level properties of the original facial stimuli, but lack social relevance. Hence, we expected to observe a reduced saccadic curvature in response to scrambled faces as compared to both open and closed eyes.

Experiment 2

Method

Participants

Thirty-two undergraduates (mean age = 20.7 years, $SD = 3.89$, 11 male) participated.

Apparatus, stimuli and procedure

These were nearly identical to Experiment 1, the only exception being that scrambled versions of each face were also included as control stimuli. Scrambled faces were created with a dedicated algorithm (http://telegraphics.com.au/sw/product/scramble) devised for Adobe Photoshop CS6 for Mac. Face was included as a three-levels factor in the analyses (open eyes vs. closed eyes vs. scrambled faces). Overall, 480 experimental trials were administered.

Results and discussion

Data handling

Both trial exclusion procedure (blinks: 1.2%; latencies: 9.5%; amplitudes: 6%) and analyses were identical to Experiment 1. Saccades that landed on the area occupied by the distractor were rare (0.2%) and not

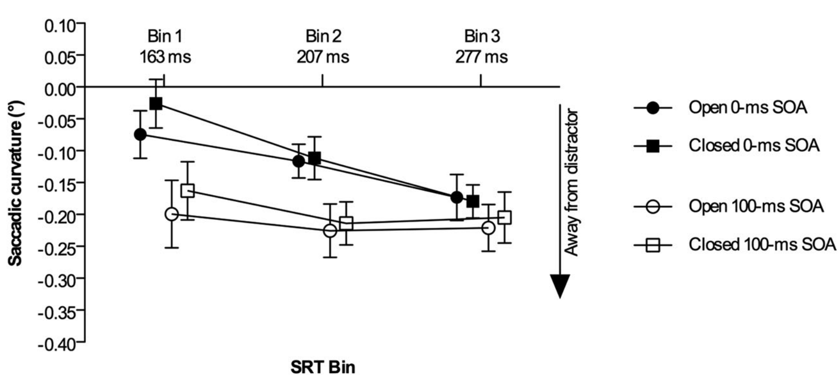

Figure 2. Mean saccadic curvatures (degrees of visual angle) as a function of SRT Bin (1 vs. 2 vs. 3), Face (Open vs. Closed eyes) and SOA (0 vs. 100 ms) in Experiment 1. Error bars are SEM. The SRT value associated with each Bin has been calculated as the average across the different experimental conditions for illustrative purposes, although it should be remembered that in the analyses each Bin was calculated separately for each participant and experimental condition.

analysed further. Data of scrambled faces generated from open- and closed-eyes faces were collapsed as no difference among these stimuli emerged in preliminary analyses.

No participant was excluded based on AQ scores (range: 6–24; mean = 15, $SD = 4.5$).

Saccadic reaction times

The main effect of SOA was significant, $F(1, 31) = 673.423$, $p < .001$, $\eta_p^2 = .956$, due to shorter SRTs at the 100 ms ($M = 189$ ms, SE = 5.8) than at the 0 ms SOA ($M = 241$ ms, SE = 6.2), as well as the main effect of Bin, $F(2, 62) = 530.271$, $p < .001$, $\eta_p^2 = .945$, and the SOA × Bin interaction $F(2, 62) = 4.287$, $p = .018$, $\eta_p^2 = .121$. No other significant results emerged ($Fs < 1$, $ps > .573$; see Table 2). In distractor-absent trials no significant result emerged ($p = .1$; 0 ms SOA: $M = 258$ ms SE = 6; 100 ms SOA: $M = 254$ ms SE = 6.2).

Saccadic curvatures

The main effect of SOA was significant, $F(1, 31) = 34.177$, $p < .001$, $\eta_p^2 = .524$, due to greater curvatures at the 100 ms than at the 0 ms SOA, as well as the SOA × Bin interaction, $F(2, 62) = 6.114$, $p = .004$, $\eta_p^2 = .165$. Crucially, the Face × SOA × Bin interaction was significant, $F(4, 124) = 2.747$, $p = .031$, $\eta_p^2 = .081$. No other significant results emerged ($Fs < 1.1$, $ps > .350$). To explore the three-way interaction, three separate ANOVAs, with Face and SOA as within-participants factors, were conducted for each Bin (for a similar approach see also Laidlaw et al., 2015; Qian et al., 2015). For Bin 1, SOA led to the only significant result, $F(1, 31) = 16.055$, $p < .001$, $\eta_p^2 = .341$ (other $Fs < 1$, $ps > .379$), as well as for Bin 2, $F(1, 31) = 22.446$, $p < .001$, $\eta_p^2 = .420$ (other $Fs < 1.886$, $ps > .160$). For Bin 3, the main effect of SOA was significant, $F(1, 31) = 9.643$, $p = .004$, $\eta_p^2 = .237$, whereas the main effect of Face was not significant ($F = 2.031$, $p = .140$). Importantly, the Face × SOA interaction was significant, $F(2, 62) = 3.663$, $p = .031$, $\eta_p^2 = .106$. Two ANOVAs, with Face as within-participants factor, were conducted for each SOA. For the 0 ms SOA, the main effect of Face was non-significant ($F = 1.917$, $p = .156$). Importantly, at the 100 ms SOA, the main effect of Face was significant, $F(2, 62) = 3.586$, $p = .034$, $\eta_p^2 = .104$. Simple effect analyses indicated that larger curvatures emerged in response to faces with open eyes ($M = -.267°$, SE = .039), as compared to both faces with closed eyes ($M = -.199°$, SE = .0418), $F(1, 31) = 4.390$, $p = .044$, and scrambled faces ($M = -.192°$, SE = .0325), $F(1, 31) = 6.041$, $p = .02$ (see Figure 3). As a different strategy to explore the Face × SOA × Bin interaction, two separate ANOVAs, with Face and Bin as within-participants factors, were conducted for each SOA. At the 0 ms SOA, only the main effect of Bin was significant, $F(2, 62) = 4.866$, $p = .011$, $\eta_p^2 = .136$ (all other $Fs < 1.622$, $ps > .173$). At the 100 ms SOA, the main effects of Face and Bin were both non-significant ($Fs < 1$, $ps > .475$), while the Face × Bin interaction approached statistical significance, $F(4, 124) = 2.276$, $p = .065$, $\eta_p^2 = .068$. Three separate ANOVAs, with Face as within-participants factor, revealed no differences among faces for both Bin 1 and 2 ($Fs < 1.604$, $ps > .209$), while a significant difference emerged for Bin 3, $F(2, 62) = 3.586$, $p = .034$, $\eta_p^2 = .104$, as in previous analyses. In sum, the two approaches led to a comparable pattern of findings. Finally, no significant results emerged from correlational analyses between AQ scores and the magnitude of saccadic curvatures for the three faces (fdr-corrected $ps > .6$). In distractor-absent trials no significant result emerged ($p = .6$).

Table 2. Mean SRTs (ms) as a function of face (Open vs. Closed eyes vs. Scrambled), SOA (0 vs. 100 ms) and Bin (1 vs. 2 vs. 3).

	0 ms SOA			100 ms SOA		
Face	Bin 1	Bin 2	Bin 3	Bin 1	Bin 2	Bin 3
Open	191.3 (29.96)	234.7 (37.95)	299.0 (46.63)	141.2 (24.01)	180.4 (35.91)	246.9 (53.84)
Closed	189.7 (28.79)	233.4 (36.13)	297.3 (44.99)	139.3 (23.81)	177.7 (33.84)	250.0 (42.83)
Scrambled	189.9 (27.42)	234.2 (35.93)	296.7 (43.68)	140.4 (21.40)	178.6 (31.94)	246.6 (48.03)

Values in parentheses are SEM.

In Experiment 2, evidence supporting the "eye contact effect" emerged. Faces with open eyes elicited a larger saccadic curvature, as compared to both faces with closed eyes and scrambled faces, although the effect was observable only at longer SRTs, in line with previous evidence (e.g., Laidlaw et al., 2015).

General discussion

The aim of this study was to investigate whether perceived eye contact with another individual can shape saccadic curvature. In two experiments, participants were asked to make upwards or downwards saccades towards a symbolic target while distractor faces with

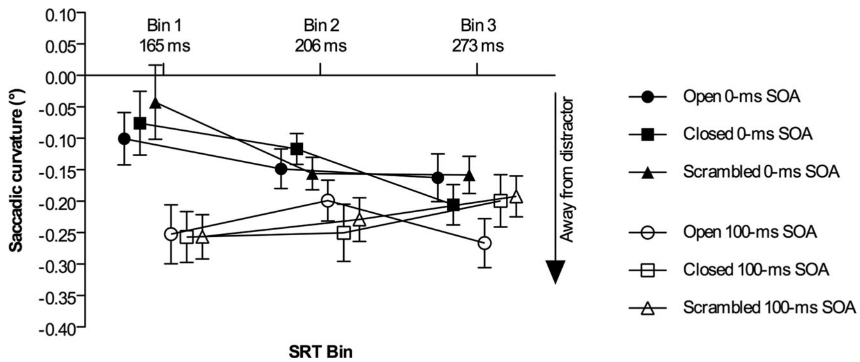

Figure 3. Mean saccadic curvatures (degrees of visual angle) as a function of SRT Bin (1 vs. 2 vs. 3), Face (Open vs. Closed eyes vs. Scrambled) and SOA (0 vs. 100 ms) in Experiment 2. Error bars are SEM. The SRT value associated with each Bin has been calculated as the average across the different experimental conditions for illustrative purposes, although it should be remembered that in the analyses each Bin was calculated separately for each participant and experimental condition.

open or closed eyes (Experiments 1 and 2) and scrambled faces (Experiment 2) could appear to the left or right of the target. Overall, saccadic curvatures were larger in response to faces with open eyes, as compared to the other two conditions, consistent with the "eye contact effect" (Senju & Johnson, 2009).

The impact of eye-gaze stimuli on human cognition is highly pervasive and the "eye contact effect" corroborates this notion (Senju & Johnson, 2009; see also Conty, George, & Hietanen, 2016). For instance, direct-gaze faces can be better recognized, a result observed both at behavioural (e.g., Mason, Hood, & Macrae, 2004) and neural (e.g., Sessa & Dalmaso, 2016) levels. Direct-gaze faces can also capture attention but, so far, the magnitude of this attentional capture in adults has been mainly inferred from manual reaction times analyses (e.g., Böckler et al., 2014; Hietanen et al., 2016; Senju & Hasegawa, 2005). To the best of our knowledge, no studies focused on saccadic curvature, whose employment can offer some advantages with respect to manual responses. First, saccadic curvature can provide a more direct index of attentional allocation over space (see Van der Stigchel, 2010). Second, because we tend to explore the social environment around us mainly through eye movements, saccadic parameters can be considered as a more reliable, refined, and ecological measure when attentional mechanisms are investigated (e.g., Kristjánsson, 2011).

The present results seem to suggest that temporal parameters can play a role in revealing the "eye contact effect" signature in saccadic curvatures. In Experiment 1, SOA and saccadic latencies did not influence the observed modulation of open vs. closed eyes. In Experiment 2, a more complex pattern emerged, suggesting that the "eye contact effect" may require time to develop. However, it must be stressed that saccadic latencies are not independent of SOA (because of possible foreperiod effects) and therefore results from Bin analyses should be taken cautiously. This issue should be addressed in future studies, possibly adopting paradigms that facilitate time-based analyses, such as that developed by Ross and Ross (1980; see also Laidlaw et al., 2015).

Our results could be also interpreted as indirect evidence of a link between the mechanisms underlying the "eye-contact effect" and the saccadic curvature generation system. Even if these two mechanisms are still not entirely clear, it is important to note that a subcortical structure, namely the Superior Colliculus (SC), would be involved in both cases. On the one hand, the SC would be part of a fast route devoted to eye contact detection (Senju & Johnson, 2009). On the other hand, the SC would also contribute to the inhibitory mechanisms that would generate saccadic curvatures (Van der Stigchel, 2010). The neural underpinnings of these two domains merit further investigation.

The study of social vision through eye movements is an intriguing and rapidly growing field of research that can provide new insights at both behavioural (e.g., Edwards, Stephenson, Dalmaso, & Bayliss, 2015) and neural (e.g., Pfeiffer, Vogeley, & Schilbach, 2013) levels. Remarkably, several aspects of saccadic curvatures in social vision need further investigations, since most of the studies conducted so far focused on non-social attentional mechanisms (e.g., Doyle & Walker, 2001;

Sheliga et al., 1995; Van der Stigchel, 2010). For this reason, the impact of social stimuli on saccadic curvatures represents a fruitful topic. For instance, future research could explore whether individual differences other than autism-like traits or the processing of other highly-salient social stimuli, such as those associated with the self (e.g., Sui & Humphreys, 2015), are reflected in saccadic curvature or even in other oculomotor metrics (e.g., Yankouskaya, Palmer, Stolte, Sui, & Humphreys, 2016). The role of higher order processes on vision represents a thrilling topic that is likely to inspire research for many years to come.

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