Dysfunctional perceptual antecedent can justify the social orienting deficit in autism spectrum disorder: an eye-tracking study

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Abstract

Purpose – *Children with Autism Spectrum Disorder (ASD) show reduced attention to social stimuli. The reasons for these impairments are still being debated by researchers. The aim of this study is to analyse if reduced attention towards social stimuli is determined by initial underlying difficulties in the control of visual attention. Among the variables that could produce these difficulties, the authors considered geometric complexity and typology of geometric figures.*

Design/methodology/approach – *To test this hypothesis, in this paper, an eye-tracker paradigm was used for assessing visual exploration and recognition memory towards geometric figures (curved vs rectilinear) with two levels of geometric complexity (low and high) in 17 children with ASD matched with 17 children with typical development (TD).*

Findings – *The results showed that the ASD group seemed indifferent to both the geometric complexity and the typology of figures (curved and rectilinear), whereas the TD group showed higher performances with highly complex and curved geometric figures than with low complex and rectilinear geometric figures.*

Research limitations/implications – *Because of the chosen research approach, the research results may lack generalizability. Therefore, researchers are encouraged to test the proposed hypotheses further.*

Practical implications – *This paper includes implications upon the presence of an unspecified visual attention deficit that is present from the early stages of the processing of stimuli.*

Social implications – *The understanding of this deficit from the early stages of the processing of stimuli can help educators to intervene at an early stage when disturbances in social relationships are starting.*

Originality/value – *This study contributes to understanding the presence of dysfunctional perceptual antecedents that could determine general difficulties in paying attention to social stimuli in ASD subjects.*

Keywords *Visual attention deficit, Shape stimuli, Autism, Complex stimuli, Deficit to social stimuli*

Paper type *Research paper*

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Introduction

The ability to select information with sense organs is the basis of human knowledge. Through inputs from the surrounding environment, the individual acquires information regarding reality that is indispensable to interact with it and build more elaborate forms of knowledge, such as thoughts and memories (Parker and Gibson, 1979). As attention is a key component for complex cognitive operations, a deficit in this function could hinder the development of higher order cognitive and social skills. This difficulty of paying attention to stimuli, especially social stimuli (faces), is present, for example, in subjects with Autism Spectrum Disorder (ASD) (American Psychiatric Association [APA], 2013; Mukherjee *et al.*, 2018). ASD is a complex neurodevelopmental condition characterized by socio-communicative impairments and restricted and repetitive patterns of behaviors and interests (APA, 2013).

Researchers are still debating the reasons for this reduced attention. It is possible that subjects with ASD pay less attention to social stimuli because these are not “interesting and motivating” (Chevallier *et al.*, 2015; Martin *et al.*, 2019) or because these are not a priority in their attention system (Chawarska *et al.*, 2010). Moreover, the difficulty of focusing on social stimuli (Chawarska *et al.*, 2012, 2013; Fabio *et al.*, 2018a, 2018b; Fabio, 2017; Fabio *et al.*, 2011; Lim, 2019; Shic *et al.*, 2011) is likely to be the direct result of greater emphasis on non-social stimuli, including objects related to circumscribed interests and geometric (Sasson and Touchstone, 2014; Pierce *et al.*, 2011; Pierce *et al.*, 2015; Shi *et al.*, 2015; Shaffer *et al.*, 2017). Despite these results, other studies have also shown that basic deficits in ASD can be attributed to general difficulties in the control of visual attention (Bryson *et al.*, 2004; Landry and Bryson, 2004; Elsabbagh and Johnson, 2007; Elsabbagh *et al.*, 2013; Mohammadhasani *et al.*, 2018, 2019; Sacrey *et al.*, 2013).

In this study, the theory explaining the difficulties of visual exploration in ASD is related to the presence of an attention visual impairment that is present from the early stages of visual input processing (Bryson *et al.*, 2004; Landry and Bryson, 2004; Elsabbagh and Johnson, 2007; Elsabbagh *et al.*, 2013; Sacrey *et al.*, 2013). According to this theory, attention difficulties in subjects with ASD and in other pathologies as the subject with attention deficit hyperactivity disorder are not caused by differences in visual exploration of social stimuli but by initial general difficulties in the control of visual attention (Bryson *et al.*, 2004; Castelli *et al.*, 2013; Elsabbagh *et al.*, 2013; Landry and Bryson, 2004; Fabio and Caprì, 2015, 2017; Fabio *et al.*, 2015; Gangemi *et al.*, 2018; Sacrey *et al.*, 2013). More precisely, some specific, dysfunctional perceptual antecedents might determine these difficulties (Carrozza *et al.*, 2019).

Furthermore, As social stimuli (face – facial configurations) are similar in shape to curved figures (e.g. circle, oval), we considered geometric complexity and typology of geometric figures (curved vs rectilinear) among the variables that could cause these difficulties, in this study.

Several studies have found that children with ASD, compared to children with typical development (TD), display early difference in the perception of geometric stimuli (Pierce *et al.*, 2011; Pierce *et al.*, 2015; Shi *et al.*, 2015; Shaffer *et al.*, 2017). Studies have also found that ASD children, compared to TD children, show the following:

- longer fixation time (FT) for geometric stimuli rather than social stimuli (Pierce *et al.*, 2011; Pierce *et al.*, 2015);
- a preference for geometric stimuli that is present at an early age (starting from the first year) (Chien *et al.*, 2015; Fabio and Urso, 2014; Pierce *et al.*, 2011; Pierce *et al.*, 2015; Shaffer *et al.*, 2017); and

Table 1 Demographic and clinical characteristics of the sample

	ASD (N = 17) *Mean (SD)*	*TD (N = 17)* *Mean (SD)*	*t* (33)-values	p-values
Age (months)	63.35 (11.45)	53.41 (12.44)	2.37	0.02
Gender (M:F)	12:5	12:5	—	—
DQ (GDMS)	52.88 (10.70)	56.64 (13.10)	1.00	0.31
Language DQ	57.47 (11.23)	62.94 (13.11)	1.17	0.25
Manual eyepiece DQ	56.76 (13.82)	53.76 (16.07)	0.49	0.62
Performance DQ	60.64 (15.34)	64.11 (16.82)	0.65	0.51
Practical reasoning DQ	37.05 (14.86)	46.36 (18.65)	1.6	0.08
ADOS – 2 Total	14.6 (5.0)	—	—	—

- difficulty in memory of complex geometric stimuli compared to simple stimuli (Minshew and Goldstein, 2001; Pallett and MacLeod, 2011).

In contrast to these results, Shi *et al.* (2015) have shown that the stimuli used by Pierce *et al.* (Pierce *et al.*, 2011; Pierce *et al.*, 2015) with subjects of 2–3 years were not adequate with subjects at a later age (4–6 years). To confirm this hypothesis, they presented the stimuli used by Pierce *et al.* (2011, 2015) to a sample of preschool children. From this study, no statistically significant differences were found between the ASD group and the TD group. Instead, when the same group of subjects (preschool children) were exposed to more complex social stimuli (children engaged in interacting and playing with each other), they showed reduced attention to more complex social stimuli and greater attention to non-social dynamic stimuli (geometric patterns and letters) (Shi *et al.*, 2015).

Regarding the typology of geometric stimuli (curved or rectilinear), few studies have investigated the impact of type of geometric stimuli on subjects with ASD and their effects on some processes such as judgments, decisions and preferences. For example, McPartland *et al.* (2011) investigated patterns of visual attention to different types of stimuli (faces, three-dimensional objects and geometric figures) in an ASD group of adolescents. The results showed that ASD subjects, compared to TD subjects, looked more closely at the top region of the stimuli irrespective of the category of belonging (social vs non-social) (McPartland *et al.*, 2011). Recently, Chien *et al.* (2015) have found that ASD subjects, compared to TD subjects, showed attention and mnemonic difficulties with complex geometric stimuli (Chien *et al.*, 2015). A year later, Belin *et al.* (2017) investigated the effects of simple geometric stimuli (curved and rectilinear) on attention responses of school-aged children with ASD and with TD (Belin *et al.*, 2017). The results showed that TD children, as widely demonstrated in literature, explored curved geometric shapes more, also by attributing positive emotional connotations to these shapes (Salgado-Montejo *et al.*, 2015; Bertamini *et al.*, 2016; Velasco *et al.*, 2016). Instead, subjects with ASD observed rectilinear geometric shapes longer and perceived them "positively". In addition, it was found that when group participants with ASD looked at curved stimuli, they attributed a social value to them (probably because they are similar in shape to facial configurations; face = oval) (Belin *et al.*, 2017; Cotter *et al.*, 2017).

Summarizing the above, there are several differences between the ASD and TD groups. In effect, from the first months of life, children with TD show a preference for curved and rounded lines and figures rather than straight or rectilinear ones (Westerman *et al.*, 2012; Van Oel and Van Den Berkhof, 2013; Vartanian *et al.*, 2013; Palumbo *et al.*, 2015; Salgado-Montejo *et al.*, 2015; Bertamini *et al.*, 2016; Gómez-Puerto *et al.*, 2016; Palumbo and Bertamini, 2016; Velasco *et al.*, 2016; Cotter *et al.*, 2017). Preference for curved features in children with TD is because of a sort of natural coupling between perceptual features and sensorimotor processes that are attuned to curved configurations.

In a current review, Gómez-Puerto *et al.* (2016) defined a general framework that explained the preference for curvature considering four explanatory mechanisms: eye movement, specific neural activity, gestalt principles and an appraisal approach (Gallese, 2016; Gómez-Puerto *et al.*, 2016; Belin *et al.*, 2017; Cotter *et al.*, 2017).

With reference to the first mechanism, children preferred curved lines because they allow them to preserve cognitive load, and also because curved lines are related to the ease of eye motion (Gómez-Puerto *et al.*, 2016). Also, some movements are preferred, as they generated fluency and comfort (Gómez-Puerto *et al.*, 2016).

In terms of neurophysiology of the visual system, Fantz and Miranda (1975) showed that, in the early days of life, neonates focused longer on curved stimuli than on rectilinear stimuli (Fantz and Miranda, 1975; cit in Gómez-Puerto *et al.*, 2016). They hypothesized that this early preference is because of cortical cell activity which increases on seeing curved lines (Hubel and Wiesel, 1968; cited in Gómez-Puerto *et al.*, 2016).

Regarding Gestalt principles, a curve can be considered a set of strongly grouped points (Tonder and Spehar, 2013). Some studies reported that preference for curvature is likely caused by intrinsic characteristics of the lines, which can be described as cases of good continuation or good gestalt (Gómez-Puerto *et al.*, 2016). According to Belin *et al.* (2017) and Cotter *et al.* (2017) individuals associate curved lines in positive terms, such as *quiet*, *lazy*, *graceful* and *playful*, whereas rectilinear lines/shapes are considered *agitating, hard or furious.*

However, pleasure and interest are distinct responses and many pleasant things are not always interesting to individuals (Graf and Landwehr, 2015). Some studies show that people respond differently to certain low-level stimulus features such as familiarity and complexity. As to the complexity of geometric stimuli, this feature has long been discussed in literature (Nadal *et al.*, 2010; Bertamini *et al.*, 2016). Nadal *et al.* (2010) suggest that there are three different forms of complexity that contribute to people's perception of visual complexity:

1. the amount and variety of elements;,
2. the way those elements are organized; and
3. asymmetry (Nadal *et al.*, 2010).

In a recent study, Bertamini *et al.* (2016) calculated the complexity of some geometric shapes with regard to two parameters: articulation (considered as a set of points in a plan, so that the product of the distances is constant) and shape (curved vs rectilinear). From the results of the study, it emerged that in general people preferred geometric curved shapes to rectilinear ones. With reference to complexity, rectilinear geometric shapes were considered more complex than curved ones. According to researchers, these results are due to different articulation and an "ambiguous" orientation of rectilinear lines. The lack of clear orientation influenced the perception of the complexity of the forms (Bertamini *et al.*, 2016).

According to other research, the complexity of stimuli also affects the memory of these stimuli (Huhmann, 2003; Pallett and MacLeod, 2011; Hyde *et al.*, 2016). Specifically, some studies have found that school-aged children are able to remember more simple stimuli than complex ones (Huhmann, 2003). This result is not in agreement with evidence that has emerged in other studies, where it was found that undergraduates tend to remember more complex stimuli (Pallett and MacLeod, 2011). These controversial results depend on the different age of subjects in the studies and on the different stimuli (Huhmann, 2003; Pallett and MacLeod, 2011; Hyde *et al.*, 2016).

Based on literature, the main aim of this study was to understand if visual impairments regarding social stimuli in ASD subjects derive from an attention deficit that is present in the early stages of stimuli processing. Among the variables that could lead to the attention deficit towards social stimuli, this study considered geometric complexity (high vs low) and typology of geometric figures (curved vs rectilinear). Thus, the specific goal of this paper was to assess whether geometric complexity associated with typology of geometric figures influenced the attention deficit towards social stimuli. In addition, considering the influence that this visual attention deficit may have on the development of some cognitive processes (for example learning and memory), this study also investigated the recognition memory of this specific category of stimuli.

The underlying logic of this work is as follows:

- If the time of visual exploration and number of recognitions of children with ASD were affected both in figures with low geometric complexity and with high geometric complexity, this may be due to the presence of a non-specific attention visual deficit from the early stages of processing of stimuli (pre-attention phase).

- If children with ASD looked at and memorized figures with a low geometric complexity (irrespective of typology) better than those of high geometric complexity, then the contributing factor may be the level of complexity (geometric).
- Finally, if there was a difference in visual exploration and in memory of recognition between curved and rectangular figures, irrespective of complexity (high vs low), this would mean that the underlying factor is not the complexity, but the specific deficiency of visual exploration towards curved figures (similar in form to facial configurations).

Methods

Participants

The ASD group was comprised of 17 children (12 males and 5 females) between 36 to 72 months (M = 63.35, SD = 11.45). They were enrolled through the Institute of Applied Sciences and Intelligent Systems (ISASI) – National Research Council of Italy (CNR) – Messina and Provincial Health Service (ASP), Catania, Italy.

ASD diagnosis was made according to DSM-V criteria (APA, 2013) by an experienced multidisciplinary team including two child psychiatrists and two developmental psychologists.

The Autism Diagnostic Observation Schedule - 2 edition (ADOS-2; Lord *et al.*, 2012) was used as part of the diagnostic process.

Developmental quotient was assessed using the Griffiths Mental Development Scales (GMDS) (Griffith *et al.*, 2006). The ASD group (M = 63.35, SD = 11.45) was individually matched for gender and verbal developmental quotients (DQ) with a control group of 17 infants (M = 12, F = 5; M = 53.41; SD = 12.44) with TD. These children were recruited from private schools in Messina and Catania. The same team of experts observed also TD children and found that none of them presented any neurological or psychiatric disorders nor had a first-degree family member with a developmental, learning or neurological disorder. None of these children were on medication. Participant characteristics are summarized in Table 1.

The study protocol was approved by the Ethics Committee of the Department of the University. All participants' parents gave written informed consent.

Apparatus

Infrared eye-tracking recording was performed using SMI Eye Tracking device provided by SensoMotoric Instruments (Teltow, Germany). The SMI system measures the gaze direction of each eye and from these measurements it can be evaluated where on the screen the subject is looking. This system recorded the data of both eyes from the reflection of an infrared light source on the cornea and pupil (Billeci *et al.*, 2016).

During the task, children were seated in a chair, approximately 50–55 cm from a 22-inch flat screen monitor with a remote camera. Distance from the screen and inclination angle of the system were adjusted for each child to obtain good tracking of the eyes. Before starting the experimental task, a five-point calibration sequence run, with recording only, started when at least four points were marked as properly calibrated for each eye. To obtain calibration information, children were first shown a coloured ball that appeared in one of five locations on the screen. If calibration quality was poor or fair for any of these points, the process was repeated three times for each subject. Gaze date were recorded with a sample rate of 120 Hz and accuracy better than 1 degree of visual angle. After the calibration sequence, four arrays were presented on the monitor (Figures 1 and 2). Only during the presentation of the first array, did the experimenter gave the subject the following instruction: "Please, carefully observe the figures on the screen: circle, triangle, oval, and rhombus. Then I'll ask you what you've seen before". After each slide, a black cross was presented in the centre

Figure 1 Array with geometric figures (curved vs rectilinear)

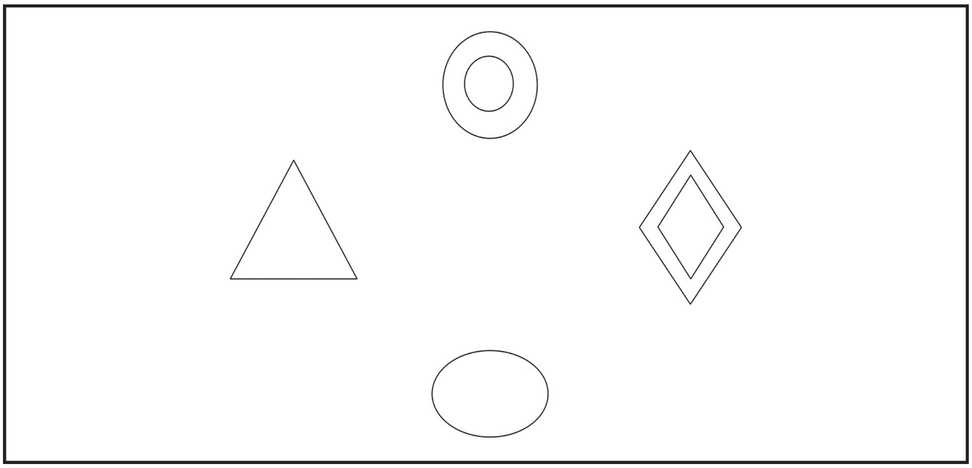
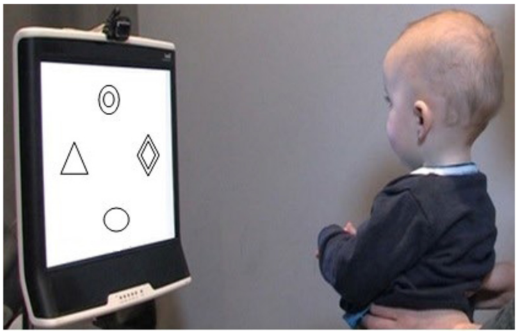


Figure 2 Position of the subject in front of the eyetracker



of the screen to ensure that the children's gaze was directed to the centre. Each array presentation lasted 10,000 ms. Subsequently, the four recognition memory tasks were presented in sequence. Only during the presentation of the first task did the experimenter ask the subject: "Which of these images have you already seen?" (The child could use two types of response: pointing to the stimulus or labelling it.) The correct answer was scored 1; the wrong one, 0. The duration of these tasks depended on the time taken by the subject to provide the answer. When children did not respond, the task timed out after 10 seconds.

Eye tracking measures

For the geometric figures of arrays, Fixation Time (FT) was evaluated, that is the sum of the fixation durations inside the area of interest (AOI). On the other hand, for the stimuli of recognition memory tasks, the sum of the correct recognized items (for each: 0 = wrong, 1 = correct) was considered.

Stimuli

In this study, a task was created with reference to the studies by Bertamini *et al.* (2016) and Belin *et al.* (2017). Specifically, with regard to the variable typology of stimuli, in particular the category of curved stimuli, we used curved stimuli presented in the study by Bertamini *et al.* (2016). Unlike in that study, the eye-tracker paradigm was used (Falck-Ytter *et al.*, 2013; Guillon *et al.* al., 2014; Chita-Tegmark, 2016) to locate and characterize the subtle variations in visual attention of subjects with ASD to the stimuli presented. In addition, to evaluate the different responses of the two groups (ASD vs. TD) compared to the two typologies of stimuli (curved vs. rectilinear), rectilinear stimuli were also included in this study (Belin *et al.*, 2017). In relation to the geometric complexity parameter (high vs. low), all the studies that conceptualized geometric complexity in terms of quantity of intrinsic elements, orientation, position, articulation and size of geometric (curved and rectilinear) figure were considered (Zhao and Stough, 2005; Wang *et al.*, 2008; Plemenos and Miaoulis, 2009; Nadal *et al.*, 2010; Bertamini *et al.*, 2016). According to these researchers, the level of geometric complexity (high vs. low) depends on the number of visible elements, the area of each element, and the distance and orientation of each element (Zhao and Stough, 2005; Wang *et al.*, 2008; Plemenos and Miaoulis, 2009; Nadal *et al.*, 2010; Bertamini *et al.*, 2016).

In accordance with these studies, in a first phase, eight geometric figures with low complexity (4 rectilinear figures: square, triangle, rhombus and rectangle; 4 curved figures: circle, oval, infinite and cornet) were produced. Subsequently, to create the same figures with high complexity, denseness/area were added to the eight geometric shapes (Anobile *et al.*, 2015; Anobile *et al.*, 2016; Cicchini *et al.*, 2016;) each of them having the same small size (Tables 2 and 3). The geometric figures (n = 16) were inserted into randomly assigned arrays (n = 4) (Figure 1). The array submission order was randomized and counterbalanced for all participants in the study.

Additionally, for the recognition memory, four recognition memory tasks were entered after each array. Each task contained a target stimulus and a distracting stimulus.

The task (calibration, arrays, fixing points and recognition memory tasks) had an average duration of approximately 4 minutes.

In order to extrapolate gaze data of each subject, rectangular AOIs were defined in the array (5 AOIs: 4 for the figures and 1 for background), in the fixing point (1 AOI) and in the recognition memory tasks (2 AOIs: 1 for the figure and 1 for distractor). The AOIs were the same size.

Table 2 Means (SD) of the fixation time of curved and rectilinear figures

Stimuli	*ASD* *Means (SD)*	*TD* *Means (SD)*
Low complexity		
Square	1.52 (2.09)	2.23 (1.67)
Triangle	1.23 (1.82)	3.29 (2.88)
Rectangle	0.76 (1.09)	2.35 (1.90)
Rhombus	2.17 (2.48)	3.52 (3.16)
Circle	1.11 (1.21)	2.17 (1.77)
Oval	0.76 (1.09)	2.76 (2.38)
Cornet	1.64 (2.05)	2.94 (2.46)
Infinity	1.00 (1.62)	2.82 (2.57)
High complexity		
Square	1.29 (1.49)	1.76 (2.27)
Triangle	1.70 (2.02)	2.94 (2.01)
Rectangle	1.29 (1.57)	3.29 (2.61)
Rhombus	1.82 (2.62)	2.88 (2.91)
Circle	2.29 (3.31)	4.17 (3.02)
Oval	2.17 (2.50)	2.00 (1.45)
Cornet	1.88 (1.83)	6.11 (3.31)
Infinity	1.88 (1.83)	6.11 (3.31)

Table 3 Means (SD) of the number of correct responses

Stimuli	*ASD Means (SD)*	*TD Means (SD)*
Low complexity		
Rectilinear	2.18 (1.55)	2.62 (1.66)
Curved	2.18 (1.32)	2.75 (1.43)
High complexity		
Rectilinear	1.81 (1.32)	3.06 (0.99)
Curved	1.75 (1.23)	2.37 (0.95)

Statistical analyses

Data were analysed using SPSS Version 24.0 for MacOS. Descriptive statistics on the characteristics of the experimental sample were presented separately for subjects with ASD and subjects with TD. Comparisons between the two groups were performed using independent samples *t*-tests. The descriptive statistics of the two groups show that there are significant differences only with respect to chronological age, t (33) = 2.37, $p < .02$, while for the quartile spread (QS) no statistically significant effects occur.

Regarding the analysis of parameters extracted from the eye-tracking, the following tests were used: repeated measures analysis of variance and *t*-tests for paired samples. The data were analysed considering two parameters: visual exploration (FT) and recognition memory (sum of correct response) of both groups (ASD and TD). Alpha level was set to 0.05 for all statistical tests. For all statistical tests, in cases of significant effects, the effect size of the test was reported.

Results

The results are presented firstly in relation to visual exploration parameters and after in relation to recognition memory. Before analyzing these two parameters, the FT of the four matrices of both groups was evaluated. An analysis of variance was performed: 2 (Groups: ASD and TD) × 4 (Order of the arrays: 1st, 2nd, 3rd and 4th). Based on the results, it was found that the order of the arrays factor has no significant effects. These data indicated that each of the four matrices was explored for the same time by both groups.

Visual exploration

With respect to the first parameter (FT), repeated measures analysis of variance with a between subject factor and two within subject factors was performed: 2 (Groups: ASD vs TD) × 2 (Geometric Complexity: High vs Low) × 2 (Typology of Figures: Curved vs Rectilinear). The Group factor showed significant effects, F (1, 32) = 12, 93, $p < 0.001$, $\eta 2p = 0.92$. This indicated that subjects with ASD, compared to subjects with TD, fixated figures within the arrays for less time. The variable Geometric Complexity also had significant effects, F (1, 32) = 12.92, $p < 0.001$, $\eta 2p = 0.91$. This indicated that when geometric complexity was high, both groups tended to fixate the stimuli for longer time than when geometric complexity was low (Table 2).

Regarding Typology of Figure (curved and rectilinear), statistically significant differences were found, F (1, 32) = 9, 92, $p < 0.001$, $\eta 2p = 0.91$. The interaction Group × Typology of Figures also showed significant effects, F (1, 32) = 3.71, $p < 0.005$, $\eta 2p = 0.92$. This indicated that subjects with ASD fixated both types of shapes for the same time; instead, subjects with TD looked at curved forms for a longer time than rectilinear ones. The interaction Groups × Complexity × Typology of Figures showed significant effect, F (1, 32) = 2.27, $p < 0.05$, $\eta 2p = 0.68$. When geometric complexity increased, subjects with

ASD, compared to subjects with TD, reduced fixations towards curved stimuli (see Figure 3).

Recognition memory

Regarding recognition memory, a repeated measures analysis of variance was performed: 2 (Groups: ASD vs TD) × 2 (Geometric Complexity: High vs Low) × 2 (Typology of Figures: Curved vs Rectilinear). The parameters considered were: FT towards the target stimulus and the distracting stimulus and Correctness of responses.

With reference to the first parameter (FT), no statistically significant differences were observed in either group.

Instead, in relation to the second parameter (Correctness of the answers), the variable ‘Group’ showed significant effects, $F(1, 32) = 3.08$, $p < 0.005$, $\eta 2p = 0.83$. This indicated that subjects with ASD, compared to subjects with TD, generally tended to remember the forms seen earlier to a lesser extent. This result was consistent with that of visual exploration. Specifically, subjects with ASD explored and recalled less rectilinear and curved shapes than the TD group (Table 3). Finally, recognition did not seem to be influenced by the other variables considered.

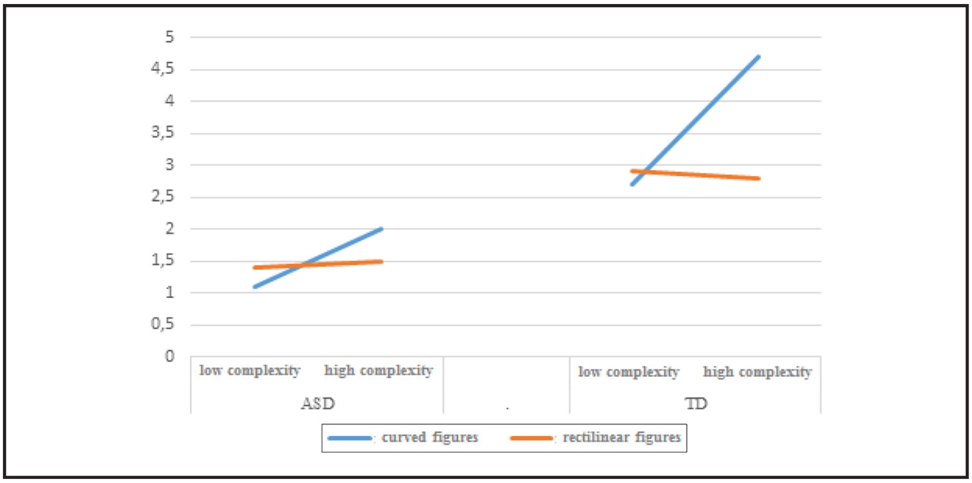
Discussion

The aim of this paper is to understand whether the visual impairment of visual exploration towards social stimuli (faces) in the development of ASD symptoms derives from an attention deficit present from the early stages of processing of stimuli. Among the variables that could cause the attention deficit to social and non-social stimuli, geometric complexity and typology of geometric shapes (curved vs. rectilinear) were evaluated in this study. The basic idea is to investigate whether the perception of geometric complexity linked to curved and rectilinear (simple and complex) figures influences the deficit towards social stimuli in subjects with ASD.

The data were analysed considering two parameters: visual exploration and recognition memory.

Visual exploration results indicate that both variables considered (geometric complexity and typology of geometric figures) were statistically significant. Specifically, as far as the

Figure 3 Fixation Time (FT) of the Interaction Group × Complexity × Typology of figures



typology of figures are concerned, the data confirm what emerged in literature, namely that subjects with TD compared to subjects with ASD look more at curved than at rectilinear lines and figures (Westerman *et al.*, 2012; Van Oel and Van Den Berkhof, 2013; Vartanian *et al.*, 2013; Palumbo, Ruta and Bertamini; 2015; Salgado-Montejo *et al.*, 2015; Bertamini *et al.*, 2016; Gómez-Puerto *et al.*, 2016; Palumbo and Bertamini, 2016; Velasco *et al.*, 2016; Cotter *et al.*, 2017). In relation to the complexity variable, the results showed that subjects with ASD seem indifferent to the complexity or to the typology of figures (curved or rectilinear) (Chien *et al.*, 2015; Belin *et al.*, 2017).

Regarding recognition memory, the results show that subjects with ASD, compared to subjects with TD, generally tend to recall previously seen rectilinear and curved shapes to a lesser extent. These data were consistent with visual exploration results. Thus, subjects with ASD did not explore or remember rectilinear and curved shapes as well as the TD group.

With reference to the hypotheses expressed in the introduction, results confirmed the three points analysed (a, b, c). Subjects with ASD a) generally had low indexes of visual exploration on all stimuli; b) they seem indifferent to both geometric complexity c) and to type of figures (curved and rectilinear). Since all the variables considered reflect an inclusive, rather than exclusive, model of deficit, it is possible to hypothesize the presence of an unspecified visual attention deficit from the early stages of processing of stimuli (c).

Following from the above, these results could be interpreted as perceptual functional antecedents that can explain the visual exploration deficit to social stimuli. Specifically, if subjects with ASD do not pay attention to curve and complex figures, this could explain their difficulty in paying attention to faces that are in themselves curved and complex stimuli.

Despite the fact that functional perceptions of the lack of orientation towards social stimuli in subjects with ASD have been investigated, the limit of the present work is the use of "abstract stimuli" (geometric figures). Therefore, future research should focus on the following aspects: a) evaluation of visual exploration and recognition memory of more ecological and naturalistic simple and complex stimuli; b) the study of simple and complex stimuli from other sensory domains (e.g. auditory) and finally c) analysis of complexity in wider samples and with subjects from different age groups (toddler, school-aged children, adolescent and adult). Because of the chosen research approach, another limitation of this research is the lack generalizability of the results. Therefore, researchers are encouraged to further test the proposed hypotheses in the future.

Conclusion

This study contributes to understanding the presence of dysfunctional perceptual antecedents that could determine general difficulties in paying attention to social stimuli in ASD subjects. Understanding this deficit from the early stages of the processing of stimuli in children with ASD has important implications for clinical and therapeutic aspects. With regard to the clinical aspect, this knowledge on how children with ASD in early stages explore some stimuli (social stimuli) allows to investigate and study specific difficulties in the control of visual attention and the consequences that these difficulties might have on important cognitive development (such as learning and memory). Moreover, from a therapeutic point of view, this knowledge could have important consequences for the timeliness of the intervention (early, intensive intervention allows to exploit the brain plasticity which is typical of the first three years of life) and for the setting of therapeutic work (such as typology of intervention, areas to be strengthened and which methodology to use based on the difficulties and the functioning capacity of the subject).

The manuscript received ethics approval and consent to participate. The datasets during and/or analysed during the current study available from the corresponding author on reasonable request. The authors declare that they have no competing interests. The author received no funding.

CC was a major contributor in writing the manuscript, RAF analysed, interpreted and wrote all the results. Both authors read and approved the final manuscript.

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