Vision Research 127 (2016) 115–121

Contents lists available at ScienceDirect

Vision Research

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

Reduced saccadic inhibition of return to moving eyes in autism spectrum disorders

Tiziana Zalla [a,*], Laura Gabriela Fernandez [a,1], Marie Pieron [a], Magali Seassau [b], Marion Leboyer [c,d]

[a] Ecole Normale Supérieure, PSL Research University, Département d'études cognitives, CNRS UMR 8129, Institut Jean Nicod, F-75005 Paris, France
[b] e(ye)BRAIN, 1 bis rue Jean le Galleu, 94200 Ivry-sur-Seine, France
[c] Department of Psychiatry, INSERM U 955, IMRB & University Paris Est Creteil, AP-HP, Henri Mondor-Albert Chenevier Hospitals, Creteil, France
[d] Fondation FondaMental, French National Science Foundation, France

A R T I C L E I N F O

Article history:
Received 14 January 2016
Received in revised form 14 July 2016
Accepted 14 July 2016

Keywords:
Gaze shift
Attention orienting
Autism
Gaze detection
Face orientation

A B S T R A C T

Inhibition of Return (IOR) refers to slower reaction time to a target presented at the same location as a preceding stimulus. Here, we examine reflexive attention orienting via the saccadic IOR using a shift in gaze direction (i.e. from averted to direct) in faces presented as a peripheral cue, in upright and inverted orientations, in adults with Autism Spectrum Disorder (ASD) and typically developed comparison participants. While both groups showed an IOR in the inverted face condition, this effect was reduced in participants with ASD in the upright face condition, as compared to comparison participants, suggesting that moving eyes do not trigger reflexive exogenous orienting in individuals with ASD. Impaired reflexive orienting to eye gaze might severely compromise the later development of social functions in ASD, such as joint attention, face emotion recognition and mindreading.

1. Introduction

Orienting is a primitive function that allows the shifting of attention towards or away from a source of stimulation in the environment. While endogenous orienting is under the voluntary control of motivational and goal-directed processes, exogenous orienting refers to the reflexive, stimulus-driven allocation of attention in response to the salient features of the environment (Jonides, 1981). Food, predators, playmates, desirable objects, a novel stimulus, or an abrupt change in luminance can be salient cues that capture the observer's attention in an involuntary or automatic manner.

Eye gaze is considered to be a salient social cue that captures visual attention both in a voluntary and automatic manner (Frischen, Bayliss, & Tipper, 2007; Laidlaw, Risko, & Kingstone, 2012). The ability to follow direction of another person's eye gaze arises early in infancy and plays a crucial role in intention attribution, mindreading, and communication. It allows the child to be aware of what another person is attending to and to establish joint attention with others (Butterworth & Jarrett, 1991). Previous studies have shown that this attentional capture is more effective when the gaze shifts is directed towards the observer compared to when the gaze shifts is directed away from the observer (an averted gaze) (Yokoyama, Ishibashi, Hongoh, & Kita, 2011). A direct gaze is detected more readily than an averted gaze, even when gaze discrimination is not the primary task at hand (Senju, Hasegawa, & Tojo, 2005; Doi & Shinohara, 2013). By capturing the observer's attention, direct gaze modulates the observer's subsequent attentional and cognitive processing of perceptual information (Senju & Johnson, 2009).

Autistic spectrum disorder (ASD) is a pervasive developmental disorder characterized by qualitative impairments in communication, social interaction, and a restricted range of interests and stereotyped repetitive behaviors. Reduced sensitivity to gaze direction and eye contact avoidance constitute core features of ASD. There is indeed substantial evidence that children with autism exhibit diminished sensitivity to eye gaze and are impaired in face and gaze processing (Baird et al., 2000; Baron-Cohen et al., 1996). Children with ASD, unlike children with typical development, exhibit a lack of or a delayed ability to follow gaze (Leekam, Hunnisett, & Moore, 1998) or do not show faster detection of direct gaze as compared to averted gaze (Senju, Kikuchi, Hasegawa, Tojo, & Osanai, 2008; Senju, Yaguchi, Tojo, & Hasegawa, 2003). In addition, the processing of direct gaze in ASD is associated with abnormal event-related potentials and atypical brain activation (Senju, Tojo, Yaguchi, & Hasegawa, 2005; von dem Hagen, Stoyanova, Rowe,

* Corresponding author at: Ecole Normale Supérieure, Département d'études cognitives, Institut Jean Nicod-CNRS, 29, rue d'Ulm, F-75005 Paris, France.
E-mail address: tiziana.zalla@ens.fr (T. Zalla).

[1] Current address: Centro de Investigación y Transferencia en Acústica (CINTRA), UTN-FRC, Unidad Asociada CONICET, Córdoba, Argentina.

http://dx.doi.org/10.1016/j.visres.2016.07.008
0042-6989/

Baron-Cohen, & Calder, 2013). Because eye gaze is a special sort of stimulus that plays a crucial role in the development of joint attention and social functions, it is important to assess whether reflexive orienting to gaze direction is present in individuals with ASD.

The cues triggering exogenous attention are typically non-predictive, and thus observers have no especial incentive to maintain attention at the location being cued for a long time. Therefore, if the target appears at the cued location shortly after the cue onset, reaction times (RTs) are slower than for targets located at an uncued location. This phenomenon, first noted by Posner and Cohen (1984), is called inhibition of return (IOR). IOR is classically attributed to an automatic inhibitory mechanism preventing the return of attention to a previously attended location. This inhibitory mechanism helps the observer to explore the visual environment efficiently, by avoiding repeated processing of the same location (Klein, 2000). According to Lupiáñez, Martín-Arévalo, and Chica (2013), the IOR effect is the result of a cost for detecting the occurrence of new attention capturing information (e.g., the target) at locations where attention has been already allocated in response to a previous salient event (e.g., the cue). The peripheral cue that initially activates the attentional neural network, the ventral fronto-parietal attention network (Corbetta, Patel, & Shulman, 2008), undergoes habituation. When the target later appears at the same location it would not capture attention any more effectively than if it had appeared in a new location. Thus, cued targets are filtered out as less relevant than uncued targets resulting in a long lasting IOR effect.

Theeuwes and Van der Stigchel (2006) showed that IOR can also be elicited by social stimuli. The authors used a modified spatial cuing paradigm in which they presented two peripheral objects (either a face or a non-face) to the left or the right of a central fixation. After a variable stimulus onset asynchrony (SOA), i.e. the time interval between the cue and the target onset, participants had to make a saccade to one of the two locations. The authors observed a delayed response to the peripheral location that previously contained a face stimulus, as compared to the location that contained an object. They concluded that peripheral faces could summon attention with an exogenous event. It is worth noting that the faces had a direct gaze, which could have increased the attentional capture by the peripheral face. In this study, the IOR effect might be attributed to the cost in directing attention towards a peripheral location, previously occupied by a salient object, that automatically captured the observer's attention. Interestingly, Grison, Paul, Kessler, and Tipper (2005) found a greater IOR effect when the faces used as cue and target were upright, than when the cue and/or target faces were inverted. This can be explained by the fact that upright faces are processed holistically, whereas inverted faces sharing similar low-level features are processed like objects, at a local analysis level (Rhodes, Brake, & Atkinson, 1993). Importantly, the neural mechanisms recruited for upright and inverted face processing could be different (Haxby et al., 1999; Sadeh & Yovel, 2010). Thus, the existence of a specialized brain circuit for face processing might explain why the detection of the facial social relevance is compromised and the attentional capture is reduced, when faces are perceived in the inverted orientation (Yin, 1969).

Previous evidence on the ability to orient visuospatial attention to social stimuli, such as faces and eye gaze, in individuals with autism has so far yielded contradictory results. Ristic et al. (2005) found that adults with ASD showed disrupted orienting to gaze only under non-predictive cueing conditions indicating an insensitivity to the social relevance of the gaze in this population. Goldberg et al. (2008) did not find the validity effect in children with ASD in response to non-predictive static drawings of gaze. Conversely, others studies reported a preserved ability to orient visuospatial attention in children with ASD in response to non-predictive gaze cues (Kylliäinen & Hietanen, 2004; Swettenham, Condie, Campbell, Milne, & Coleman, 2003).

Recently, Marotta et al. (2013) investigated manual IOR effect in young individuals with ASD using social and non social stimuli, presented as central eye gaze cue and peripheral cue, respectively. In this study, central cues consisted of a gaze directional shift in the direction of one of two lateral locations (left or right), while peripheral cues consisted on the brightening of one of two peripheral boxes located on the left and on the right of a central fixation cross. Results showed a manual IOR effect for the two cues in the control group while an IOR effect only for peripherally cued locations, but not for the centrally cued locations by eye gaze shifts in the ASD group, likely reflecting a specific social attentional deficit. The authors reported a preserved manual IOR effect in response to non-social cues (Marotta et al., 2013) in line with Rinehart, Bradshaw, Moss, Brereton, and Tonge (2008) who found preserved saccadic IOR effect in young individuals with ASD. More recently, Antezana, Mosner, Troiani, and Yerys (2016) examined the IOR effect using neutral and angry facial expressions in children and adolescents with ASD, as compared to a typically developing group. The authors showed a significantly stronger IOR effect in the ASD participants that correlated positively with their social impairments, as measured by ADOS (Autism Diagnostic Observation Schedule-generic, Lord et al., 2000).

In the current study, we aimed to investigate whether a non-predictive peripheral gaze direction shift would capture reflexive attention orienting in adults with ASD, as compared to a group of typically developed adults. We developed a new adaptation of the Posner's cueing attention-orienting paradigm in which a gaze direction shift (from averted to direct) was used as a peripheral cue to capture the subject's attention. To control whether reduced or absent IOR effect in ASD is specific to eye gaze or whether it reflects a general impairment in reflexive orienting, the same stimuli were presented as cues in the upright and inverted orientation conditions. Given that the occurrence of IOR to a location only follows the reflexive shift of attention to that location, if a shift in gaze direction embedded in a face stimulus does capture spatial attention, similarly to the way attention is attracted by a peripheral abrupt onset, we would expect to observe a stronger IOR effect for valid cues than for invalid cues. Based on previous findings (Grison et al., 2005), the attention orienting in response to eye-gaze should be modulated by face orientation, with greater IOR effect for upright than with inverted faces. Upright faces are processed holistically whereas inverted faces are processed more like other objects, at a local analysis level (Rhodes et al., 1993). Thus, we assumed that inverting the eyes might severely disrupt gaze sensitivity, irrespective of the face orientation, suggesting that some form of relational/configurational mechanism is involved in gaze processing (Jenkins & Langton, 2003). Based on these previous findings, we predicted a stronger IOR effect in response to eye movement in the upright face condition in typically developed participants, relative to the inverted face condition, and absent or blunted IOR effect in participants with ASD reflecting reduced exogenous orienting to eye gaze shift in this population. Moreover, based on previous studies reporting difficulties with saccadic inhibition in ASD (Goldberg et al., 2002; Pieron, Seassau, Leboyer, & Zalla, 2015), we expected to find more anticipation errors or misses in participants with ASD than in the comparison group.

2. Materials and methods

2.1. Participants

Sixteen male participants meeting a clinical diagnosis of ASD participated in the study. All participants received an official diagnosis from experienced clinicians based on DSM-IV criteria (American Psychiatric Association, 2000), ASDI (Asperger Syndrome Diagnostic Interview, Gillberg, Gillberg, Råstam, & Wentz, 2001) and the ADOS (Lord et al., 2000) criteria, according to a semi-structured standardized assessment of social interaction, communication and imagination. The diagnoses were confirmed by means of interviews with parents or caregivers using the ADI-R (autism diagnostic interview, Lord, Rutter, & Le Couteur, 1994) in the three domain areas: reciprocal social interaction, communication and stereotyped behaviors. Standard clinical ADI-R algorithm cut-offs were employed (reciprocal interaction 10, communication 8 and stereotyped behaviors 3). Participants in the ASD group were recruited from the Albert Chenevier Hospital in Créteil (France). None were on psychotropic medication at the time of testing (Table 1).

Sixteen male comparison participants (CP) matched for age, gender, educational level, and Intelligence quotient (IQ) to the clinical group took part in the study. Prior to their recruitment, all participants were screened to exclude any history of neurological or psychiatric disorders, and received a basic neuropsychological screening, which included Verbal and Performance IQs (WAIS-R) (Wechsler, 2000). All had an IQ above 70. There were no significant differences between groups for age, education, gender and IQ level (verbal, performance and full scale) (see Table 1 for statistical comparisons). All participants were native French speakers, right-handed and reported normal or corrected to normal vision.

The investigation was carried out in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki) and was approved by the Institutional Human Experimentation Committee (INSERM, National Institute of Health and Medical Research, Paris, France). Written consent for participation in the study was obtained through a detailed consent form, after explanation of the experimental procedure.

2.2. Apparatus

Eye movements were recorded using the Mobile Eyebrain Tracker (Mobile EBT®, e(ye)BRAIN, www.eye-brain.com), an eye-tracking device conceived for medical purposes. The Mobile EBT® incorporates head-mounted cameras that allowed recording of eye movements simultaneously and independently. Recording frequency was set to 300 Hz. The precision of this system is reportedly 0.5° (see www.eye-brain.com, for more details). There is no obstruction of the visual field with the recording system. Calibration procedure, preceding each experiment block, is similar to that used in a previous study (Pieron et al., 2015). During the calibration procedure, each participant was asked to fixate a grid of 13 points (diameter 0.5 deg) mapping the screen. A polynomial function with five parameters was used to fit the calibration data and to determine the visual angles.

Stimuli were displayed on a PC screen of 22″ with a resolution was 1920 × 1080 and a refresh rate was 60 Hz.

2.3. Stimuli

Stimuli consisted of gray-scaled front view photographs of faces selected from digitalised colour portraits of adult faces (8 identities: 4 men/4 women), created by George (see Vuilleumier, George, Lister, Armony, & Driver, 2005). Each individual picture was taken with gaze directed towards the camera and with gaze averted by 30°, under the same lighting and viewpoint conditions. Gazes oriented towards the right and the left were obtained by mirror-imaging with Photoshop element software. Faces were presented either upright or inverted. All faces were unknown to the participants, and had no emotional expressions. They were also judged to be neutral in terms of trustworthiness and dominance during a pre-test phase. Pairs of photographs, presented simultaneously on each trial, were matched for physical attributes, such as luminance, contrast, and spatial frequency, as well as for gender and age.

2.4. Procedure

Participants were seated at approximately 60 cm from the computer monitor with their head positioned in the chinrest of the eye-tracking device, in a dark and quiet room. After the calibration procedure, a practice session consisting of 16 training trials preceded the session of 192 experimental trials composed by 12 blocks of 16 trials each. During the experiment, a break was proposed after each two blocks.

As illustrated in Fig. 1, each trial was composed by the following sequence of events: a white central fixation cross appeared on the computer screen for 1000 ms or 2000 ms. Then, two faces with an averted gaze appeared on the screen simultaneously and peripherally at 9° on the left and on the right of the fixation cross against a dark background, and aligned according to their eye position for 500 ms. This face display was followed by the cue, that is the eye gaze of one of the two faces shifted from averted to directed for 200 ms. The cue presentation was followed by the face display remaining on the screen for 300 ms. Face display then disappeared for a delay of 100 ms, and appeared again for 300 ms. This interstimulus interval was inserted to favour the attention disengagement from the gaze cue, and to minimize the potential confounding effect of an attention disengagement deficit in ASD participants (Lupiáñez et al., 2013). The target was a semitransparent gray square covering the whole face, randomly presented on the cued (valid trial) or the uncued face (invalid trial) for 200 ms. After its removal, the two faces continued to be displayed until the participants made a response. The stimulus onset asynchrony (SOA), i.e., the time between the cue onset and the target onset, was 900 ms. Between each trial, a blank screen was presented for 1000 or 2000 ms (Fig. 1).

The participants were asked to fixate the white central fixation cross and informed that two faces would appear, one on the right and one on the left side of the computer screen. They were also

Table 1
Means (and standard deviations) of demographic and clinical data for the ASD and CP groups.

	ASD	CP	Group difference
Age (years)	35.8 (10.2)	31.6 (11.5)	t = −1.1, p = 0.27
Education (years)	14.7 (2.9)	15.6 (2.4)	t = −0.92, p = 0.37
Full scale IQ	109.2 (15.2)	108.8 (10.1)	t = −0.09, p = 0.92
Verbal IQ	110.2 (15.1)	110.9 (12.2)	t = −0.14, p = 0.89
Performance IQ	105.7 (16.1)	105.7 (9.5)	t = 0.13, p = 0.98
ADI-R [B,C,D]*	15.7 (6.6); 9.8(4.8); 4.4(2.6)	–	
ADOS** [com, soc, RSB]	5.5 (2.9); 7.9 (3.8); 1.1(0.8)	–	

* [B] = reciprocal social interaction, [C] = communication, [D] = restricted and stereotyped behavior.
** [com] = communication, [soc] = social interaction, [RSB] = restricted and stereotyped behavior.

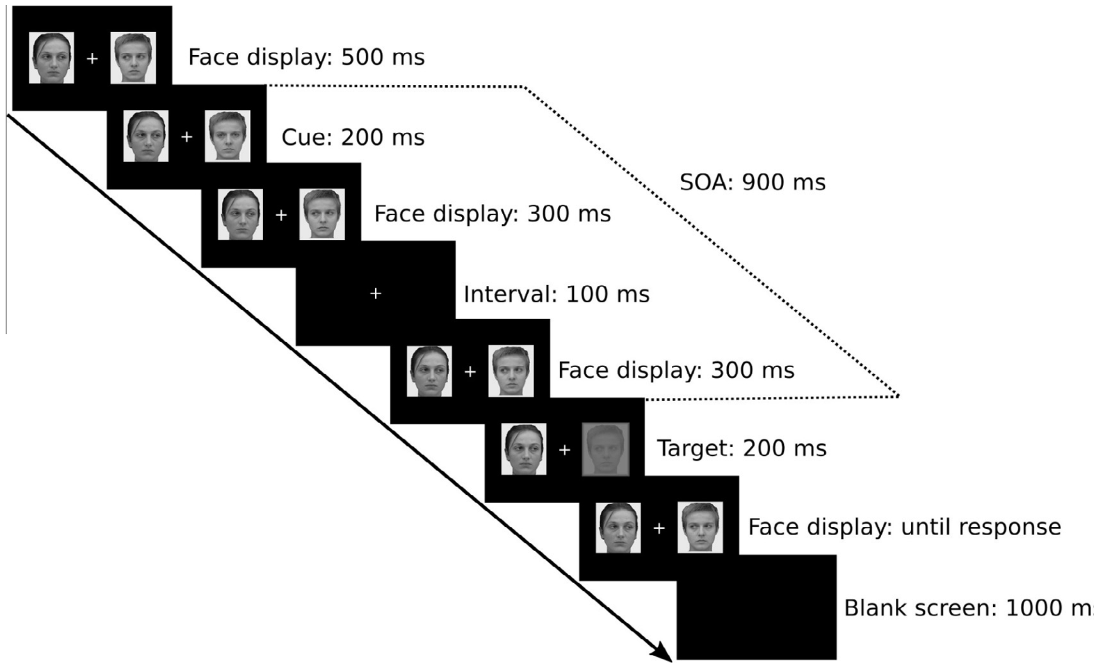

Fig. 1. Graphic representation of the experimental procedure. SOA = stimulus onset asynchrony.

informed that there would be an eye gaze movement, but that this change would not be informative about the target location and that they did not have to respond to it. They were instructed to make a horizontal saccade in the direction of the target as soon as they detected it. The fixation cross remained visible during the whole trial and was lined up with the gaze area of the two faces. The position of the lateral cue (right vs. left) and the target (left vs. right) was counterbalanced in a factorial manner. The upright and inverted faces were presented into different blocks and the order of blocks was counterbalanced across participants.

A pilot study preceding the experimental task was undertaken in twenty typically developed individuals to determine the SOAs at which a robust IOR effect might occur under these experimental conditions. In the pilot study, participants responded with a manual key-press to the target appearance. The results indicated that the present experimental paradigm elicited a strong IOR effect at the SOA of 900 ms ($t(19) = 2.22$, $p < 0.005$).

2.5. Data collection and analyses

For oculomotor data, the calibration procedure allowed determining the calibration factors from the eye positions. Saccadic eye movements extracted using the software MeyeAnalysis (provided with the e(ye)BRAIN eye tracker, www.eye-brain.com, France) and a "built-in saccade detection algorithm" was used to automatically determine the onset and end of each saccade (Nyström & Holmqvist, 2010). All recorded saccades were verified by the investigators and corrected or discarded, if necessary.

We recorded saccadic RTs or latencies (i.e. the time between the onset of the target and the beginning of the eye movement), and the mean value of this variable was calculated for both eyes and for each participant. Saccades with latencies shorter than 100 ms were deemed to be anticipations, and those longer than 1100 ms were deemed to be misses; saccades in the wrong direction were considered as erroneous. Data from anticipatory responses (ASD = 3.9%, SD ± 4; CP = 1.2%, SD ± 1.9), misses and incorrect saccades (ASD = 1.6%, SD ± 1.7; CP = 0.3%, SD ± 0.5) counted as errors and were analyzed separately.

We calculated the validity effect by subtracting the RTs in the valid cue condition from the RTs in the invalid cue condition: positive values reflect the facilitation effect, and negative values reflect the IOR effect.

Since the present data violated the parametric assumption of normal distribution, we performed non-parametric tests. Between-subject (ASD and CP) differences were tested with the Mann-Whitney rank test, and within-subject difference between variables was estimated with the Wilcoxon signed rank test. An alpha level of 0.05 was used for all the analyses.

3. Results

3.1. Saccadic Reaction time

The Wilcoxon Sign Rank Test revealed that in the Upright face condition RTs for valid trials were significantly slower than for invalid trials ($z = -2.999$, $p = 0.027$) in CP, whereas in participants with ASD, RTs for valid and invalid trials did not significantly differ ($z = -0.621$, $p = 0.535$). In the Inverted face condition, RTs on valid trials were significantly longer than RTs for invalid trials in both CP ($z = -3.258$, $p = 0.001$) and ASD participants ($z = -2.792$, $p = 0.005$) revealing the presence of an IOR effect in all participants (Table 2).

3.2. Validity effect

The validity effect was calculated as the difference between RTs for invalid and valid trials in the Upright and Inverted face conditions. The Mann-Whitney test yielded a significant group difference for the upright face condition ($z = -2.186$, $p = 0.028$) revealing a greater validity effect in the CP group than in the ASD group, but no group difference on validity effect in the inverted face condition ($z = -0.829$, $p = 0.41$) (Table 2 and Fig. 2).

A within-group analyses using the Wilcoxon Sign Rank Test revealed that the validity effect in the upright face condition did not significantly differ from that in the inverted face condition for either the CP ($z = -0.77$, $p > 0.05$) or ASD ($z = -1.19$, $p > 0.05$) group.

Table 2
Mean RT (ms) and standard deviation (SD) of valid and invalid cue trails in the Upright and Inverted face orientation conditions, and validity effect (VE) for the ASD and CP groups.

		ASD		CP	
		Mean (SD)	VE	Mean (SD)	VE
Upright face condition	Valid	324.3 (53.7)	−4.95 (27.3)	333.2 (55.9)	−22.3 (21.4)
	Invalid	319.4 (60.1)		310.9 (47.7)	
Inverted face condition	Valid	312.5 (50.9)	−14.7 (17.9)	334.1 (50.9)	−19.3 (16.9)
	Invalid	297.9 (55.4)		314.8 (50.3)	

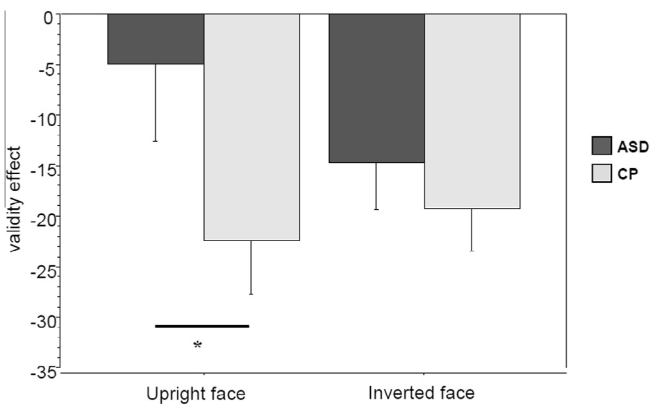

Fig. 2. Validity effect (RTs of invalid trials–RTs of valid trials) in upright and Inverted face conditions in ASD and CP groups. Error bars represent standard errors.

3.3. Saccadic errors

The Mann-Whitney rank test on the number of anticipated saccadic movements (response < 100 ms after onset of the target) revealed that participants with ASD committed significantly more anticipation errors (M = 7.5, SD = 7.74) than the CP (M = 2.3, SD = 2.2) [U = 65.5; z = −2.35, p = 0.018].

When we compared the two groups for the number of misses (absence of saccadic response or saccadic response after 1100 ms), we found that the participants with ASD committed significantly more misses (M = 3.1, SD = 3.2) than the CP (M = 0.5, SD = 1.0) [U = 68; z = -2.26, p = 0.016].

4. Discussion

The aim of the present study was to examine the saccadic IOR effect in response to a lateral target, a face stimulus, previously cued by a change in gaze direction in adults with ASD and matched typically developed volunteers. To our knowledge, this is the first study investigating the saccadic IOR effect in individuals with ASD using moving eyes as peripheral cues. We found a robust IOR effect in typically developed adults, that is, faster RTs for targets appearing at a non-cued than at the cued location, showing that eye gaze is a highly salient signal capturing attention automatically in the peripheral visual field. In comparison with the typically developed group, our participants with ASD exhibited a reduced IOR effect to eye gaze shift cued by the upright faces, suggesting that in this population eye movement does not trigger rapid reflexive attentional orienting, and that the moving eyes are not prioritized and automatically processed as a salient stimulus at the early stages of visual analysis.

Furthermore, all participants exhibited an equally strong IOR effect when the eye movement was cued by inverted faces. While the reduced IOR effect in the upright face condition in strongly suggest the disruption of a specific orienting mechanism for detection of gaze direction in individuals with ASD, the presence of an IOR effect for the eye movement cued by inverted faces indicated that there is no general IOR impairment in ASD. These results are consistent with previous reports showing no gaze orienting under non predictive cue conditions (Goldberg et al., 2008; Ristic et al., 2005) and reduced manual IOR effect for eyes gaze directional shift (central cued) in participants with ASD (Marotta et al., 2013).

It has been reported that reflexive attention to gaze can be inhibited by manipulations that compromise face processing, such as face inversion (Kingstone, Friesen, & Gazzaniga, 2000). Thus, we hypothesized that since inverted faces lose their configural properties, inverting the faces would extinguish the reflexive cue effect of eye gaze in typically developed individuals, but not in ASD individuals (Falck-Ytter, 2008). Although, in the present study, it was unexpected that the face inversion did not eliminate the reflexive cueing effect in the control group, previous studies have already reported a preserved reflexive cueing effect of eye movement using inverted faces as central cues in both children with typical development and with ASD (Swettenham et al., 2003). Grison et al. (2005) found a weaker - but still present - IOR effect for inverted faces, as compared to upright faces, in typically developed individuals. Even if we did not observed a more pronounced IOR effect for eye gaze cued in upright faces in CP, the IOR effect for eye gaze shift cued in inverted faces in our task was of the same magnitude (−19.3 ms) as that reported for inverted faces in Grison et al.'s study (2005). It has been suggested that the presence of an IOR effect with upright faces is generated by higher-level face identity information, while the same effect for inverted faces, which are hard to recognize during the cue and target sequences, might be induced by low-level features, such as signal changes in luminance, motion transients, or novel events in the periphery (Ando, 2002; Jonides & Yantis, 1988; Yantis & Jonides, 1984; Yeshurun, Kimchi, Shashoua, & Carmel, 2009).

Reduced attention to eye gaze and eye contact avoidance in ASD have been extensively documented and interpreted in terms of attenuated attention on the eyes (Senju, Tojo, Dairoku, & Hasegawa, 2004; Remington, Campbell & Swettenham, 2012; Yi et al., 2013), reduced sensitivity to social salience and self-relevant information (Zalla & Sperduti, 2013), increased salience for the lower face region ("mouth bias"), a specific expertise for mouth regions due to a language mediated compensation strategy (Klin, Jones, Schultz, Volkmar, & Cohen, 2002), or the result of an active avoidance of unpredictable rapid moving and aversive eyes (Gepner & Féron, 2009). In line with the latter hypothesis, it could be argued that the reduced IOR effect for moving eyes in ASD results from the voluntary avoidance of direct eye gaze perceived as aversive, leading to the active orientation of attention towards the uncued face with the static averted gaze. However, if this was the case, we should have observed a "facilitation" effect, i.e., faster RTs in valid than in invalid trials, and an IOR effect for the uncued location. Indeed, ASD participants exhibited faster RTs in invalid than in valid trials (−5 ms), even though this difference was significantly reduced, as compared to TD participants.

Crucially, the present results strongly suggest that the diminished exogenous attention orienting to eye gaze shift in our participants with ASD, as indexed by a reduced IOR effect, reflects an impairment at the early stages of visual analysis, rather than the aversion for potentially threatening stimuli, suggesting a disruption of the Relevance Detection System (Sander, Grafman, & Zalla, 2003; Zalla & Sperduti, 2013). Exogenous attention orienting, which is reflexively driven by the salient information in the environment, is in play in early infancy (Atkinson, Hood, Wattam-Bell, & Braddick, 1992). This reflexive orienting has considerable adaptive advantages and cognitive functions: IOR operates automatically at an early stage of visual exogenous orienting to ensure a rapid and efficient acquisition of relevant information from the environment (McDonald, Ward, & Kiehl, 1999). It is well established that eye gaze direction is one powerful reflexive cue (Driver et al., 1999; Langton & Bruce, 1999) and that attention capture is not driven by low-level physical properties of eye gaze, such as luminance transients (Laidlaw & Pratt, 2010). Indeed, gaze is of great social and biological importance; it provides highly relevant information about interests and danger in the environment and, at a higher cognitive level, about others' intentions and mental states. Eye contact fosters communication and the expression of feelings and intentions, and regulates social interaction and turn-taking in conversation (Batki, Baron-Cohen, Wheelwright, Connellan, & Ahluwalia, 2000). Importantly, attention orienting to eye gaze is subserved by specialized cortical pathways, encompassing temporal and parietal areas, and lateralized to the hemisphere specialized for processing upright faces (Haxby et al., 1999; Sadeh & Yovel, 2010).

In ASD, insensitivity to direction of gaze has been reported at 18 months of age (Baird et al., 2000; Baron-Cohen et al., 1996), and although some children (particularly those who have an IQ of 70 or above) might develop this ability later, the onset of gaze following is still severely delayed relative to children with typical development (Leekam et al., 1998). In adults, a large body of evidence has documented failure to interpret gaze movement as an index of others' mental state, and abnormal visual scanning of faces, in particular reduced looking time at the eye region (Klin et al., 2002; Pelphrey et al., 2002; Ristic et al., 2005). The present results provide evidence that the reduced sensitivity to moving eyes would results from a low-level reflexive attentional impairment. If present in early infancy, reduced sensitivity to eye gaze shift might severely compromise the later development of social functions in ASD, such as joint attention, face emotion recognition and mindreading.

As expected, we found an increased number of saccadic errors (i.e., anticipation errors and misses) in ASD group reflecting difficulties with inhibition of automatic saccades and diminished control of ocular-motor behavior, as also reported in previous studies using oculomotor tasks (Goldberg et al., 2002; Manoach, Lindgren, & Barton, 2004; Minshew, Luna, & Sweeney, 1999) and the IOR paradigm (Pieron et al., 2015). Interestingly, using five SOAs Pieron, Seassau, Leboyer, and Zalla (2015) reported an accelerated time course of saccadic IOR in adults with ASD, as the IOR effect occurs earlier (300 ms SOA) than in typically developed adults (500 and 700 ms SOAs). In addition, in this study, the number of anticipatory saccades positively correlated with the restricted and stereotyped behavior, as assessed by the ADI-R (Lord et al., 1994). In a previous study, Minshew et al. (1999) proposed that difficulties to suppress context-inappropriate saccadic responses reflect abnormalities of the fronto-cortical attentional system.

We should acknowledge some limitations of the present study. First of all, although the present findings showed reduced IOR effect in ASD, we cannot conclude, based on this experiment alone, that this effect is only found for moving eyes. It is possible that any changes in the peripherally presented upright faces or in the whole head might also fail to orient attention reflexively in ASD. The use of different moving social and non-social cues, matched for stimulus complexity, is warranted in future research. Second, further studies should investigate whether the temporal course of IOR and facilitation effects for eye gaze and social stimuli in general is different in individuals with and without ASD, as suggested by previous reports using non social stimuli (Pieron et al., 2015). Third, following Theeuwes and Van der Stigchel (2006), we assumed that the presence/absence of the IOR effect implies the presence/absence of prior attentional capture by the cue. It must be noted, however, that it is not generally acknowledged that attention capture necessarily precedes IOR (see Posner & Cohen, 1984, and Berlucchi, 2006; Lupiáñez et al., 2013; for a more recent discussion about this issue). Hence, confidence in our inference that these cues did not capture the attention of our ASD participants in upright faces would be enhanced by directly testing for capture by using targets presented immediately after the cues. Lastly, because our sample is small and includes only male participants, replication studies with larger sample sizes and female participants are needed to draw straightforward conclusions that can be generalized to the broader ASD population.

Acknowledgments

We gratefully acknowledge the commitment of the participants and their families to the pursuit of research in autism. This research was supported by Fondation de France and Fondation FondaMental to TZ and ML The authors wish to thank Nathalie Georges for generously sharing her data bank of face stimuli. Designed research: T.Z., M.P., M.S., Performed research and clinical measurement: M.P., M.S., M.L. Analyzed data: T.Z., L.G.F., Wrote the paper: T.Z., L.G.F. No conflict of interest.

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