Vision Research 49 (2009) 2151–2156

Contents lists available at ScienceDirect

Vision Research

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

Search superiority in autism within, but not outside the crowding regime

Stefano Baldassi [a,c,*], Francesca Pei [c], Nicola Megna [a,c], Giorgia Recupero [a], Marco Viespoli [a], Roberta Igliozzi [b], Raffaella Tancredi [b], Filippo Muratori [b,d], Giovanni Cioni [b,d]

[a] Dipartimento di Psicologia, Università di Firenze, Firenze, Italy
[b] IRCCS Stella Maris, Calambrone, Pisa, Italy
[c] Associazione Italiana di Scienze della Visione, Cascina, Pisa, Italy
[d] Divisione di Neuropsichiatria Infantile, Università di Pisa, Italy

ARTICLE INFO

Article history:
Received 18 March 2008
Received in revised form 5 June 2009

Keywords:
Autism
Visual search
Crowding
Attention
Psychophysics

ABSTRACT

Visual cognition of observers with autism spectrum disorder (ASD) seems to show an unbalance between the complementary functions of integration and segregation. This study uses visual search and crowding paradigms to probe the relative ability of children with autism, compared to normal developments children, to extract individual targets from cluttered backgrounds both within and outside the crowding regime. The data show that standard search follows the same pattern in the ASD and control groups with a strong effect of the set size that is substantially weakened by cueing the target location with a synchronous spatial cue. On the other hand, the crowding effect of eight flankers surrounding a small peripheral target is virtually absent in the clinical sample, indicating a superior ability to segregate cluttered visual items. This data, along with evidence of an impairment to the neural system for binding contours in ASD, bring additional support to the general idea of a shift of the trade-off between integration and segregation toward the latter. More specifically, they show that when discriminability is balanced across conditions, an advantage in odd-man out tasks is evident in ASD observers only within the crowding regime, when binding mechanism might get compulsorily triggered in normal observers.

1. Introduction

Do observers with ASD see the tree but not the forest? Several studies on the visual cognition of observers with ASD have wondered whether this condition shifts the balance between the need of integration of local information into global shapes – a forest out of a pack of trees – and segregation of individual objects embedded in complex visual scenes – a tree out of a dense forest. Recent studies (Vandenbroucke, Scholte, van Engeland, Lamme, & Kemner, 2008) have advanced the possibility that the visual system of observers with autism has weaker long-range connections within V1, the neural mechanism for contour binding, and this would be reflected into a functional bias toward local information found in these observers (Iarocci & McDonald, 2006). Our companion study (Pei et al., 2009) shows that the integration system allowing the binding of contours is unresponsive, while the neural correlates of the integration of complex surfaces (i.e. textures) are intact in children with autism. Since textures processing seems to be mediated by vertical feed-back modulatory connections to V1 from higher cortical areas, this or other circuits may compensate (Pei et al., 2009; Vandenbroucke et al., 2008) and mediate the residual ability to complete contours found in several studies.

The 'forest-tree' issue is not depleted by the evidence of inefficient integration mechanisms. A system scarcely able to process the forest as a whole is supposedly more liable to segregate individual item in cluttered visual scenes. Indeed, visual search processes have been shown to suffer from the presence of distractors to a lesser extent in children with autism relative to comparable groups of normal observers (O'Riordan, 2004; O'Riordan, Plaisted, Driver, & Baron-Cohen, 2001). The ease with which ASD populations seem to ignore the presence of distractors fits well with their difficulty in some visual integration tasks if we assume that the detrimental effect of distractors hinders segregation as an effect of a compulsory form of "texture analysis when the observer does not want it to occur" (Parkes, Lund, Angelucci, Solomon, & Morgan, 2001). In other words, a weakened integration process might help in segregation tasks.

Indeed, a mechanism of compulsory texture analysis has been used to explain visual crowding in normal observers. The term 'crowding' refers to a well known phenomenon of middle vision consisting in the inhibition of identification of a known target in the presence of adjacent elements falling within the radius of 0.5E (i.e. half the eccentricity) (Bouma, 1970) and it plays a role in more complex visual behaviors such as face recognition and reading (Martelli, Majaj, & Pelli, 2005; Pelli et al., 2007).

* Corresponding author. Present address: University of Florence, Department of Psychology, Via di San Salvi, 12, Padiglione 26, 50135 Florence, Italy. Fax: +39 050 760863.
E-mail address: stefano.baldassi@unifi.it (S. Baldassi).

0042-6989/$ - see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.visres.2009.06.007

It is therefore of great importance to know whether patients with ASD show abnormal visual behavior in these tasks as it may provide a more complete framework to interpret the middle vision mechanisms of this population. The present study probes visual segregation processes in autism using two comparable paradigms for testing both visual search for sparse elements (Experiment 1) and the presence of crowding (Experiment 2) in children with autism.

2. Materials and methods

2.1. Stimuli and apparatus

Stimuli were generated in Matlab, using Psychophysics Toolbox extensions for Windows (Brainard, 1997) and presented on a 19″ Mitsubishi Diamond Plus display at 75 Hz refresh rate and with a mean luminance of 29 cd/m^2. The individual elements were Gabor patches (90% contrast cosinusoidal gratings windowed by a Gaussian luminance modulation) either vertically oriented or with a tilt off-vertical of variable amount. The spatial frequency of each element was two or four cycles per degree while the sigma of the Gaussian aperture was 0.5° or 0.25° for Experiment 1 and Experiment 2, respectively. In all conditions the stimuli were displayed for 200 ms to avoid scanning eye movements. The spatial layout of the stimuli will be reported later for each experiment separately.

2.2. Experimental procedure

Observers performed the task in a dimly lit room and were seated at a viewing distance of 57 cm from the display. In both experiments, observers were asked to discriminate the direction of tilt of a target element displayed in isolation or in the presence of distractors of varying number, all vertically oriented, and orientation discrimination thresholds were computed with the use of the QUEST adaptive procedure (Watson & Pelli, 1983). In order to sketch a full psychometric function and control for saturation effects, we jittered the threshold value computed at each trial by the QUEST procedure of an amount, set on the base of pilot sessions, that was sufficient to obtain a sigmoidal shape of the function for each observer and condition. At the beginning of the session each observer was instructed both verbally and with a standard computerized instruction tutorial that included an offline trial of the task. In the training session, they were asked to maintain the fixation at the center of the monitor, where a fixation star symbol was continuously shown. They were asked to report the direction of tilt of the only element displayed ('a circle with stripes') by manually pointing to one of two probes shown to the right and to the left of the fixation symbol (Fig. 1), each having a clear clockwise or counterclockwise tilt, respectively. When subjects reported no offset from vertical they were asked to select one of the two probes at random; however, the target stimulus was always tilted by an amount that spanned from highly discriminable offsets to values well below threshold (i.e. indistinguishable from vertical) in order for the procedure to build a psychometric curve. When the experimenter was confident that the orientation discrimination task was correctly comprehended by the subject, up to two practice sessions of the actual experiment with both target and distractors, each lasting 20 trials, were administered before the actual sessions of measure. The experimenter stored the pointing response by pressing one of two keys of a mouse. Three to six blocks of 20 trials were executed until the threshold value converged reliably. If thresholds did not converge by six blocks, the subject was excluded from the measure (see Table 1). Stimuli were presented briefly enough to prevent saccades to the target, but a second experimenter sat behind the monitor observing the gaze of the observer to ensure the stability of the fixation.

2.3. Subjects

A total of 27 observer were selected for this study, 12 of which had diagnosis of high-functioning autism made with the DSM IV (Diagnostic and Statistical Manual of Mental Disorders), the

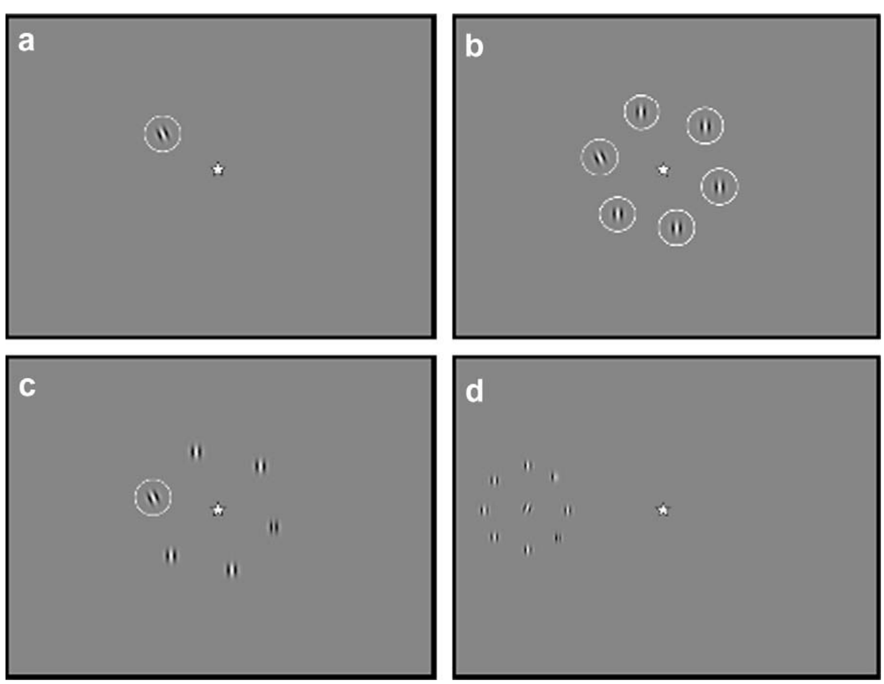

Fig. 1. Examples of the experimental conditions. Panels a to c depict the three conditions of the visual search experiment at Set Size 1 (a), Set Size 6 (b) and Set Size 6 with cue (c). The fourth panel (d) reports an example of the display for the crowding experiment. The target alone condition of this experiment (not reported) consisted in an individual tilted stimulus of the same size of the stimuli used in (d) displayed randomly to the right or to the left of fixation, at the same eccentricity of the central element of the crowded condition. Notice that the relative aspect ratio of the search (a–c) and the crowding experiment do not respect the actual differences for graphical needs. See Section 2 for details.

Table 1
Details of the groups of this study. The control group and the clinical group were constituted to be of comparable age and performance IQ (first and second line from top). The diagnostic scores of the ADOS-G and the ADI-R scales are reported from the third to the seventh line for the ASD group.

	Clinical group (*N* = 12)		Control group (*N* = 15)	
	Mean	*SD*	*Mean*	*SD*
Chronological age (years)	11.2	3.1	12.4	2.9
Non-verbal skills	90.1	12.1	96.1	7.3
ADOS-G (communication)	5.16	1.42	–	–
ADOS-G (social impairment)	8.3	2.3	–	–
ADI-R (social impairment)	18.7	3.4	–	–
ADI-R (communication)	14.4	5.4	–	–
ADI-R (repetitive interests)	6.08	2.25	–	–

ADI-R interview (Lord, Rutter, & Le Couteur, 1994) and the ADOS-G scale (Lord et al., 2000). They were all recruited from the Stella Maris Scientific Institute, Calambrone, Pisa, Italy. The other 15 observers formed the control group and was composed of elementary, middle and high-school students who were never referred to specialists for neuropsychiatric and/or neurological conditions. Table 1 reports in detail mean and standard deviation of the age and the non-verbal IQ for the two groups along with the scores of the ADOS-G and ADI-R scales for the clinical group. The two groups were matched by average performance score at the Wechsler Intelligence scales as well as by age range. Each member of the group executed both the visual search and the crowding experiment.

All the subjects of both groups have normal or corrected to normal vision. The study was approved by the Ethical Committee of the Stella Maris Scientific Institute and was therefore performed in accordance with the ethical standards of the 1964 declaration of Helsinki. Informed consent for participation was obtained from parents of all children.

3. Experiment 1. Cued and uncued visual search

This task was designed to test the observers' ability to discriminate the direction of off-vertical tilt of a target item displayed along with a variable number of vertical distractors and to verify whether any effect of distractors on performance could be modulated by exogenous attention as summoned by a spatial cue. Comparable task and stimulus layout have been extensively used in psychophysical studies to probe the mechanisms of visual search (Baldassi & Burr, 2000; Baldassi, Megna, & Burr, 2006; Baldassi & Verghese, 2002; Morgan, Ward, & Castet, 1998), indicating that individual elements are processed independently at a perceptual level nevertheless distractors hinder performance as they overwhelm the decisional stage (Palmer, 1994; Palmer, Ames, & Lindsey, 1993; Palmer, Verghese, & Pavel, 2000; Verghese, 2001).

We tested three conditions. In the Set Size 1 (SS1) condition (Fig. 1a), a unique Gabor patch was displayed in a random location around a notional annulus of 5° eccentricity and the target occupied one of the N locations at random (Fig. 1a); this served as a baseline to assess the effect of the distractors. In the Set Size 6 (SS6) condition, we added five vertical distractors that accompanied the target and the position of the target itself was unknown (Fig. 1b). In both the SS1 and the SS6 condition a white circle of radius 0.6° with a luminance of 43.6 cd/m^2 outlined each element in order to minimize the effect of spatial intrinsic uncertainty; the circles were synchronous with the stimuli in order not to expand the display duration to favor saccades to the target. In the Set Size 6 cued (SS6C) condition we cued the target location by removing the outlining circle from the five distractors. For temporal constraints on the management of patients, only six of the 12 observer from the ASD group participated to this last condition. A similar modulation has been successful in similar studies to void the effect of distractors (Baldassi & Burr, 2000, 2004).

3.1. Results

We measured orientation discrimination thresholds for 12 children with ASD (six in the cued condition) and 15 control patients at the two set sizes. Thresholds were computed by fitting the psychometric function with a cumulative Gaussian function and corresponded to a criterion level of 75% of correct discriminations (where 50% is the guessing rate in a similar 2AFC task).

This is a standard measure in psychophysics but in visual search it has the additional advantage of comparing performance in different conditions while keeping the target-distractor discriminability under control across set sizes (for review, see Verghese, 2001). Absolute thresholds are reported in Table 2, but in order to perform statistical comparisons of the set size effects in the two groups, whose absolute sensitivity differed (it was higher in the control group), we have transformed the thresholds of each individual observers by normalizing the thresholds of the SS6 and the SS6 Cued condition to the threshold at SS1, that was forced to 1. Fig. 2 reports the relative thresholds for the two conditions with distractors in the two groups, while the key comparisons are

Table 2
Descriptive summary of the results obtained in all groups and conditions. The last column reports the group size for each condition.

Condition	Group	*Mean* (°)	S.E.M.	*N*
Thresholds				
Search SSI	Control	1.15	0.16	15
	ASD	2.59	0.31	12
Search SS6	Control	4.05	0.35	15
	ASD	7.96	0.93	12
Search SS6 cue	Control	1.01	0.14	14
	ASD	5.13	1.16	6
Crowding SSI	Control	1.23	0.17	15
	ASD	3.56	0.43	12
Crowding SS9	Control	3.17	0.66	15
	ASD	3.82	0.49	12

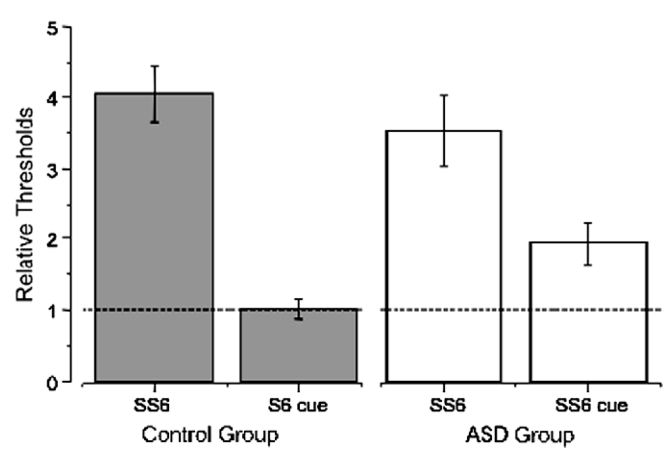

Fig. 2. Relative thresholds of the control group (left, dark gray bars) and of the group with ASD (right, light gray bars) for the Set Size 6 (left bar) and the cued condition (right bars). Each bar represents the group average of the threshold elevation factors of individual observers relative to the threshold obtained at Set Size 1, which is forced to 1. In both the control and the ASD group adding five distractors impaired performance by a factor of about 4. Cueing the target decreased threshold to reach the baseline in the control group while the control group showed a significant decrement but not sufficient to equate thresholds at SS1 (see Table 3 for statistical comparisons).

Table 3
The table shows the entire set of statistical comparisons performed on both absolute and relative thresholds. Note that comparison of absolute thresholds is required when the key condition are compared to Set Size 1, while relative thresholds get compared when it is important to reveal potential differences between the two groups of observers, in order to discount sensitivity differences.

Condition	Group	Dataset	P value	Significance
Search SS6	Control vs. ASD	Relative	0.41	NS
Search Cued	Control vs. ASD	Relative	0.022	*
Search SSI vs. Search Cued	Control	Absolute	0.54	NS
	ASD	Absolute	0.006	**
Search SS6 vs. Search Cued	Control	Relative	<0.001	**
	ASD	Relative	0.013	*
Crowding SSI vs. Crowding SS9	Control	Absolute	0.009	**
	ASD	Absolute	0.34	NS
Crowding SS9	Control vs. ASD	Relative	0.008	**

summarized in Table 3. Either group evidenced a clear effect of distractors in the SS6 condition, with thresholds increasing by a factor of about four in the Control group (Fig. 2 Dark Gray bars) and of about 3.5 in the 3.5- and 4-fold in the ASD group (Fig. 2, Light Gray bars). Importantly, the decrement of performance due to the presence of relevant distractors did not differ in the two groups ($p = 0.41$), implying no superiority in the search performance by children with ASD. Finally, in the cued condition the Control group did not differ from the Set Size 1 condition (Table 3, first line), while the ASD did (Table 3, second line). However, thresholds of the cue condition in the ASD group were significantly lower than the Set Size 6 uncued condition, suggesting that the intermediate performance could be due to a suboptimal use of the spatial cue. It is important to note that if we compared the three conditions extracting the six observers who did the SS Cued condition, we observe only one difference with the present pattern, that is a non significant difference between SS1 and SS6 Cued probably due to a naturally higher variability of the data at SS1 when considering a smaller sample, but a trend toward slightly higher threshold is evident. On the other hand, mean thresholds of the same six observers at SS6 Cued are significantly lower than at SS6, confirming the results obtained with the larger sample.

Absolute thresholds differed by a factor of more than two in the two groups, showing lower sensitivity in the group of children with ASD, but this difference did not have any impact on the relative assessment of the set size effect nor on the attentional modulation of the effect of the distractors. These data show clearly that as long as attention may act to keep individual stimuli segregated, visual processes in ASD are influenced by the context of distracting information like in normal vision.

We then executed a second set of measures of orientation discrimination for a visual target in crowding conditions, that is a spatial layout with which normal observers fail in segregating a target in a known location in the presence of abutting distractors (Gheri & Baldassi, 2008; Parkes et al., 2001).

4. Experiment 2. Crowding of oriented signals

In this task we used a psychophysical paradigm that shared task and measures with that used in Experiment 1, making possible direct comparisons, and that was successfully used in previous studies to test models of crowding (Gheri & Baldassi, 2008; Parkes et al., 2001). Specifically, observers were instructed about the spatial location of the tilted target that is crowded by a surrounding array of abutting vertical distractor. This condition is virtually identical to the cued condition of Experiment 1, in that the observer is punctually instructed about the observer's location, with the additional help of a stable target location across trials. What differed from the previous condition was the stimulus layout. Target and distractors were Gabor patches (4 c/deg sinusoidal gratings of 90% contrast windowed within a circular Gaussian aperture of sigma = 0.25° space constant). In the control condition the target was displayed alone to measure the observer's orientation discrimination threshold that served as a baseline to compare the effect of the crowding flankers. In the crowding condition (Fig. 1d), a stimulus set comprised 1 central target centered at 6° eccentricity from fixation that was always tilted and eight flanking elements, all vertical, arranged around a notional circle centered on the target's center of $\lambda 3\sqrt{2}$ radius. The entire array was randomly displayed to the left or to the right of fixation for 200 ms to ensure central fixation of the observers. Because eccentricity was a fundamental variable in this experiment, an experimenter sat behind the monitor to detect possible eye movements of the observer and trials were discarded whenever the observer gazed elsewhere from central fixation during a trial sequence (<3% of the trials).

4.1. Results

We have measured orientation discrimination thresholds of 12 children with ASD and 15 control patients for the target alone and the crowding condition. Thresholds were computed with the same procedure of Experiment 1. Absolute thresholds are reported in Table 2, but in order to perform statistical comparisons of the set size effects in the two groups, whose absolute sensitivity in the baseline condition differed by a factor of almost three, coherently with the absolute difference of the search experiment, we have transformed the thresholds of each individual observers by normalizing the thresholds of the crowding condition to the threshold obtained for the target alone, that was forced to 1. Fig. 3 reports the relative thresholds of the crowding condition in the two groups, showing no effect of the surrounding flankers in the group of

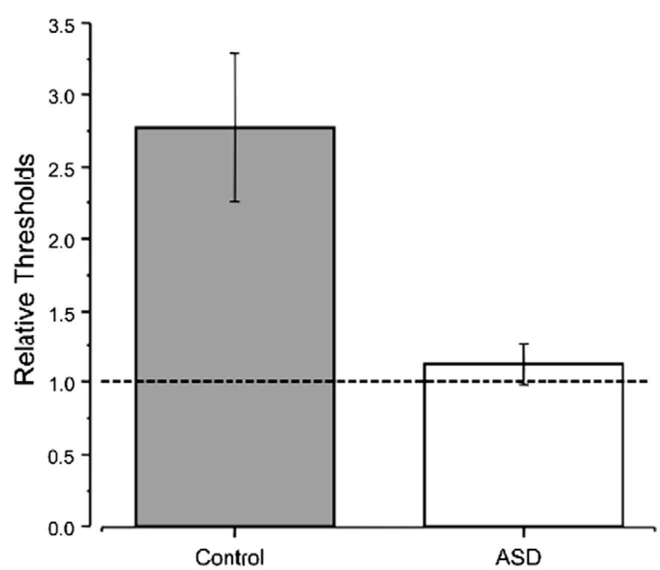

Fig. 3. Relative thresholds of the control group (dark gray bar) and of the group with ASD (light gray bar) for the Crowding experiment. Each bar represents the group average of the threshold elevation factors of individual observers relative to the threshold obtained for the target alone. The control group showed a strongly significant difference between the condition with and without distractors, while the opposite was found for the group with ASD (see the statistical comparisons between absolute thresholds in Table 3). In fact, the comparison between the two groups shows a significant reduction of the crowding effect in the group with ASD.

observers with autism, with comparable thresholds in the target alone and the crowding condition, while normal observers were affected by the crowding condition, in which thresholds were elevated by a factor of about three. The statistical significance of the effect is highlighted in the t test outputs of Table 3. A 3-fold threshold elevation is exactly what expected by the averaging model of crowding (Parkes et al., 2001), as well as by several accounts of integration of individual items into orientation defined textures (SC Dakin & Watt, 1997).

5. Discussion

In this study, we have compared the performance of two groups of observers, children with autism and children with normal development, using a psychophysical test of orientation discrimination for a visual target under different contextual and attentional conditions. In the first set of experiments we have measured thresholds for a tilted target displayed in an unknown location among a set of vertical distractors in a spatial layout with sparse stimuli that could be included in or excluded from the decision set on the base of attentional cues. In these conditions the two groups exhibited comparable effects consisting on a reduction of orientation sensitivity (higher thresholds) with increasing distractors, that is a set size effect. However, when a spatial cue consisting in one or more outlining circles shown simultaneously with the stimulus array indicated the location of the relevant items, both groups were able to segregate the important stimuli and discard completely, in the control group, or partially, in the ASD group, the uncued ones from the decisional space. In the crowding condition instead, when the stimuli were reduced in scale so to result in a small, compact array, even though the target identity was perfectly defined in the instructions and known by the observers, the control group showed the 'normal' impairment due to crowding, while the group with autism revealed a previously unknown 'superiority' – i.e. the ability to exclude flankers well within the crowding regime (i.e. the Bouma's law, Bouma, 1970) from the computation. In other words, children with autism did not show performance superiority in standard search tasks, as proposed in previous studies, but they succeded in segregating small stimuli in the presence of crowding flankers known to impair identification in a compulsory fashion in normal vision.

It is important to notice that the absolute sensitivity is not an issue here, i.e. data cannot be explained by a saturating effect of the increase of threshold for the target presented individually in the crowding experiment, because we observed a 3-fold increase in the thresholds of children with autism in all the tests executed in this study. Nevertheless, in the search experiment thresholds of observers with ASD worsened with increasing set size at a rate comparable to that observed in normal observers. The set size effect observed here is also a sign that the instructions were followed and the task was well executed in the clinical sample.

As for the difference in absolute sensitivity between the clinical and the control group, thresholds reflect noise sources at different levels, therefore it is hard to formulate specific hypotheses about what led to a general drop of sensitivity in the clinical sample. However, it is noticeable that increased levels of noise seem to be a general trait of the neural processing in autism (Dinstein et al., 2008; Markram, Rinaldi, & Markram, 2007; Rubenstein & Merzenich, 2003).

Previous studies have investigated visual search processes in children and adults with autism often finding a search "superiority" in children with autism (Brenner, Turner, & Muller, 2007; O'Riordan, 2004; O'Riordan et al., 2001; Plaisted, O'Riordan, & Baron-Cohen, 1998). However, the present study presents several novelties. First, virtually all the studies investigating visual search in ASD have measured reaction times, a measure that cannot be used to reveal the basic properties of the early levels of the visual system as suitably as the psychophysical measure of sensitivity and thresholds; additionally, they interpreted the results in light of the slope of the RTs vs. Setsize slope in different conditions, that relates to the classical serial/parallel dichotomy triggered by feature and conjunction search respectively, while we use search paradigms to probe specific properties of the spatial vision mechanisms in observers with ASD without the need of assuming particular mechanism of visual search. Noticeably, in a recent study in our laboratory (Megna & Baldassi, 2007), we have shown that reaction times in a search task are affected by the perceptual noise that arise from adding distractors as well as by noise sources at the decision stage; this suggests that reaction times cannot reveal univocally a perceptual mechanism. Second, the measure of thresholds as a fixed criterion level of accuracy throughout the range of set sizes used keeps under direct control discriminability, a factor that has been shown to be a primary variable to determine the slope of RTs vs. Set Size functions (Verghese, 2001). Third, we can tell a posteriori that the spatial layout of the stimuli, i.e. the spatial scale and the relative distance of individual elements, is an issue and it was not controlled by other studies that let target and distractors to appear at random position/eccentricities in the display. Fourth, we use visual search and crowding to probe basic processes of spatial integration/segregation rather than referring to general theories such as that of a weak central coherence.

In fact, we think that these results raise several issues for the analysis of the middle visual mechanisms in observers with ASD, especially in relationship to our finding of an absence of the neural signature for contour processing in this group of observers (Pei et al., 2009). One of the explanations of crowding (Parkes et al., 2001) raised the implication that crowding may consist in a form of compulsory texture integration when the observer does not want it to occur. Texture and contour processing on one side and crowding on the other side, are indeed the two flip sides of the same coin, possibly relying on the same mechanism for the two opposite tasks of integrating (binding) and segregating, respectively. Crowding can be thought of as mediated by an 'integration field', a second order field that combines features extracted at the elementary level within a given area (Toet & Levi, 1992). It has been proposed that the integration field and the 'association field' (an idea proposed to explain contour binding over quasi-colinear paths (Field, Hayes, & Hess, 1993)) coincide (May & Hess, 2007; Pelli, Palomares, & Majaj, 2004). Moreover, the possibility that crowding depends on long-range intra-cortical connections, the most plausible neural mechanism for contour binding (Cass & Alais, 2006; Gilbert, Das, Ito, Kapadia, & Westheimer, 1996), cannot be ruled out completely (Levi, 2008). Finally, although literature on the development of crowding is scarce, there are data indicating a relatively late development (Atkinson, 1991), similar to what happens to contour integration (Kovacs, Kozma, Feher, & Benedek, 1999). If we relate the present psychophysical results with the electrophysiological finding that observers with ASD lack the neural signature of one of the two key integration tasks, it is then legitimate to raise the suggestion that the ability to resist to crowding is due to the lack of 'compulsory' integration in observers with ASD (see Dakin & Frith, 2005 for review). The natural trade-off between integration and segregation, the forest and the trees, which in normal vision is biased toward integration for patterns within the crowding range, moves substantially in these categories of observers who show superior segregation abilities under these conditions.

6. Conclusions

Understanding the perceptual processes in ASD is a hard task that has been considered more and more important in the last few years, also due to the expansion of the diagnosed cases. We think we have made a contribution toward the underpinning of the middle vision processes in children with autism, a necessary step to fully comprehend their visual cognition process without neglecting the constraints posed by the low, hard wired levels of the visual system. The neural mechanisms for binding contours were not detected by our VEP paradigm (Pei et al., 2009), and this could reflect into abnormally better segregation skills such as the ones we observed in crowding. One of the skills that is directly related to our present findings is the span of enumeration of visual objects, which seems to be greatly expanded in autistic observers (Gagnon, Mottron, Bherer, & Joanette, 2004). We are currently investigating whether this happens and, in case, if it is just a matter of the way to deal with visual clutter in ASD observers.

Acknowledgments

We thank an anonymous referee for suggesting substantial improvements to earlier versions of this manuscript. This work was supported by a Grant of the Cure Autism Now Foundation (USA) and by the Italian PRIN 2007.

References

Atkinson, J. (1991). Review of human visual development: Crowding and dyslexia. In J. Stein (Ed.), *Vision and visual dyslexia*. Boca Raton: CRC Press.
Baldassi, S., & Burr, D. (2000). Feature-based integration of orientation signals in visual search. *Vision Research, 40*(10–12), 1293–1300.
Baldassi, S., & Burr, D. (2004). Pop-out of targets modulated in luminance or colour: The effect of intrinsic and extrinsic uncertainty. *Vision Research, 44*(12), 1227–1233.
Baldassi, S., Megna, N., & Burr, D. (2006). Visual clutter causes high-magnitude errors. *PLoS Biology, 4*(3), e56.
Baldassi, S., & Verghese, P. (2002). Comparing integration rules in visual search. *Journal of Vision, 2*(8), 559–570.
Bouma, H. (1970). Interaction effects in parafoveal letter recognition. *Nature, 226*(5241), 177–178.
Brenner, L., Turner, K., & Muller, R. (2007). Eye movement and visual search: Are there elementary abnormalities in autism? *Journal of Autism Developmental Disorders, 37*(7), 1289–1309.
Cass, J., & Alais, D. (2006). The mechanisms of collinear integration. *Journal of Vision, 6*(9), 915–922.
Dakin, S., & Frith, U. (2005). Vagaries of visual perception in autism. *Neuron, 48*(3), 497–507.
Dakin, S., & Watt, R. (1997). The computation of orientation statistics from visual texture. *Vision Research, 37*(22), 3181–3192.
Dinstein I., Thomas C., Humphreys K., Minshew N., Behrmann M., & Heeger, D. J. (2008). *Dysfunctional mirror neurons and Autism – A doubtful connection.* In Paper presented at the International Meeting for Autism Research, London, UK.
Field, D., Hayes, A., & Hess, R. (1993). Contour integration by the human visual system: Evidence for a local association field. *Vision Research, 33*(2), 173–193.
Gagnon, L., Mottron, L., Bherer, L., & Joanette, Y. (2004). Quantification judgement in high functioning autism: Superior or different? *Journal of Autism Developmental Disorders, 34*(6), 679–689.
Gheri, C., & Baldassi, S. (2008). Non-linear integration of crowded orientation signals. *Vision Research, 48*(22), 2352–2358.
Gilbert, C., Das, A., Ito, M., Kapadia, M., & Westheimer, G. (1996). Spatial integration and cortical dynamics. *Proceedings of the National Academy of Sciences of the United States of America, 93*(2), 615–622.
Iarocci, G., & McDonald, J. (2006). Sensory integration and the perceptual experience of persons with autism. *Journal of Autism Developmental Disorders, 36*(1), 77–90.
Kovacs, I., Kozma, P., Feher, A., & Benedek, G. (1999). Late maturation of visual spatial integration in humans. *Proceedings of the National Academy of Sciences of the United States of America, 96*(21), 12204–12209.
Levi, D. (2008). Crowding-an essential bottleneck for object recognition: A mini-review. *Vision Research, 48*(5), 635–654.
Lord, C., Risi, S., Lambrecht, L., Cook, E. J., Leventhal, B., DiLavore, P., et al. (2000). The autism diagnostic observation schedule-generic: A standard measure of social and communication deficits associated with the spectrum of autism. *Journal of Autism Developmental Disorders, 30*(3), 205–223.
Lord, C., Rutter, M., & Le Couteur, A. (1994). Autism diagnostic interview-revised: A revised version of a diagnostic interview for caregivers of individuals with possible pervasive developmental disorders. *Journal of Autism Developmental Disorders, 24*(5), 659–685.
Markram, H., Rinaldi, T., & Markram, K. (2007). The intense world syndrome – an alternative hypothesis for autism. *Frontiers of Neurosciences, 1*(1), 77–96.
Martelli, M., Majaj, N., & Pelli, D. (2005). Are faces processed like words? A diagnostic test for recognition by parts. *Journal of Vision, 5*(1), 58–70.
May, K., & Hess, R. (2007). Ladder contours are undetectable in the periphery: A crowding effect? *Journal of Vision, 7*(13). 9.1-15.
Megna, N., & Baldassi, S. (2007). Direct behavioural evidence of the effect of internal noise on the time course of perceptual decisions. *Perception, 36* (ECVP Abstract supplement).
Morgan, M., Ward, R., & Castet, E. (1998). Visual search for a tilted target: Tests of spatial uncertainty models. *The Quarterly Journal of Experimental Psychology A. Human Experimental Psychology, 51*(2), 347–370.
O'Riordan, M. (2004). Superior visual search in adults with autism. *Autism, 8*(3), 229–248.
O'Riordan, M., Plaisted, K., Driver, J., & Baron-Cohen, S. (2001). Superior visual search in autism. *Journal of Experimental Psychology-Human Perception and Performance, 27*(3), 719–730.
Palmer, J. (1994). Set-size effects in visual search: The effect of attention is independent of the stimulus for simple tasks. *Vision Research, 34*(13), 1703–1721.
Palmer, J., Ames, C., & Lindsey, D. (1993). Measuring the effect of attention on simple visual search. *Journal of Experimental Psychology-Human Perception and Performance, 19*(1), 108–130.
Palmer, J., Verghese, P., & Pavel, M. (2000). The psychophysics of visual search. *Vision Research, 40*(10–12), 1227–1268.
Parkes, L., Lund, J., Angelucci, A., Solomon, J., & Morgan, M. (2001). Compulsory averaging of crowded orientation signals in human vision. *Nature Neuroscience, 4*(7), 739–744.
Pei, F., Baldassi, S., Procida, G., Igliozzi, R., Tancredi, R., Muratori, F., et al. (2009). Neural correlates of texture and contour integration in children with autism spectrum disorders. *Vision Research*.
Pelli, D., Palomares, M., & Majaj, N. (2004). Crowding is unlike ordinary masking: Distinguishing feature integration from detection. *Journal of Vision, 4*(12), 1136–1169.
Pelli, D., Tillman, K., Freeman, J., Su, M., Berger, T., & Majaj, N. (2007). Crowding and eccentricity determine reading rate. *Journal of Vision, 7*(2). 20.21-36.
Plaisted, K., O'Riordan, M., & Baron-Cohen, S. (1998). Enhanced visual search for a conjunctive target in autism: A research note. *Journal of Child Psychology and Psychiatry, 39*(5), 777–783.
Rubenstein, J. L., & Merzenich, M. M. (2003). Model of autism: Increased ratio of excitation/inhibition in key neural systems. *Genes Brain Behavior, 2*(5), 255–267.
Toet, A., & Levi, D. (1992). The two-dimensional shape of spatial interaction zones in the parafovea. *Vision Research, 32*(7), 1349–1357.
Vandenbroucke, M., Scholte, H., van Engeland, H., Lamme, V., & Kemner, C. (2008). A neural substrate for atypical low-level visual processing in autism spectrum disorder. *Brain, 131*(Pt 4), 1013–1024.
Verghese, P. (2001). Visual search and attention: A signal detection theory approach. *Neuron, 31*(4), 523–535.
Watson, A., & Pelli, D. (1983). QUEST: A Bayesian adaptive psychometric method. *Perception and Psychophysics, 33*(2), 113–120.