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BRIEF REPORT

Brief Report: Perceptual Load and the Autism Spectrum in Typically Developed Individuals

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Abstract A fundamental task of the cognitive system is to prioritize behaviourally relevant sensory inputs for processing at the expense of irrelevant inputs. In a study of neurotypical participants ($n = 179$), we utilized a brief flanker interference task while varying the perceptual load of the visual display. Typically, increasing perceptual load (i.e., with greater numbers of search items) reduces interference from a competing peripheral distractor. We show that individuals who score above average on the Autism Spectrum Quotient (AQ) show stronger interference at high perceptual load than individuals with below-average AQ scores. This is consistent with recent findings in individuals with autism spectrum conditions, and supports the idea that the cognitive style of the autistic brain is reflected in a broader phenotype across the population.

Keywords Flanker task · Autism spectrum quotient · Perceptual load · Attention · Visual search

Introduction

Individuals with a pervasive developmental condition on the autism spectrum (Autism Spectrum Conditions, 'ASC') show impaired social functioning, poor communication skills, restricted interests and repetitive behaviours. The social difficulties are thought to be due to an impaired ability to represent other peoples' mental states (impaired 'Theory of Mind'; Leslie et al. 2004). However, people with autism also present low-level perceptual abnormalities such as impaired motion perception and a bias toward the processing of local features at the expense of global/contextual information (see Dakin and Frith 2005; Simmons et al. 2009; for reviews). The degree to which these social and perceptual deficits are related is an important question (see Behrmann et al. 2006; Happé 1999; Mottron et al. 2006 for varying perspectives). Undoubtedly, interactions between high- and low-level stages of cognition are subtle and complex and their contribution to autism may not be explainable by a single underlying mechanism (Happé et al. 2006).

The attention system also appears to operate differently in ASC. For example, individuals with ASC show superior visual search performance relative to non-clinical controls. Plaisted et al. (1998) studied performance in feature and conjunction search tasks where participants are asked to quickly find a single target in a large or small array of distractors. As well as overall quicker reaction times (RT) to find the targets, individuals in the autistic group showed a shallower search slope, meaning that as set size (i.e., number of distractors) increased, RT increased only modestly relative to controls. This suggests that individuals with ASC find it easier to perceptually discriminate distractor stimuli from targets, allowing for highly efficient search relative to control participants.

Autistic Traits in the Typically Developed Population

As the term 'autism spectrum conditions' indicates, there is a continuum of autistic traits that encompasses low and high functioning autism and Asperger's syndrome. There is evidence that the spectrum may also extend into the non-clinical population (Dawson et al. 2002). The Autism Spectrum Quotient (AQ; Baron-Cohen et al. 2001) can detect diagnosed individuals but is also sensitive to

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variation of non-clinical autistic traits and does not correlate with overall IQ (Baron-Cohen et al. 2001). For example, Bayliss et al. (2005) showed that the strength of the visual orienting response to the direction of another person's eye gaze was negatively correlated with AQ score. That is, individuals closer to the autistic end of the spectrum show weaker 'gaze cueing' effects (see also Bayliss and Tipper 2005, 2006; Hermans et al. 2009; Puzzo et al. 2009, for other work with the AQ in the social perception literature).

Interestingly, differences in (non-social) visual perception also exist within the typically developed population as a function of AQ score. For example, Grinter et al. (2009a) showed that performance on the Embedded Figures Test (EFT) and the Block Design component of the Weschler Intelligence Scale is positively related to AQ score (see also Almeida et al. 2010). Grinter and colleagues also showed high performance in the EFT along with weak global form and motion detection (Grinter et al. 2009b). Together, these findings indicate that individuals reporting relatively more autistic-like traits share strong performance on these classic markers of visuo-spatial skill in autism (e.g., Shah and Frith 1983).

Perceptual Load in Autism

Here we demonstrate a further similarity between the performance of individuals with ASC and that of non-clinical individuals scoring high on autistic traits. Of central importance to the formation of our hypotheses are the recent findings of Remington et al. (2009). In their study, participants with and without diagnoses of autism or Asperger's Syndrome completed a variant of the Eriksen Flanker task (Eriksen and Eriksen 1974; as adapted by Maylor and Lavie 1998) to investigate the role of perceptual load on flanker interference in a response-conflict paradigm. The task was to discriminate between an 'X' and an 'N' presented briefly in one of six locations near the centre of the screen. A larger letter was simultaneously presented more peripherally that was either 'incompatible' with the target (e.g., an 'N' when the target is an 'X'), or 'neutral' (i.e., not associated with a response). The reaction time cost between incompatible and neutral trials is an index of distractor processing. The larger the cost, the deeper the irrelevant distractor is assumed to have been processed. The critical manipulation of increasing the 'perceptual load' of the display is achieved by introducing more non-targets (see Fig. 1 for examples of our task). This manipulation has a reliable effect on the magnitude of distractor interference: The higher the perceptual load, the weaker the interference effect induced by the large incompatible peripheral distractor. The level to which one must raise the perceptual load of a display before abolishing interference can be interpreted as indicating the perceptual capacity of the system (see Lavie 2005 for a review of the perceptual load theory of attention).

Remington et al. (2009) reported that to abolish the interference effect in their ASC sample, the perceptual load of the display had to be *higher* (set size of six) than in the control group (set size of four). This novel finding suggested to the authors that individuals with a ASC have a higher perceptual capacity than the typically developed population. At levels of moderately high perceptual load, the central task does not exhaust resources in ASC as it does in the typically developed population.

Here we test the hypothesis that individuals in the typically developed population share many aspects of the autistic cognitive style. In particular, we are interested in whether this important feature of selective attention, namely its sensitivity to perceptual load, varies as a function of position on the autism spectrum even in a non-clinical sample. We used a simplified version of Remington et al.'s (2009) experiment, retaining the conditions that we hypothesized would best differentiate the performance of the groups. To pre-empt our findings, only participants with few self-reported autistic traits showed abolished interference at moderately high levels of perceptual load; their counterparts with high AQ scores showed strong interference at both levels of perceptual load that we tested. These results clearly mirror those of Remington et al., providing

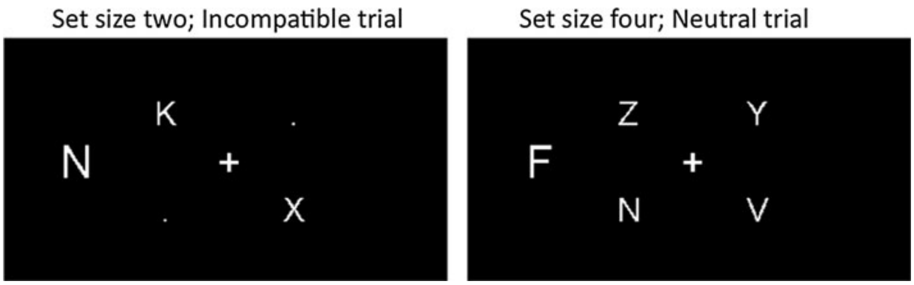

Fig. 1 Examples of trial displays. On the *right*, is a high load (set size four) neutral trial. Because the large flanker is not in the target response-set, it does not interfere with performance. The *left panel* shows an incompatible trial at set size two. Strong interference effects are found because the flanker competes for response with the actual target

strong support for the notion that individual differences in fundamental cognitive functions are related to a broader autistic phenotype.

Method

Participants

One hundred and seventy-nine participants[1] completed the perceptual load task and the autism spectrum quotient as part of course work. Participants with AQ scores of 15 or above were assigned to the 'High AQ' group (mean AQ = 19.9, SD = 4.3; 63 females, 23 males; mean age = 20.1 years, SD = 2.5 years). The remaining participants composed the 'Low AQ' group (mean AQ = 10.6, SD = 2.6; 69 Females, 24 Males; mean age = 19.8 years, SD = 1.8 years). Participants were tested in groups of up to twenty-five and all reported normal or corrected-to-normal vision and gave informed consent.

Stimuli

Stimuli were controlled with E-Prime 1.2 software, and were presented in white on a black background on monitors running at 60 Hz with 1,024 × 768 resolution. The letters 'X' and 'N' served as targets, with 'Z', 'H', 'K', 'Y' and 'V' as distracters (all were in Arial font type and subtended 0.6° × 0.7°). These letters would appear at four locations 2.5° from a central fixation cross (0.5° × 0.5°) at placeholders that were at the corners of an imaginary square. Either four or two letters were presented on each trial, with small placeholder dot (0.1° × 0.1°) taking the place of letters on two-letter trials (as in Remington et al. 2009). An additional large letter, 0.7° × 0.9°, was presented 5.0° to the left or right of fixation (either 'N', 'X', 'D' or 'F'; see Fig. 1). Responses were made on a standard keyboard to the targets 'X' and 'N' with the corresponding keys.

Design

In addition to the between-subjects factor, 'AQ group', there were two within-subjects variables, 'Set Size' was the number of small centrally-presented letters, and had two levels, 'Two' and 'Four'. On Set Size Two trials, the central display consisted of one target item ('X' or 'N'), one non-target letter, two placeholder dots and one peripheral distracter. Set Size Four trials had one target, three non-target letters and one distracter. The second within-subjects variable was 'Compatibility', which was 'Neutral' (the peripheral distracter was not part of the response set), or 'Incompatible' (the distracter was always the alternative target letter; when the target letter was X, the flanker was 'N' and vice versa).

Procedure

Participants were instructed to fixate the central cross during each trial and that a target letter ('X'/'N') would appear in one of the locations around the fixation cross. They were told to ignore the large flanking letter and to respond quickly and accurately on the keyboard to indicate the identity of the target. On each trial, the search display appeared for 100 ms, followed by a screen with only a fixation cross for 2,900 ms. Participants completed 16 practice trials before 160 experimental trials. There were 40 trials in each of the four conditions (Set Size Two/Four and Compatibility Neutral/Incompatible). Target location (one of four placeholder locations), distracter position (left or right), and non-target locations and identity were all randomized across trials.

Results

Mean accuracy for the letter discrimination task was identical for the High and Low AQ groups (88.2%). Mean proportion error rates for each subject in each condition were arc-sine transformed prior to submission to an 'AQ Group' (High vs. Low) × 'Compatibility' (Neutral vs. Incompatible) × 'Set Size' (Two vs. Four) mixed ANOVA. The main effect of 'Compatibility' was significant, $F(1,177) = 15.4$, MSe = .10, $p < .001$, $\mu_p^2 = .08$, due to more errors on Incompatible than Neutral trials (12.7 vs. 10.8%), as was the main effect of 'Set Size', $F(1,177) = 71.8$ MSe = .008, $p < .001$, $\mu_p^2 = .29$, with more errors with Set Size Four than Two (13.4 vs. 10.1%). The two within-subjects factors also revealed a significant interaction due to a larger effect of Compatibility at the larger Set Size, $F(1,177) = 6.31$ MSe = .007, $p < .013$, $\mu_p^2 = .034$. Neither the main effect of AQ Group, nor any of the remaining interactions approached significance, F's < 1.1, p's $> .29$ (see Table 1).

Before analysing mean reaction time for correct responses, outliers were removed (RTs <150 ms or >1,500 ms; 1.72% of trials). The 2 × 2 × 2 ANOVA revealed a main effect of Compatibility, $F(1,177) = 120$, MSE = 917, $p < .001$, $\mu_p^2 = .40$, due to slower reaction times on Incompatible than Neutral trials (684 vs. 709 ms; an interference effect). The main effect of Set Size was also significant, due to faster reaction times for the smaller set size compared with the larger set size (661 vs. 733 ms), $F(1,177) = 726$, $MSE = 1{,}290$, $p < .001$, $\mu_p^2 = .80$. The

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[1] Data from an additional 11 participants were discarded due to high error rates (>30%).

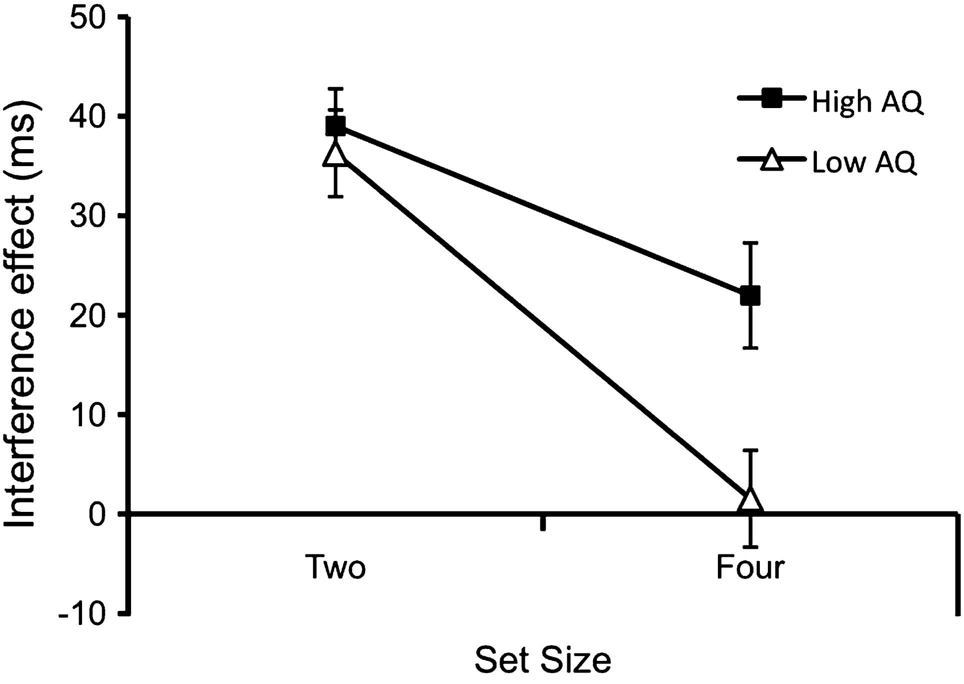

Fig. 2 Graph of interference effects (RT Incompatible minus RT Neutral) at the two Set Sizes for both High and Low *AQ* groups. *Error bars* denote standard error of the mean

interaction between Set Size and Compatibility was also significant, $F(1{,}177) = 28.9$, $MSE = 980$, $p < .001$, $\mu_p^2 = .14$, due to a stronger interference effect at Set Size Two than Set Size Four—a standard effect of perceptual load on distractor interference (e.g., Lavie 1995). Neither the AQ Group x Set Size interaction, $F(1{,}177) = 2.90$, $MSe = 1{,}290$, $p = .09$, $\mu_p^2 = .016$, nor the main effect of AQ Group, $F(1{,}177) < 1$, reached significance. However, the AQ Group x Compatibility effect was significant, $F(1{,}177) = 6.83$, $MSe = 917$, $p = .01$, $\mu_p^2 = .037$, due to a weaker compatibility effect in participants with Low AQ scores (19 ms) than High AQ scores (31 ms). Finally, the critical three-way interaction was also significant, $F(1{,}177) = 4.16$, $MSe = 980$, $p = .043$, $\mu_p^2 = .023$ (see Table 1; Fig. 2).

The source of the significant three-way interaction was investigated using the magnitude of the interference effect (RT on Incompatible trials minus RT on Neutral trials) as the measure. Independent-samples *t*-tests showed that the interference effect at Set Size Two did not differ significantly between the Low and High AQ Groups, $t(177) = .42$, $p = .68$, $d = .06$. However, at the higher level of perceptual load, the interference effect was weaker amongst the Low AQ group than the High AQ group, $t(177) = 2.98$, $p = .003$, $d = .45$.[2]

General Discussion

Here we demonstrate that individuals with more self-rated autistic traits show interference at higher levels of perceptual load than people with low scores on the AQ. This finding suggests that High AQ participants have higher perceptual capacity than Low AQ participants: At set size four, the distractor with the opposite response mapping to the target (i.e., incompatible) caused interference only for

Table 1 Mean reaction times (in ms) and percent correct for each condition (SD in parentheses) for high and low AQ groups

	Set size two		Set size four	
	Neutral	Incompatible	Neutral	Incompatible
Low AQ				
RT	642 (88)	678 (91)	736 (94)	738 (96)
Accuracy	91.5 (5.7)	88.1 (7.3)	87.2 (7.4)	85.9 (7.6)
High AQ				
RT	642 (97)	681 (97)	718 (97)	741 (107)
Accuracy	91.1 (5.6)	88.8 (7.4)	87.0 (8.4)	86.3 (8.5)

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[2] The pattern of results is the same with the cut-offs originally used by Bayliss and Tipper (2005). With Low ($AQ < 14$; $n = 82$) and High ($AQ > 17$; $n = 53$) groups showing equal interference effects at Set Size Two, $t(133) = 1.04$, $p = .30$, $d = .18$, but the High AQ group showed stronger interference at Set Size Four, $t(133) = 2.14$, $p = .035$, $d = .38$. Finally, we also calculated linear correlations between AQ score and RT Interference (in ms) for both Set Sizes for the sample as a whole. At Set Size Two, there was no significant linear relationship, $r = .09$, $n = 179$, $p = .25$, two-tailed. Corroborating the other analyses, the correlation was significant at Set Size Four, $r = .17$, $n = 179$, $p = .027$, two-tailed. The quadratic relationship between AQ score and interference effect magnitude was non-significant ($r < .1$).

the High AQ participants. There are a number of striking features of the data we present. First, there are no main effects of RT or accuracy between the groups. This means that processing fluency is not overall better in one group or the other, and so cannot explain the data pattern. Second, performance at set size two is identical between the groups—differences only emerge at the higher set size (see Fig. 2). Therefore, competition at the level of response or attentional selection is the clearest explanation for the group differences (as opposed to, for example, enhanced peripheral perception in the high AQ group, which would predict greater interference at *both* set sizes).

We also note the similarity in performance between our High AQ group and the ASC group of Remington et al. (2009). In our High AQ group, interference at set size four drops only slightly relative to set size two. Our Low AQ group is also similar to Remington et al's control group insofar as strong interference at set size two is completely abolished at set size four. The possibility, therefore, that a high AQ group might be indistinguishable from an sample of people with autism in this kind of paradigm is particularly striking. Finally, it is interesting that the effects of AQ are strong in our female-dominated sample (see also Hermans et al. 2009; Bayliss and Tipper 2005 for similar findings). In their study primarily concerned with gender differences, but which used the AQ with a subset of their sample, Bayliss et al. (2005) queried whether gender or AQ would prove to be more influential in determining individual differences in attention. The evidence in favour of the latter is mounting. This is surprising given the autism spectrum quotient aims to tap into a cognitive style associated with a constellation of conditions with a high male:female ratio (e.g., Fombonne 1999).

These data show that individual differences in perceptual capacity affect attentional selection in a typically developed sample as a function of position on the autism spectrum. A challenge for future research is to describe how these differences can influence higher-level aspects of cognitive processing (e.g., attention switching) and social processing (e.g., joint attention). As a final note, it is worth considering our data from a converse viewpoint. One may equally conclude that individuals with Low AQ scores have *abnormally low* perceptual capacity. Indeed, in many reports of perceptual load, a set size of six is required to abolish interference (e.g., Maylor and Lavie 1998), whereas our Low AQ sample show no interference even at set size four. The implications for research on attention and perception that draw from the typically developed and clinical populations alike are clear. Firstly, researchers should consider carefully their choice of sample, even when drawing from the typically developed population. Secondly, future work could explore the notion of a 'Low AQ' phenotype with specific behavioural traits in perception and attention in addition to high levels of empathy and social cognitive skill (e.g., Baron-Cohen 2002).

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