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ORIGINAL PAPER

Visual Search Targeting Either Local or Global Perceptual Processes Differs as a Function of Autistic-Like Traits in the Typically Developing Population

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Abstract Relative to low scorers, high scorers on the Autism-Spectrum Quotient (AQ) show enhanced performance on the Embedded Figures Test and the Radial Frequency search task (RFST), which has been attributed to both enhanced local processing and differences in combining global percepts. We investigate the role of local and global processing further using the RFST in four experiments. High AQ adults maintained a consistent advantage in search speed across diverse target-distracter stimulus conditions. This advantage may reflect enhanced local processing of curvature in early stages of the form vision pathway and superior global detection of shape primitives. However, more probable is the presence of a superior search process that enables a consistent search advantage at both levels of processing.

Keywords Autism-Spectrum Quotient · Visual search · Embedded Figures Test · Radial frequency patterns · Visual processing

Introduction

Superior search ability in individuals with autism or high levels of autistic-like traits has been extensively researched (Almeida et al. 2010a; Jarrold et al. 2005; Jolliffe and Baron-Cohen 1997; O'Riordan 2004; O'Riordan et al. 2001; Plaisted et al. 1998b; Shah and Frith 1983; Simmons et al. 2009). One visual search task that has been particularly effective in demonstrating this enhanced performance is the Embedded Figures Test (EFT; Witkin et al. 1971), which requires searching for and detecting a simple shape 'embedded' within a more complex structure. The EFT was constructed atheoretically by camouflaging a simple shape through the introduction of various factors, such as overlap, segmentation and colour variation. Therefore our previous studies (Almeida et al. 2010a, b) sought to systematically deconstruct the EFT to determine which properties are critical in enabling superior performance by those with high levels of autistic-like characteristics.

Almeida et al. (2010a) created a new visual search task using radial frequency (RF) patterns as elements. These are closed contours produced by sinusoidal modulation of the radius as a function of polar angle (Wilkinson et al. 1998) and the RF of a pattern refers to the number of cycles of deformation (see Fig. 1 for example patterns). RF patterns are mathematically well-defined shapes and can be manipulated in a controlled manner (Loffler et al. 2003). Further, they can be linked to specific neural mechanisms, with local curvature being first extracted in early cortical areas V1 and V2 (Poirier and Wilson 2006) and the global shape then determined in area V4 (Gallant et al. 1996; Pasupathy and Connor 2002; Wilkinson et al. 2000) using a process that detects the polar angle between points of maximum curvature (Bell et al. 2008). Almeida et al.'s (2010a) first study examined whether enhanced ability to de-clutter (or ignore overlap) was the basis for superior search ability in individuals with high levels of autistic traits, as measured with the Autism-Spectrum Quotient (AQ; Baron-Cohen et al. 2001). The reaction time (RT) for detecting a target (RF3) was measured as a function of the number of distracter (RF4) elements in the display. The

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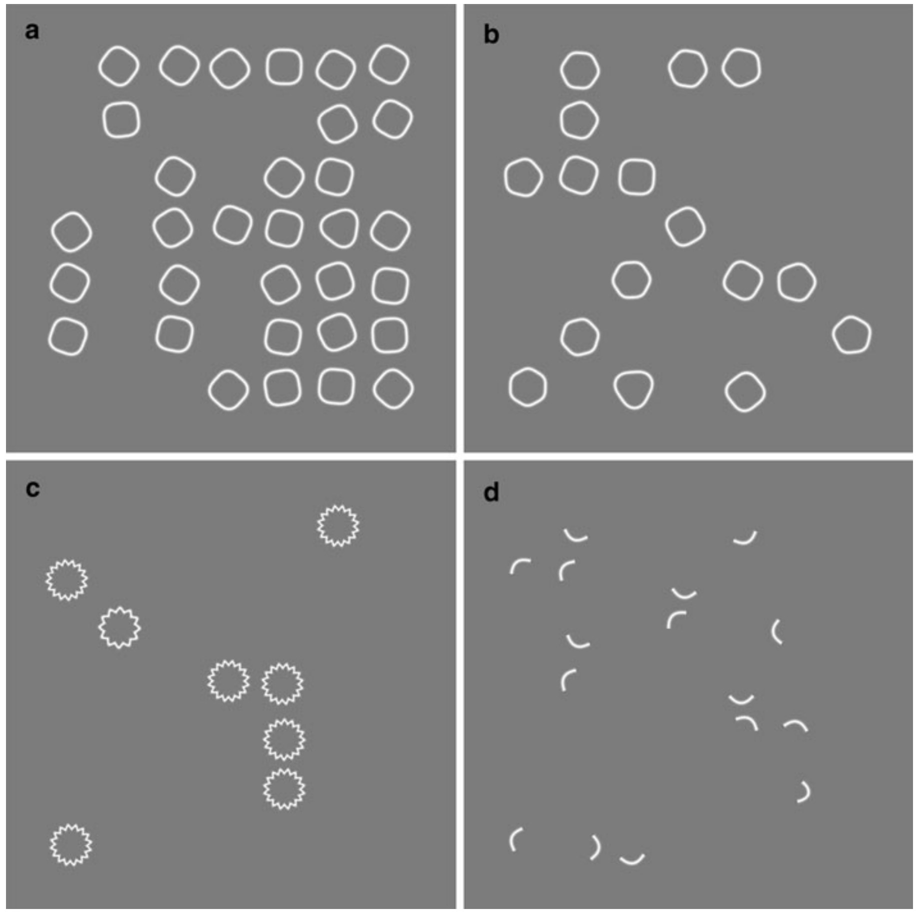

Fig. 1 Examples of the stimuli used for each of the four experiments. **a** Presents a SS 32 example of the stimuli used in Experiment 1 where the target was an RF3 and the distracters were RF4s. **b** Displays a SS 16 example from Experiment 2 where the target was an RF3 and the distracters were a combination of RF4s, RF5s, and RF6s. An example from Experiment 3 with a SS of 8 is presented in **c** where the target was an RF12 and the distracters were RF16s. **d** Illustrates an example of the stimulus display from Experiment 4, where the target was a segment of an RF3 and the distracters were segments of RF4s. A SS of 16 is presented here

slope of the function relating RT to set size (SS) provided a critical indicator of search efficiency. Clutter was manipulated systematically by overlapping the RF stimuli. The high AQ group showed more efficient search (i.e. shallower slopes for the RT functions) than the low AQ group in *all* clutter conditions. That is, while clutter did increase task complexity and slow search for both groups, the relative advantage in slope of the RT function for the high relative to the low AQ group remained constant across conditions (and was present even when no overlap of elements existed, e.g. see Fig. 1a). Almeida et al. (2010a) concluded that overlap was not critical for observing the difference between groups, and thus could not account for the superior search observed by individuals with high AQs. Almeida et al. (2010a) proposed that the high AQ group may have weaker inhibitory interactions between RF-tuned channels, allowing the target to be processed more independently of the distracters.

In the EFT, spurious segmentation cues are introduced through the use of additional lines. To mimic this feature of the test, Almeida et al. (2010b) introduced two random lines traversing a surrounding box in order to segment the display in the RF search task, which again involved detecting an RF3 from a background of spatially discrete RF4 patterns. The lines were constrained to have a variety of specific interactions with either target or distractor elements. Consistent with the earlier study, the high AQ group demonstrated superior search (i.e. shallower slopes) in all conditions. The addition of lines resulted in increased intercepts for the fitted functions but it did not provide any additional differentiation between the two groups, signifying that lines as segmentation cues in the EFT are unlikely to be critical in producing the search performance differences between high and low AQ groups (Almeida et al. 2010b).

Previous explanations of superior EFT performance have argued for weak central coherence (WCC) which describes a weakened ability of individuals with autism to perceive the global configuration of a visual display, paired with attention to the local elements which make up the whole (Frith 1989; Frith and Happe 1994; Happe 1999; Shah and Frith 1983, 1993). More recently, WCC has been redefined as superior local processing ability without a necessary deficit in global processing (Happe and Frith 2006). This is consistent with the enhanced perceptual functioning (EPF) framework (Mottron et al. 2006; Mottron and Burack 2001) which describes superior low-level and local processing with no accompanying global or 'integrative' deficit (Manjaly et al. 2007; Mottron et al. 1999, 2003; Ozonoff et al. 1994; Plaisted et al. 1999). In examining these propositions, the terms 'local' and 'global' have acquired an array of meanings in the literature. In WCC, the terms usually refer broadly to a simple 'target' within a wider meaningful 'context', for instance, a homograph within a contextual sentence (e.g. tear in "In her eye/dress there was a big tear"; Happe 1997) or a simple shape (e.g. triangle) embedded within a complex structure (e.g. a grandfather clock, a trial in the Children's Embedded Figures Test; Witkin et al. 1971). However, at other times, such meaning is not evident in the complex structure (e.g. as with the complex shapes used in the adult EFT). With various interpretations possible for 'local' and 'global', a diverse set of visual tasks has been used to investigate WCC. Indeed, Milne and Szczerbinski (2009) identified 14 visual tasks attempting to assess local or global processing or the relative influence of the two. Significantly, when Milne and Szczerbinski administered those tasks to neurotypical adults and subjected the data to exploratory analysis, seven factors emerged, indicating divergence in the processes assessed. Given the varied, and at times poorly specified, use of the terms 'global' and 'local', the implications of research findings in terms of specific underlying visual and cognitive mechanisms have been limited.

In the vision literature, RF patterns have been used to provide evidence of both global and local contributions to shape discrimination, irrespective of stimulus size (Grinter et al. 2010; Bell and Badcock 2008; Bell et al. 2007; Loffler 2008; Loffler et al. 2003). That is, rather than referring to a 'local' target shape in a 'global' structure, as is often the case in the WCC literature, the terms are used in the research on RF patterns to refer to processing based either on local pattern features (e.g. curvature maxima) or, alternatively, on the whole of a connected contour. Researchers have employed patterns varying in RF to study different levels of form processing (Loffler et al. 2003; Wilkinson et al. 1998; Grinter et al. 2010; Bell et al. 2007) by measuring the degree of deformation required to differentiate between a circle and an RF pattern. Loffler et al. (2003) established that the modulation in RF patterns is detected by global processes when the modulation frequency is low (less than approximately 10 cycles per 360°). This was indicated by a rapid decrease in the modulation threshold as more complete cycles of a specified frequency were added to the contour (Bell and Badcock 2008; Poirier and Wilson 2006; Wilkinson et al. 1998). Evidence from fMRI has indicated that this global pooling of orientation information for low RF patterns occurs in V4 (Wilkinson et al. 2000). In contrast, a shallower decrease in threshold with additional cycles of deformation was observed for stimuli of higher radial frequency, with the rate of improvement predictable by probabilistic summation of local detection processes, suggesting each deformation was detected independently, possibly using local orientation-tuned cells in V1 (Loffler et al. 2003).

The simple closed-contours used as targets in the EFT have corner frequencies in both the local and global ranges (i.e. some simple shapes have only four corners, whereas others have up to 12). However, it is uncertain whether this aspect of the simple shapes is critical to EFT superiority in individuals with high levels of autistic traits. It is important to note that in this study we are not referring to a 'local' target *within* a 'global' context. Rather, all tasks employ an array of elements with the target being an element within it, and, instead, we vary the nature of the individual elements to systematically address local and global contour-processing within the visual system.

The aim of the current study, then, was to manipulate the elements of the search task (i.e. the RF patterns) to examine whether employing targets that require either global or local closed-contour detection processes influences the performance difference between high and low AQ groups on the RF search task. If individuals with high levels of autistic-like traits have enhanced local processing abilities, they may display a superior search advantage on tasks which require local visual processing mechanisms. First, high and low AQ groups were selected, and their performance on the EFT was examined to determine whether high levels of autistic-like traits correlated with increased EFT search ability, as previously observed (Almeida et al. 2010a, b; Russell-Smith et al. 2010; Grinter et al. 2009a, b). In addition, each group completed a series of four experiments, which involved various manipulations of the RF search task (Almeida et al. 2010a). As noted earlier, at deformation threshold, patterns with low RFs have been shown to be processed globally while high RF patterns depend on local detection processes (Bell and Badcock 2008; Bell et al. 2007; Loffler et al. 2003). These thresholds represent minor deviations from circularity and would render a search task very onerous, so for the search tasks here, suprathreshold versions of the stimuli were chosen as before (Almeida et al. 2010a). These suprathreshold low RF patterns evoke global contour processing (Bell et al. 2009, 2010; Bell and Kingdom 2009; Schmidtmann et al. 2012). One consequence of employing suprathreshold patterns is that they take on the appearance of different shapes (triangles, squares, etc.), similar to EFT targets, rather than approximations to circles. The experimental manipulations, described in detail below, first examined search performance with a globally processed RF target among arrays composed using a single type of globally detected RF distracter. Secondly, the target was presented among several types of globally detected RF distracters, as the distracting elements in the EFT are not a uniform array of the same element. Next, locally detected RF targets and distracters were used, to see if the global or local property is central to the search advantage previously identified for high AQ scorers. Finally, single lobes of the RF patterns were used as the search task elements to determine whether closed contours are required or whether instead local aspects of the contours are sufficient to obtain the performance differences.

General Method

Participants

The AQ was administered to 812 undergraduates from the University of Western Australia. Volunteers from the upper and lower 15 % of scorers formed the high AQ ($n = 19$) and low AQ ($n = 25$) groups that completed all experiments in this study (see Table 1 for descriptive statistics). There were no significant differences between groups in IQ ($t(42) = 1.828$, $p = .077$) or gender distribution ($\chi^2(1, N = 44) = .053$, $p = .817$). All had normal or corrected-to-normal visual acuity (assessed using a Snellen chart). The research was approved by the Human Research Ethics Committee at the University of Western Australia.

Psychometric Measures

The AQ (Baron-Cohen et al. 2001) was administered to determine the level of autistic-like characteristics reported by an individual. Possible scores could range from 0 to 50, higher scores indicating more self-reported autistic-like traits. Although the AQ is not used as a diagnostic tool, Baron-Cohen et al. (2001) identified that a clinical cut-off score of 32 captured the majority of adults with Asperger Syndrome and high functioning autism. Form A of the EFT (Witkin et al. 1971) was administered and scored in accordance with the manual. Performance on the EFT was indexed by the mean search RT (in s) across the 12 trials of the test (Almeida et al. 2010a; Grinter et al. 2009a; Jolliffe and Baron-Cohen 1997; Witkin et al. 1971) and by the number of errors. The two subtest form (Vocabulary and Matrix Reasoning) of the Wechsler Abbreviated Scale of Intelligence (WASI; Weschler 1999) was administered to ensure matching of groups on general ability.

Table 1 Descriptive statistics of high and low AQ group characteristics

	Low AQ ($N = 25$)	High AQ ($N = 19$)
Male:female	6:19	4:15
AQ	9.28 (1.84)	26.79 (4.57)
Cut-off	≤11	≥23
IQ	112.10 (8.21)	117.20 (10.08)
EFT RT (s)	31.60 (13.36)	20.46 (10.74)
EFT errors	5.24 (3.88)	3.63 (2.61)

Male–female ratio and means (and SD) for AQ, IQ, EFT RT (s) and EFT errors

Apparatus and Materials

The experimental protocol for all four RF search tasks was written in Matlab 7.0 (Mathworks, Natick, MA, USA) and implemented on a PC (Pentium 4-3 GHz). The stimuli were presented on a Sony Trinitron G520 monitor from the frame buffer of a ViSaGe [Cambridge Research Systems (CRS), Kent, UK] visual stimulus generator. The screen resolution was 1,024 × 768 (w × h) pixels, with a refresh rate of 100 Hz, and a background luminance of 45 cd/m^2. Luminance calibration was executed using an Optical OP 200-E photometer (head model number 265) and associated software (CRS; Metha et al. 1994). A chinrest maintained the constant viewing distance of 65.5 cm where one pixel subtended 2′, generating a display area of 34.13° × 25.60° (w × h). Observers indicated their decisions using a CB6 button box (CRS).

Stimuli

All stimuli were derived from RF patterns. Participants were required to detect a target RF pattern within a background of distracter RF stimuli. Individual RF patterns were created by a radial sinusoidal modulation to a base circle, such that the radius at polar angle (θ) is:

$$r(\theta) = r_{\text{mean}}(1 + A\sin(\omega\theta + \varphi)) \quad (1)$$

where r_{mean} is the mean radius (1° unless otherwise specified), A is the radial modulation amplitude, and ω is the radial frequency. The orientation of the pattern is determined by its angular phase (φ). On each trial the RF stimuli were randomly presented on the points of intersection of an implicit 7 × 7 grid providing 49 potential positions. The centre-to-centre separation of the RF patterns was approximately three degrees, and the orientation of the RF stimuli was randomised by varying φ. To ensure the RF stimuli did not strongly group into rows and columns, they were displaced a random amount (±12 arcmin) vertically and horizontally from their grid positions for each trial. The luminance profile of the RF stimuli was Gaussian along the radius (the standard deviation of the Gaussian was 4 arcmin so the full width of the Gaussian at half maximum contrast was 9.4 arcmin).

In each trial, the SS (i.e. number of RF patterns) in the stimulus display was one of either five (Experiments 1 and 3) or four (Experiments 2 and 4) potential sizes, with the SSs randomly interleaved across trials. The target RF was included in the display on 50 % of trials.

Procedure

Each observer in the high and low AQ groups was administered the WASI, EFT and all four RF search tasks during two sessions (total testing time was approximately 2.5 h). The order of the four RF search tasks was randomised across participants. For all RF search tasks, a single-interval forced choice RT procedure was used, in which participants were instructed to indicate whether the specified target was present or not amongst an array of distracter RF stimuli as quickly and accurately as possible. A response was made by pressing the left or right button of the button box if the target was present or absent respectively. RT was calculated as time taken to respond following the pattern onset and RT was recorded with 100 µs resolution. To maintain optimum performance, auditory feedback (a high or low tone) indicating accuracy was provided after each response. A practice block (containing 100 trials for Experiments 1–3 and 80 trials for Experiment 4) was completed prior to the test blocks for each RF search task.

Data Analysis

Only correct responses were included in the calculation of RTs and the lower limit of performance accuracy was set at 75 %. As the data were skewed, which is typical of search tasks (Setti et al. 2006; Storms and Delbeke 1992), the logarithm of the RTs was taken. Any log RT >3 SDs from the mean for each cell (AQ group × target present/absent × SS) in the design was considered an outlier and subsequently removed (although this resulted in less than 1 % of trials being excluded across all conditions for each experiment). The antilog of the mean of the log RT distribution was then taken and is quoted as RT below. The assumptions for ANOVA were all met for the following analyses.

To determine whether significant differences in search task accuracy existed between groups, 5 × 2 repeated measures ANOVAs, with SS as the within-subjects variable and AQ group as the between-subjects variable, were conducted for the target present and target absent data (4 × 2 ANOVAs were performed for Experiments 2 and 4 as only four SSs were used).

For the critical comparisons of the high and low AQ groups for search speed, ANOVAs of the same design (SS × AQ group) were conducted for the target present and target absent RT data. A significant main effect of AQ group would be expected if the high AQ group were faster overall than the low AQ group and a significant interaction would be expected if the high AQ showed less of an increase in RT as a function of SS (shallower slope) compared to the low AQ group.

In order to compare performance between the two groups within each of the four RF search task experiments, the RT for each SS was calculated for each observer. The mean RT data for each group were fit using linear regression and the gradient of the linear function was used as a measure of the effect of increasing SS. To examine the relative performance of the groups across the four experiments, a ratio between the two groups' gradients for each experiment was then calculated, with error bars around the ratios generated using standard error propagation techniques (Almeida et al. 2010a; Meyer 1975). As the errors in the ratio of the gradients for the high and low AQ groups were uncorrelated, the errors were added in quadrature (Almeida et al. 2010b).[1]

Finally, a Pearson product-moment correlation was calculated between participants' gradients for each RF search task (for the target present data) and their EFT scores (mean RT) to determine whether performances on the tasks were related. It was expected that correlations would be enhanced given that high and low AQ groups differ in both EFT performance (Almeida et al. 2010a; Grinter et al. 2009a; Russell-Smith et al. 2010) and search gradients (Almeida et al. 2010a, b). Therefore, analyses of covariance (Zar 1984) were performed to establish whether a common linear relationship between EFT RTs and search task gradients adequately characterised the two groups within each experiment.

Experiment 1: Target RF3, Distracter RF4

Stimuli

The target was an RF3 and distracters were RF4 patterns (Fig. 1a). The modulation amplitude, A, was defined as $1/(1 + \omega^2)$ ($\omega = 3$ or 4) so that the RF target and distracters would have flat sides and resemble triangles and squares (for RF3 and RF4, respectively) with curved vertices. Additionally, the maximum local curvature of any RF pattern with this amplitude is identical and therefore, discriminating target and distracter RF patterns is not possible using a local curvature detection mechanism.[2] Previous

[1] The standard deviation of a ratio (σ_r) depends on the individual gradients being compared, a & b, their standard deviations (σ_a & σ_b) and the correlation between the two measures (ρ_{ab}) as follows: $\sigma_r = \frac{a}{b}\sqrt{\left(\frac{\sigma_a}{a}\right)^2 + \left(\frac{\sigma_b}{b}\right)^2 - 2\frac{\sigma_a\sigma_b}{ab}\rho_{ab}}$

Since the correlation (ρ_{ab}) is zero for the current data the final term has no impact on the calculation in this case.

[2] The modulation applied to the RF3 and RF4 contours results in identical maximum curvatures at a single point on the contours. Although the receptive fields of curvature detectors are not restricted to an infinitely small region and contours in the vicinity of the point of maximum curvature will differ between target and distracters, a local curvature detection mechanism cannot account for discriminating between the two, as an investigation of RF3 detection threshold differences between high and low AQ groups revealed no threshold curvature detection differences (Almeida et al. 2011).

literature suggests that the target is discriminated from distracter RFs through employing a global mechanism of analysis, which determines the angular separation between points of maximum curvature at the centre of the figure (Bell et al. 2008; Poirier and Wilson 2006). SSs used were 2, 4, 8, 16, and 32 RF patterns. Each observer was presented with 200 trials that contained the target, and 200 trials that did not, with 40 trials per SS in each case.

Results

The EFT RT and EFT error means and standard deviations for the high and low AQ groups are presented in Table 1. The high AQ group had significantly shorter EFT RTs than the low AQ group ($t(42) = 2.974$, $p < .01$, $d = .92$), and no significant difference in EFT errors was observed between the groups ($t(42) = 1.558$, $p = .127$).

As no observer's performance fell below the lower limit set for accuracy in the RF search task, no data were excluded.[3] The accuracy of the groups did not differ in the target present data ($F(1, 42) = 2.203$, $p = .145$, $\eta^2 = .050$), nor was the SS × AQ group interaction significant ($F(4, 168) = .135$, $p = .969$, $\eta^2 = .003$). Similar results were observed in the target absent accuracy data, with no main effect of AQ group ($F(1, 42) = 2.479$, $p = .123$, $\eta^2 = .056$) and no significant SS × AQ group interaction ($F(4, 168) = .535$, $p = .710$, $\eta^2 = .013$) detected. In contrast, when comparing speed of performance on the RF search task, there was a main effect of AQ group in the target present ($F(1, 42) = 10.986$, $p < .01$, $\eta^2 = .207$) and target absent ($F(1, 42) = 17.451$, $p < .001$, $\eta^2 = .294$) data. Further, there was a significant AQ group × SS interaction effect in both the target present ($F(4, 168) = 19.315$, $p < .001$, $\eta^2 = .315$) and target absent ($F(4, 168) = 14.276$, $p < .001$, $\eta^2 = .254$) data. That is, the high AQ group were faster overall and had shallower slopes for RT as a function of SS than the low AQ group.

The RF search task gradient (change in RT with SS) for each group was calculated as a measure of search efficiency (see Fig. 2a). The ratio of the gradients demonstrated that the high AQ group was significantly faster in search time per element than the low AQ group (see Fig. 3, Experiment 1).

EFT RT was significantly correlated with the RF search task gradient (Fig. 4a), demonstrating that shorter EFT RTs were associated with smaller RF search task gradients. Analysis of covariance established that a common linear relationship between these two variables was adequate to characterise the high and low AQ groups ($F(1, 40) = 1.235$, $p = .273$).

[3] This was true for all four RF search task experiments.

Discussion

As previously observed (Almeida et al. 2010a, b; Grinter et al. 2009b; Russell-Smith et al. 2010), the high AQ group were significantly faster than the low AQ group on the EFT. Further, this enhanced performance was not the result of a speed-accuracy trade-off, as no significant group differences in error rates were observed. Performance on the RF search task also demonstrated no significant differences in accuracy between the two groups. The high AQ group were overall significantly faster, as well as less affected by the increasing SS, in target present and target absent conditions of the RF search task, relative to the low AQ group. These search task results replicate, in a different group of participants, the finding that individuals with higher levels of autistic-like traits are faster in locating a 'global' RF target among distracters of a different but fixed RF.

Experiment 2: Target RF3, Distracter RF4s, RF5s, and RF6s

In the EFT, the target is presented in a complex figure, which can often be segmented into a variety of shapes that the participant searches through. The context is therefore not an array of identical elements. We previously demonstrated that segmentation alone is not a critical factor explaining the EFT performance differences (Almeida et al. 2010a, b). Therefore, this experiment was designed to examine the role of distracter heterogeneity, and to determine whether performance differences observed in Experiment 1 would be reduced or enhanced with a variety of distracter RF patterns presented in the display as opposed to a single type of distracter. Duncan and Humphreys (1989) reported that search efficiency decreases with increasing variety in the distracter set. The task was modified so that the target was still an RF3, however, distracters were a variety of other globally-processed (Bell and Badcock 2009) RF patterns. The aim was to determine whether the group search difference observed in Experiment 1 would be maintained in this more complex search task.

Stimuli

The target was an RF3 and distracters were RF4s, RF5s, and RF6s (Fig. 1b). The modulation amplitude and trials per SS were as specified for Experiment 1. SSs consisted of 4, 8, 16 or 32 RF patterns, giving a total of 160 trials containing the target and 160 target-absent trials. In each trial, the numbers of the three types of distracter RF patterns (RF4s, RF5s and RF6s) were matched as evenly as possible (i.e. did not differ by more than one).

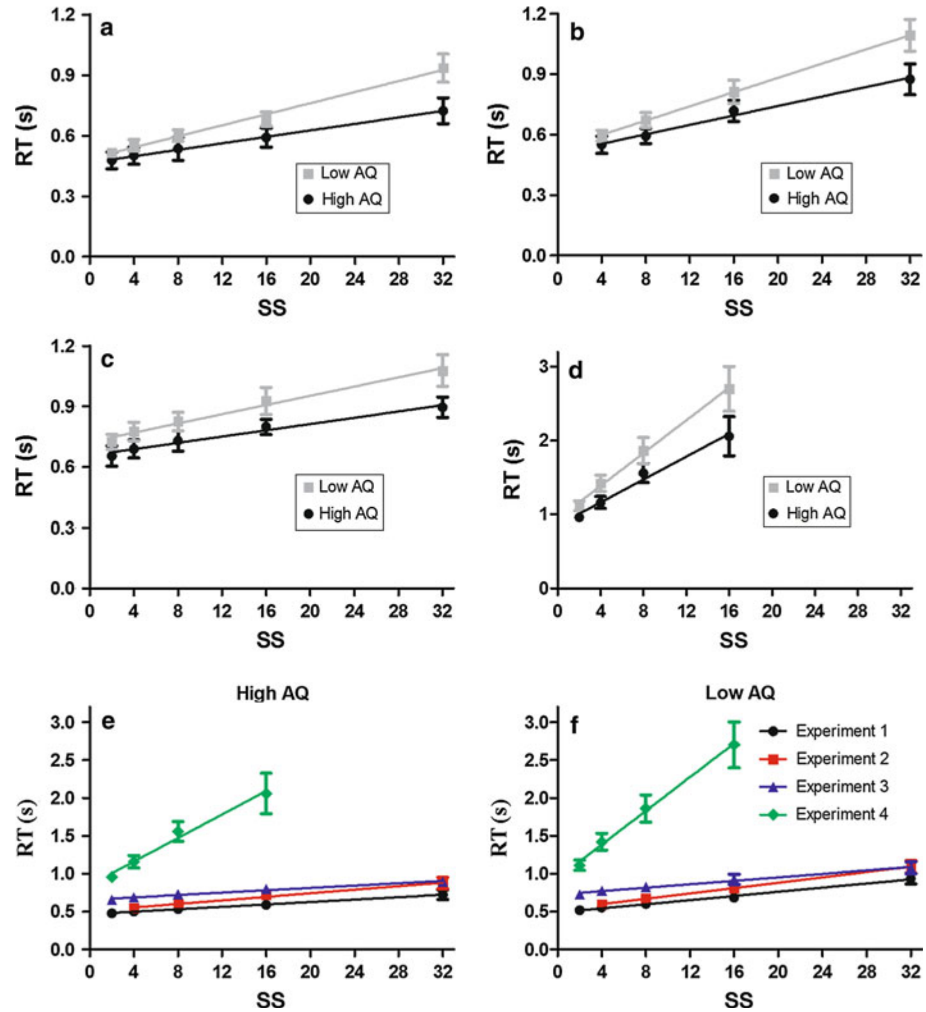

Fig. 2 Mean RT target-present data for each group across SSs for each of the four Experiments (1–4; **a**–**d** respectively). Note the change in the scale of the *y*-axis in **d** compared to **a–c**. **e, f** Present each group's data across all four experiments. The data was fit with a linear regression, with the gradient of the linear function used as a measure of performance. *Error bars* plot the 95 % confidence intervals

Results

There was no main effect of AQ group on accuracy in the target present data ($F(1, 42) = 2.520$, $p = .120$, $\eta^2 = .057$), and the SS × AQ group interaction was not significant ($F(3, 126) = 2.074$, $p = .107$, $\eta^2 = .047$). Additionally, no main effect of AQ group on accuracy ($F(1, 42) = 3.093, p = .086, \eta^2 = .069$) and no significant SS by AQ group interaction ($F(3, 126) = 2.000, p = .117$, $\eta^2 = .045$) was observed in the target absent data.

Comparing speed of performance of the two groups on the RF search task revealed a main effect of AQ group in the target present ($F(1, 42) = 11.793, p < .01, \eta^2 = .219$) and target absent ($F(1, 42) = 20.709, p < .001, \eta^2 = .330$) data, reflecting that the high AQ group were overall faster compared to the low AQ group. There was also a significant AQ group × SS interaction in the target present ($F(3, 126) = 10.779, p < .001, \eta^2 = .204$) and target absent ($F(3, 126) = 17.080$, $p < .001$, $\eta^2 = .289$) data, illustrating shallower slopes for RT as a function of SS for the high AQ group compared to the low AQ group (see Fig. 2b).

Performance on the EFT (mean RT) and the RF search task (gradient) was significantly positively correlated (Fig. 4b), and for this relationship there was no significant difference in slopes for the high and low AQ groups ($F(1, 40) = .030$, $p = .864$).

Discussion

The high AQ group were significantly faster overall than the low AQ group, and were also less impacted by the increasing SS (Fig. 2b). Consistent with previous research (Duncan and Humphreys 1989), the search efficiency of both groups was impacted by the decreased distracter homogeneity (see Fig. 2e, f where an increase in gradients from Experiment 1 to Experiment 2 can be seen for both the high AQ [0.008–0.012] and the low AQ [0.014–0.018] groups). However, the relative difference between groups was unaffected by the increased diversity of distracters (Fig. 3b). That is, while performance of both groups was slower, this occurred in a consistent way, showing that

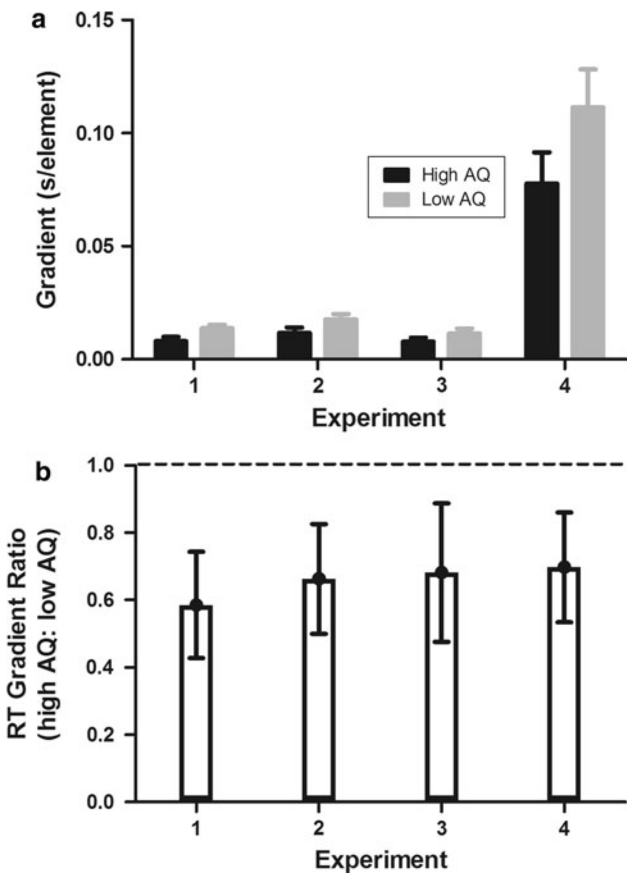

Fig. 3 **a** Presents the gradients for the high AQ (*black bar*) and low AQ (*grey bar*) groups for the target present data for Experiment 1 (target RF3, distracter RF4s); Experiment 2 (target RF3, distracter RF4s, RF5s, and RF6s); Experiment 3 (target RF12, distracter RF16s); and Experiment 4 (target RF3 piece, distracter RF4 pieces). *Error bars* plot the 95 % confidence intervals around the gradient. **b** Displays the ratio of high AQ group gradient to low AQ group gradient (presented in **a** above) for each of the four experiments. *Error bars* plot the 95 % confidence intervals around the ratio. The *dotted line* represents equivalent performance between the two groups

distracter heterogeneity has no impact on the performance differences between high and low AQ groups.

Experiment 3: Target RF12, Distracter RF16

Experiments 1 and 2 demonstrated that high AQ individuals are faster than those with fewer autistic-like characteristics on visual search tasks that require detecting a target from amongst distracters that are fixed or vary in type, where all stimuli are known to be globally detected (Bell and Badcock 2008; Bell et al. 2010; Loffler et al. 2003). Experiment 3 aimed to determine whether this performance difference would occur with RF stimuli that involve local closed-contour processing. In the EFT, the simple target shapes sometimes have few corners (e.g. four), whereas at other times they have up to 12 corners. As noted previously, low RF patterns (RF <10) engage global closed-contour processes whereas high RF patterns (RF >10) only involve local detection processes (Loffler et al. 2003). EFT simple target shapes occur in either range, so we wished to determine whether having a target in the local closed-contour processing range alters RF search performance between high and low AQ groups.

Stimuli

The target was an RF12 and the distracters were RF16s (see Fig. 1c). Given the high RF number of the patterns, the modulation amplitude, A, was set at 0.1, which was equivalent to the amplitude of the target RF3 in Experiments 1 and 2 (employing $A = 1/(1 + \omega^2)$ would result in the RF12 and RF16 patterns having flat sides and thus closely resembling circles). As A was fixed, the target could be distinguished from distracters by local curvature differences or by a texture density cue (Poirier and Wilson 2006). SSs used and number of trials per SS in each case were consistent with Experiment 1.

Results

There was no main effect of AQ group on accuracy in the target present ($F(1, 42) = .711$, $p = .404$, $\eta^2 = .017$) or target absent ($F(1, 42) = .295$, $p = .590$, $\eta^2 = .007$) data. Further, the SS × AQ group interaction was not significant in the target present ($F(4, 168) = 1.941$, $p = .106$, $\eta^2 = .044$) or target absent ($F(4, 168) = 1.837$, $p = .124$, $\eta^2 = .042$) data.

Comparisons between the two groups' speed of performance on the RF search task (see Fig. 2c) revealed a main effect of AQ group in the target present ($F(1, 42) = 11.850$, $p < .01$, $\eta^2 = .220$) and target absent ($F(1, 42) = 8.238$, $p < .01$, $\eta^2 = .164$) data. There was also a significant AQ group × SS interaction effect in the target present ($F(4, 168) = 5.063$, $p < .01$, $\eta^2 = .108$) and target absent ($F(4, 168) = 4.365$, $p < .01$, $\eta^2 = .094$) data. These results demonstrate that the high AQ group were faster overall and had shallower RT as a function of SS gradients than the low AQ group.

The correlation between EFT RT and RF search task gradient was significant (Fig. 4c), such that higher EFT RTs were associated with steeper RF search task gradients. For this relationship, there was no significant difference in slopes for the high and low AQ groups ($F(1, 40) = 1.691$, $p = .201$).

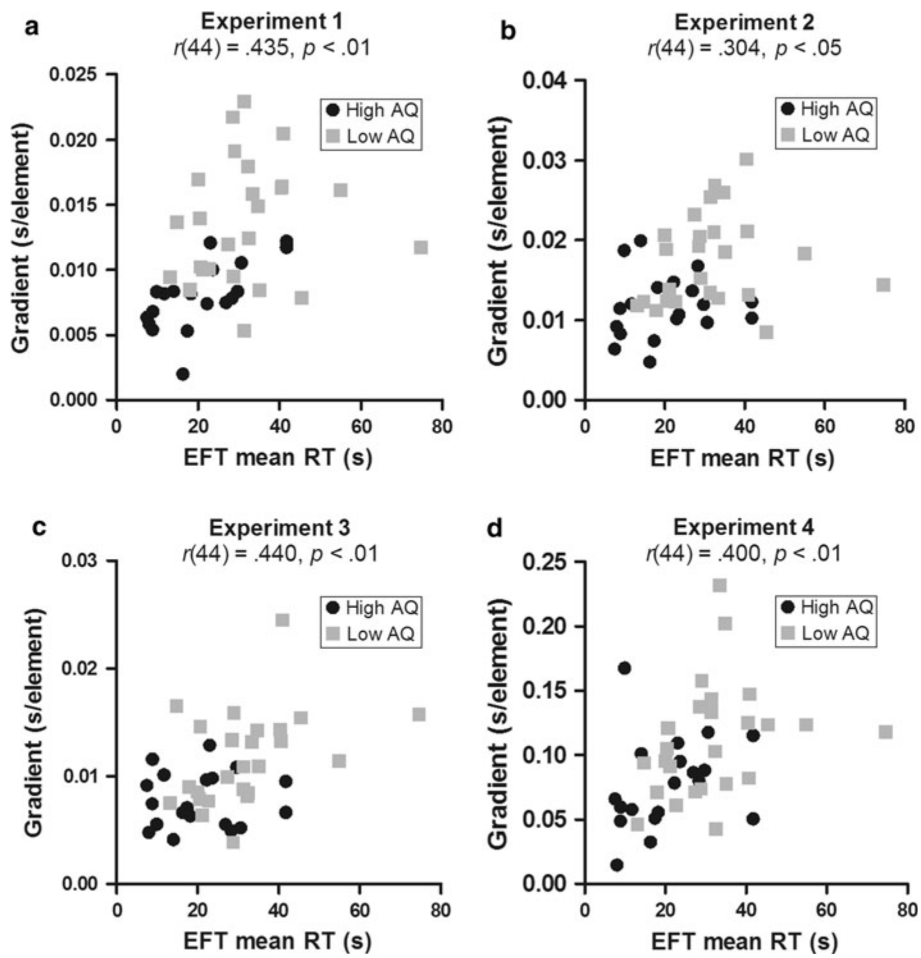

Fig. 4 Scatterplots of the high (*black circles*) and low (*grey squares*) AQ groups' performance on the EFT (mean RT) and the four RF search task experiments (*gradient*). Correlations between each RF search task in Experiment 1 through to 4 (**a**–**d**) and the EFT are presented

Discussion

This RF search task demonstrated that the high AQ group were faster overall than the low AQ group and were less affected by increasing SS (see Fig. 2c and Experiment 3 in Fig. 3a), with these differences not the result of differential speed-accuracy trade-offs in the two groups. The ratio of the gradients of the two groups in this experiment compared to the ratios from the previous two experiments revealed a similar performance difference between groups (Fig. 3b). This demonstrates that the local nature of the deformation detection processes for the RF patterns in Experiment 3 provides no additional differentiation between the groups. It also shows that globally-processed targets are not essential to obtain the effect.

Experiment 4: Target RF3 Pieces, Distracter RF4 Pieces

Given that the same relative difference in performance was observed between groups in Experiment 3 as in the earlier experiments, Experiment 4 was designed to determine whether the closed contour aspect of the RF pattern was critical to improved search ability by high AQ individuals compared to their low AQ counterparts. We previously suggested that RF search task superiority for individuals with high levels of autistic-like traits may result from them having narrower RF channel bandwidths (Almeida et al. 2010a). This proposition applies to complete contours, therefore using partial-contour targets removes this factor and should result in a change to the performance difference observed between the high and low AQ groups if channel bandwidth is the sole critical factor. The importance of the connected RF contour is also of interest given that all simple target shapes in the EFT are closed contours but it is not clear if this property is critical (Witkin et al. 1971). The stimuli in Experiment 1 were modified so that only one cycle of modulation was presented in the search display and the task required detecting an RF3 piece amongst distracter RF4 pieces (see Fig. 1d). This essentially altered the task to a search for supra-threshold differences in local curvature, where the 'pieces' had identical path lengths[4] and the only discriminating factor was the level of curvature. Experiment 3 used patterns with high RFs and Poirier and Wilson (2006) argued that discrimination of these shapes is not achieved using templates encoding curvature as a function of polar angle, but by texture available locally along the path. Therefore, Experiment 4 utilised a fragment of a low RF pattern. The aim of the task was to determine whether a similar relative difference in performance between groups still exists when only a local curvature cue remains.

Stimuli

The stimuli in this experiment were created by adapting the RF stimuli in Experiment 1 such that only a single cycle, symmetrical about the point of convex maximum curvature (from minimum to minimum of the sinusoid) was used, generating pieces of the RF pattern (Fig. 1d). The radius of the RF3 piece was scaled (by 75 %: $r_{\mathrm{mean}} = .75°$) so that the path length of the RF3 and RF4 pieces were equated (see footnote 2). We thought that rather than equating sizes used in Experiment 1 it was more critical to ensure that the path lengths were equivalent so that any length and luminosity cue would be eliminated (contour width and total luminance integrated along the contour were identical for all elements). Also by scaling the path length, we introduced curvature differences between the target and distracters, allowing discrimination on the basis of local curvature (which was not possible in Experiment 1). SSs employed were 2, 4, 8, or 16 segments. In each case, 20 trials per SS were collected. This provided a total of 80 trials containing the target and 80 trials that did not.

Results

There was no main effect of AQ group on accuracy in the target present ($F(1, 42) = 1.819$, $p = .185$, $\eta^2 = .042$) or target absent ($F(1, 42) = .268$, $p = .607$, $\eta^2 = .006$) data. The SS × AQ group interaction was also not significant in both the target present ($F(3, 126) = 1.251$, $p = .294$, $\eta^2 = .029$) and target absent ($F(3, 126) = 1.565$, $p = .201$, $\eta^2 = .036$) data.

The high AQ group was faster overall compared to the low AQ group on the RF search task, demonstrated by a main effect of AQ group in the target present ($F(1, 42) = 11.933$, $p < .01$, $\eta^2 = .221$) and target absent ($F(1, 42) = 5.436$, $p < .05$, $\eta^2 = .115$) data. There was also a significant AQ group × SS interaction effect in the target present ($F(3, 126) = 5.357$, $p < .01$, $\eta^2 = .113$) and target absent ($F(3, 126) = 2.799$, $p < .05$, $\eta^2 = .062$) data, reflecting that the high AQ group were less affected by increasing SS than the low AQ group.

A significant positive correlation between EFT RT and the RF search task gradient (target present data) was observed (Fig. 4d), and again, a single slope was sufficient to characterise this relationship for both groups ($F(1, 40) = .008$, $p = .931$).

Discussion

The final experiment demonstrated once again that high AQ individuals were overall faster and less affected by increased SS in the visual display, compared to the low AQ group, while their accuracy was not compromised. This consistent superiority remained evident, even though the task difficulty increased significantly for both groups (see Fig. 2d which highlights increased RTs and Figs. 2e, f, and 3a which demonstrate increased gradients in Experiment 4 compared to the previous three experiments). While the previous three experiments might be considered to involve processing of the boundaries of objects, this task involved lower level discrimination of properties of a path, in this case—curvature. However, the relative difference in performance between the two groups remained when comparing Experiment 4 to the prior experiments (Fig. 3b), illustrating that contour closure does not offer additional discriminatory power between groups. This result also indicates that RF search task superiority may not be solely accounted for by narrower RF channel bandwidths.

General Discussion

This study was designed to further understand the visual search superiority demonstrated by individuals with high autistic-like traits. As the EFT has repeatedly illustrated this advantage, we sought to understand which aspects of visual information in this test are critical. More specifically, we wished to determine whether their enhanced search performance would be observed when the task required detecting shapes which are known to be processed by mechanisms selective for either local or global closed-contour stimulus properties. Experiments 1 and 2 compared visual search performance between those high and low on the AQ when the task presented stimuli that involve global

[4] The path length of each 'piece' was one cycle in positive cosine phase with respect to the mid-point of the arc. That is, each piece was created by starting at the maximum negative modulation amplitude and extending to the next negative maximum. The radii of the RF3 pieces were created and then scaled using the equation below to ensure that both target (RF3) and distracter (RF4) pieces had the same length. $r(\theta) = \frac{\omega r_{\mathrm{mean}}}{4} \times \left(1 + \left(\frac{1}{1+\omega^2}\right)\cos(\omega\theta + \varphi)\right)$, where $-\pi \leq (\omega\theta + \varphi) \leq \pi$

The parameters have the same meaning as in Eq. 1.

closed-contour processing. We demonstrated that while making distracters more heterogeneous affected search times for both groups (see also Duncan and Humphreys 1989), the relative difference in performance between groups remained the same, indicating that uniformity of distracters is not critical for obtaining the group performance differences. Previous research demonstrates the existence of narrow-band RF channels (Bell and Badcock 2009) selective for the polar angle between points of maximum curvature (Bell et al. 2008) and our previous study (Almeida et al. 2010a) suggested that high AQ individuals may have narrower channel bandwidths, allowing better discrimination by the detectors labelled for radial frequency. This would be consistent with networks, of the sort reported by Pasupathy and Connor (2002), in V4, but ones that are more tightly-tuned to the polar angle between points of maximum curvature. Experiment 2 demonstrates that the same relative improvement in performance by the high AQ group holds even when multiple labelled RF detectors are active.

Experiments 3 and 4 employed stimuli that involve local visual processing mechanisms, either retaining a closed contour (as in the RF12 and RF16 stimuli), or requiring a more elementary level of local curvature detection using only a piece of the contour. Despite systematically slower searching across the two groups in Experiment 4, a very similar relative difference in performance was again observed that was comparable to that obtained across the series of experiments. This similarity in group differences is either highly coincidental or it suggests that no single enhanced nor defective global or local closed-contour processing mechanisms used to detect RF stimuli can be sufficient to explain superior search performance by individuals with high levels of autistic traits. Further, the results of the combined set of experiments indicates that the number of corners in the EFT simple shape is unlikely to influence the enhanced high AQ EFT search performance relative to a low AQ group.

This investigation was motivated by curiosity regarding why individuals with autism or those scoring high on the AQ display show improved performance on visual search tasks, such as the EFT, compared to matched controls (Almeida et al. 2010a; Edgin and Pennington 2005; Grinter et al. 2009b; Jarrold et al. 2005; Jolliffe and Baron-Cohen 1997; Russell-Smith et al. 2010; Shah and Frith 1983). WCC theory has provided a description of this phenomenon, arguing that those with autism possess increased ability to perceive and retain detail, although this occurs at the expense of developing an integrated percept (Frith 1989; Happe 1999). Thus while improved performance on tasks which require attention to detail may be observed, this corresponds with a lack of overall global, conceptual understanding. Researchers have debated whether such local enhancement occurs with a consequent deterioration of global processing, and a subsequent reconceptualization of WCC has proposed that superiority in local processing may occur without any global processing deficit (Happe and Frith 2006). Various strategies have been employed to elucidate this matter (Koldewyn et al. 2010; Mottron et al. 1999, 2006; Plaisted et al. 1999; Pring et al. 2010; Spencer et al. 2000). However, the application of the terms local and global has varied. We take a specific meaning here that can be applied to closed-contour shapes such as those used as targets in the EFT. The results from the four experiments in this study demonstrate the same relative difference in performance between the high and low AQ groups (Fig. 3b) across stimuli differentiated by using global or local information. These findings demonstrate that group differences are unlikely to be explained by a processing efficiency difference restricted to a single stage in the processing of shape primitives: V1 for oriented edge detection (Poirier and Wilson 2006), V1 and V2 for curvature detection (Dobbins et al. 1987, 1989; Koenderink and Richards 1988; Wilson 1985; Wilson and Richards 1989), and V4 for global contour shape (Gallant et al. 2000; Wilkinson et al. 2000). That is, improved high AQ search performance in the RF search task cannot be attributed to an enhancement of local processing at the expense of performance at the global level (using these terms as in the shape perception literature).

While the ratio of the gradients for the high and low AQ groups remained the same, performance was altered by the stimulus manipulations and the gradients did vary across the four experiments. In Experiment 1 global processes were active. The target and distracter stimuli had the same local curvature due to the modulation amplitude employed, thus preventing observers from doing the search task by relying on local curvature differences. While these low RF patterns could be discriminated by the polar angle between curvature peaks, in order to find its centre, the pattern must be treated globally. Comparing the results of Experiments 1 and 4 also reveals a benefit of global contour processing as the gradients in Experiment 1 are significantly smaller than those in Experiment 4 for both groups. One component of the improvement may be due to the presence of closed-contours as the performance in Experiment 3, which required the detection of locally-processed closed-contours, is also superior to that in Experiment 4. A role for global closed-contour processing mechanisms in overall task performance speed is indicated by the faster performance of both groups in Experiment 1 relative to Experiment 3 (compare Fig. 2a–c) as Experiment 1 used targets in the global RF range while Experiment 3 did not, even though the ratio of RFs for the target and distracter stimuli was the same for the two experiments (i.e. 12:16 = 3:4). However, as the ratios of group performance remain the same, the pattern features that vary across experiments are not essential for the high AQ group's superior performance.

Grinter et al. (2010) examined form processing in typically developing children and those with an ASD using an RF detection threshold task which employed an RF pattern that is globally processed (RF3) and one that is locally processed (RF24). They demonstrated poorer RF3 detection thresholds (i.e. greater deformation was required to differentiate between a perfect and distorted circle) for the ASD children compared to controls, whereas no group difference was found in detection thresholds of RF24 patterns. As a result of their observations, they concluded that individuals with an ASD demonstrate a deficit in global visual processing, consistent with WCC (Grinter et al. 2010). The RF search task data in the present study demonstrate a consistent difference in search performance between high and low AQ groups when the task requires detecting a target from among distracters which are processed using either local or global closed-contour mechanisms. The nature of a threshold task involves deliberately seeking to identify the smallest amount of signal required to make a deformation discrimination. Such a task is inherently different in nature to the RF search task, which involved detecting a complete contour, or piece of it, with high signal level (i.e. modulation amplitude well above threshold). It may be the case that individuals with high levels of self-reported autistic-like characteristics have higher thresholds for discriminating RF patterns, yet their RF channel bandwidths are narrower which enables improved search performance. The previous study (Grinter et al. 2010) also examined children with autism, the results of which may vary from adult performance due to the developmental trajectory. What does appear consistent is that that both individuals with autism and typically developing individuals with high levels of autistic-like traits have superior search ability, which may be the result of weaker integration of the display and thus more efficient access to the target.

While previous studies (Almeida et al. 2010a, b; O'Riordan et al. 2001; Plaisted et al. 1998a) have investigated individuals with autism or those with high levels of autistic characteristics, additional research performed by Snyder (2009) has examined savant skills. Savants are individuals with autism or other mental disabilities who, in the midst of their deficits in everyday functioning, demonstrate extraordinary skills which often require outstanding ability to recall detail (Snyder 2009; Sacks 2007). Snyder (2009) argues that this is made possible due to superior access to lower level, less-processed sensory information. The present study is consistent with this theoretical claim, and in addition we propose that enhanced search abilities by those with high levels of autistic-like traits exist when the task requires searching for RF stimuli (Bell and Badcock 2008; Bell et al. 2007, 2010; Loffler 2008; Loffler et al. 2003; Poirier and Wilson 2006). It appears irrelevant whether the search requires detection of a locally or globally processed stimulus; what is important is that high AQ individuals are superior at disregarding irrelevant information and extracting the target from the broader background (distracter elements in this case). In other contexts this has also been referred to as local (target) and global (broader background) information (Jolliffe and Baron-Cohen 1997; Shah and Frith 1983), highlighting the need to address underlying processes very specifically when using these terms.

It is informative to compare our results with findings of Remington et al. (2009, 2012) who examined how the Load Theory of Attention (Lavie 2005) might account for superior search ability. Under this theory, the ability to process distracters is affected by the perceptual load of the task, and Remington et al. (2012) argue that individuals with an ASD have enhanced perceptual capacity, which allows for superior search performance and more efficient distracter processing. Using a signal-detection paradigm, they demonstrated a significant decrease in visual detection performance as a function of increased perceptual load in their typically developing group, whereas those with an ASD showed no decrease in performance associated with the higher load, reflecting greater perceptual sensitivity. Our results revealed that when the perceptual load was great (e.g. Experiment 2 with multiple types of distracter RF patterns), search performance (as measured by the gradient, i.e. increase in RT with increasing SS) was reduced for both the high and low AQ groups when compared to their search performance gradients in the less complex task (i.e. Experiment 1 which contained only one type of distracter). Therefore while increasing the perceptual load of the task had an effect on visual search performance, this occurred for both groups equally as the ratio of the high AQ to low AQ gradients was the same across all four experiments, and therefore is inconsistent with the differential perceptual load effect that Remington et al. (2012) report between individuals with and without autism.

The lack of differential impact of perceptual load between the groups in our study may result from the fact that we used typically developing individuals with high levels of autistic-like characteristics. Previous studies that have reported an impact of perceptual load examined individuals with an ASD. For instance, several studies have investigated feature search tasks with varying difficulty and revealed superior performance by individuals with an ASD compared to typically developing controls, with the ASD performance advantage enhanced in the more difficult tasks where more information was processed (O'Riordan 2004; O'Riordan and Plaisted 2001). O'Riordan and Plaisted

(2001) examined performance of individuals with an ASD on a colour-form conjunction task where they varied target-distracter similarity. As target-distracter similarity increased, the typically developing group were slowed to a greater extent than the group with an ASD. Another study (Keehn et al. 2008) compared performance for individuals with an ASD and typically developing controls on a search task where the distracters employed were either homogenous or heterogeneous. The ASD group were faster than the control group in the heterogeneous (more difficult) condition, but slower in the homogeneous (easier) condition. Keehn et al. (2008) suggested that slower basic visuomotor coordination may affect the performance of individuals with an ASD, but that in more demanding search conditions, such as with heterogeneous distracters, their enhanced visual search abilities may offset their slowed visuomotor coordination. This trade-off account of visual search in ASD suggests a key difference between individuals with a clinical diagnosis and individuals with high levels of autistic-like traits selected from the general population. Our results showing enhanced search performance by the high AQ group in *all* experimental conditions are consistent with enhanced visual search ability coupled with *intact* visuomotor coordination. Thus, individuals with an ASD and individuals with milder autistic-like traits may share a superior skill in visual search, such as an enhanced capacity to disregard irrelevant information, but only the former group may have an offsetting deficit in visuomotor coordination.

None of our work suggests the EFT offers any additional explanatory advantage over the basic RF search task. Further, when examining the relationship between the performance of each search task and AQ score, correlational analyses indicated a stronger relationship between the AQ and the slope of the original RF search task employed in Experiment 1 ($r(44) = -.620$, $p < .0001$), than between the AQ and EFT RT ($r(44) = -.441$, $p < .01$).[5] Therefore, we recommend use of the RF search task instead of the EFT as it is a simple, computer-based search task which, critically, is also suitable for repeated application. Using the gradient as a measure of performance allows for comparison across experiments, which permits systematic manipulation of the RF search task to isolate different factors that may or may not underlie the enhanced ability to search for a target in the EFT exhibited by those high on the autism spectrum. The manipulations of the present study demonstrate that individuals with a high AQ have improved search performance regardless of whether the task requires local or global visual processing of closed-contours to detect the RF target. Further, we rule out the importance of variability of elements in the distracter set, or the need for a closed-contour to elicit high AQ search performance enhancement. High AQ search superiority may be explained by enhanced local processing of curvature in the early stages of the form vision pathway *and* superior global detection of shape primitives. However, enhanced local curvature processing is unlikely as recent research has demonstrated no threshold curvature detection differences between high and low AQ groups when discriminating between an RF3 and circle (Almeida et al. 2011). Further, the ratios of the gradients were the same across the four experiments. Therefore, more probable is the presence of a superior search process that allows elements to be processed more efficiently, which enables a consistent search advantage at both levels of processing.

[5] Correlations were also significant between the AQ and the search slopes derived from the other RF search tasks: (a) Experiment 2 ($r(44) = -.550$, $p < .001$); (b) Experiment 3 ($r(44) = -.432$, $p < .01$); and (c) Experiment 4 ($r(44) = -.445$, $p < .01$).

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