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Electrophysiological evidence of atypical spatial attention in those with a high level of self-reported autistic traits

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Abstract

Selective attention is atypical in individuals with autism spectrum conditions. Evidence suggests this is also the case for those with high levels of autistic traits. Here we investigated the neural basis of spatial attention in those with high and low levels of self-reported autistic traits via analysis of ERP deflections associated with covert attention, target selection and distractor suppression (the N2pc, N_T and P_D). Larger N2pc and smaller P_D amplitude was observed in those with high levels of autistic traits. These data provide neural evidence for differences in spatial attention, specifically, reduced distractor suppression in those with high levels of autistic traits, and may provide insight into the experience of perceptual overload often reported by individuals on the autism spectrum.

Keywords: autistic traits; ERP; selective attention; spatial attention, N2pc

Introduction

An important function of selective attention is to resolve competition in the visual environment by directing resources to goal relevant stimuli (Desimone & Duncan, 1995). Research has shown that those with autism spectrum conditions (ASC) demonstrate atypical selective attention compared to those who are typically developing (Burack, 1994; Plaisted, O'Riordan & Baron-Cohen., 1998). Here we used event-related potentials (ERPs) to investigate whether those who report high levels of autistic traits also show evidence of atypical selective attention.

Tasks that are used to assess selective attention in ASC typically involve detecting a target in an array of distracting information (e.g. visual search). Using a modified visual search task, Burack (1994) found that those with ASC showed a search-advantage when attention was limited to a narrow visual field, constrained by a window (12.2° visual angle). However, when irrelevant distractors were presented within the window, as opposed to outside of the window, participants with ASC showed a greater detriment to response time than typically developing controls. Burack (1994) suggested that this reflects an "inefficient attentional lens" in ASC and subsequent studies have supported this claim (e.g Mann & Walker, 2003). Other work has shown that children with ASD show reduced supression of distractors in a flanker task (Adams & Jarrold, 2012). Remington et al., (2009) demonstrated that those with ASC show strong interference from distracting flanker letters at high levels of perceptual load, a finding they consider to reflect greater perceptual capacity in those with ASC. A similar finding was also observed in those with high scores on a questionnaire which measures self-reported autistic traits in the general population (Autism Spectrum Quotient, AQ, Baron-Cohen et al., 2001). Specifically, Bayliss & Kritikos, (2011) found that those with above average autism quotient (AQ) scores showed stronger interference from distractors at high levels of load than those with below average AQ scores. Taken together, there is an

array of evidence to suggest that individuals with ASD, and also those with high levels of autistic traits, have atypical spatial attention, which may be manifested by reduced suppression of distracting information.

ERP research has identified robust neural correlates of selective attention (for a review see Luck & Kappenman, 2013). This research forms an excellent knowledge base from which to explore selective attention in the autism spectrum. In our recent paper investigating the neural basis of feature-based selective attention (Milne et al., 2013) we reported ERP data which revealed differences in resource allocation to irrelevant distractors between those with high and low levels of autistic traits. The task involved sequential presentations of single stimuli which differed in colour and / or orientation. Targets were identified on the basis of feature combination and distracters shared either two, one or zero features with targets. We found increased P3b amplitude following presentation of distractors which did not share features with the target in participants with more autistic traits compared to those with fewer autistic traits, indicating increased processing of irrelevant distractor stimuli in the high AQ group.

Here we aimed to establish whether neural indices of spatial attention are also atypical in those with high levels of autistic traits. This was achieved by presenting stimulus arrays of two to four items from which the relevant target must be identified and processed while the distracting stimuli also present should be ignored. This task generates the N2pc ERP component, which is a posterior component in the N2 time-range, recorded from electrodes over temporal/parietal areas (~200 to 300 ms post stimulus onset, Luck & Hillyard, 1990; 1994a; 1994b) The N2pc represents the difference between the signal recorded from electrodes that are either contralateral or ipsilateral to a target (Woodman & Luck, 1999). For example, when presented with a visual search display, amplitude is larger at electrodes that are contralateral to the target than electrodes that are ipsilateral to the target., The source of

the N2pc has been localised to the ventral occipital cortex (Hopf et al., 2000), and the cognitive process reflected by the N2pc is the deployment of covert attention in order to select a target in space (Eimer, 1996; Kiss, Van Velzen & Eimer., 2008). Hickey, DiLollo, and McDonald., (2009) identified two subcomponents of the N2pc, the $P_{D,}$ a positive difference between contralateral and ipsilateral waveforms, reflecting the suppression of distractors in space, and the $N_{T,}$ a negative difference between contralateral and ipsilateral waveforms which reflects target selection. Measuring these components in those who vary in levels of autistic traits enables us to investigate spatial attention in the autism spectrum. If mechanisms supporting spatial attention differ between those with high and low levels of autistic traits, then this will be evidenced by group-differences in N2pc amplitude.

We reasoned that enhanced perceptual capacity as reported in ASC (Remington et al., 2009; 2012) and in those without ASC but with high levels of autistic traits (Bayliss & Kritikos, 2011) may enable participants to process relevant and irrelevant items in a simultaneous parallel-like manner. Indeed this has been suggested as one explanation for superior visual search seen in those with ASC (Remington et al., 2009). Processing relevant and irrelevant items simultaneously may be reflected by a larger N2pc amplitude because of the need for more focused attention (Sawaki, Luck & Raymond, 2015) and an attenuated P_D because of a lack of distracter suppression. Therefore, in our first study we predicted that the N2pc would be larger in those with high levels of autistic traits compared to those with low levels of autistic traits. In our second study we predict that a large N2pc in those with high levels of autistic traits will be accompanied by an attenuated P_D.

Study One

Method

AQ Questionnaire

The AQ is a brief questionnaire which asks respondents to indicate whether they agree or disagree with 50 statements describing social/communication and behavioural traits and preferences (Baron-Cohen et al., 2001). Each of the 50 items is scored as 0 or 1, with 1 being indicative of a response associated with an autistic-trait, thus the maximum score indicative of a high level of autistic traits is 50. An example item from the AQ is: "I prefer to do things with others rather than on my own." The Cronbach alpha for the overall AQ score was found to be satisfactory in a student sample (.81) and general population sample (.71) by Hoekstra et al., (2008).

Participants

Participants were recruited on the basis of their level of self-reported autistic traits as measured by the AQ. A link to an online version of the AQ was distributed by email to all students at the University of Sheffield and was completed by 1256 people. The mean AQ score from this population was 17.8 with a range of 2-44. The top and bottom 10^{th} percentiles of the distribution corresponded to AQ scores of 27 and 10 respectively. From these tails of the distribution thirty-four participants were invited to take part in the ERP study reported here. As detailed below, some participants were excluded from the analysis. This was either because their EEG data was contaminated with artifacts (N = 10) or because they showed chance performance on the behavioural task (N = 2). The final sample was comprised of ten individuals (four female, six male) with high AQ scores and twelve individuals (seven female, five male) with low AQ scores. The high AQ group had a mean AQ score of 31 (s.d = 2.7, score range = 28 - 37), and a mean age of 25 (s.d = 9.2, range = 19 - 49), and the low AQ group had a mean AQ score of 8.5 (s.d = 1.6, score range = 6 - 10), and a mean age of 22 (s.d = 3.1, range = 19 – 28). Age did not significantly differ between groups $t(20) = 1.1$, $p = .30$, $d = 0.5$. Three participants (two in the high AQ group) were left handed. The remaining participants were right handed. Written informed consent was obtained from all participants

and the study received ethical approval from the department of Psychology ethics sub-committee. All participants were invited to declare any personal or close family ASC diagnosis (parent/sibling) before the study began and none did so. The experimenter was blind to the AQ score of each participant until post testing.

Design and Stimuli

EEG was recorded while participants completed a spatial attention task which was based on Luck et al., (1997). Targets in the task were defined by colour (blue/green), target colour alternated between blocks. Participants sat 70cm from the screen and were instructed to report whether the target letter T was upright or inverted. Each search array was composed of 4 letters. The two coloured letter Ts were presented in opposing visual hemifields and were always presented in the lower visual field. Next to each coloured T was a grey distractor T at a distance which ranged from 0.7° to 1.6° (measured centre to centre). A white fixation cross remained visible at the centre of the display at all times and participants were instructed to remain focussed on this for the duration of the task. The stimuli were presented on a grey background (3.98cd/m^2) and the coloured search items were green (CIE coordinates u' = 0.278, v' = 0.567) and blue (CIE coordinates u' = 0.204, v' = 0.274) with luminance ranges within 3% of 18cd/m^2. The grey distractor Ts were also within this luminance range. Of the 900 total trials, the green T appeared in the left visual field (LVF) in 50% of trials and in the RVF in the other 50% of trials, randomly determined within a given block. The blue T was always placed in the opposite hemifield to the green T. The letters were presented at random locations within rectangular areas that were 1.4°*1.4° in size, located 2.7° below and to the left and right of fixation. The letter Ts were 0.6° high and 0.5° wide. Of the 900 trials the Ts occurred equally in green/blue, left/right and upright/inverted. An example of this task can be seen in Figure 1.

Procedure

Each array remained on screen for 750 ms during which time participants were required to discriminate the orientation of the target T. There was a randomly varying ISI between successive arrays of 1350 ms or 1650 ms. The experimental session was preceded by two blocks of 12 practice trials, one blue and one green block. Accuracy feedback was given on screen during the practice trials but was not given during experimental trials. Participants pressed a response key with their left index finger if the target was upright and with their right index finger if the target was inverted.

Please insert Figure 1 here

EEG Recording and Processing

EEG was recorded continuously using a high-density array of 128 Ag/AgCl electrodes (Electrical Geodesics Inc.). The signal was amplified by 1000, filtered on line with a band-pass of 0.01 – 80Hz and digitised with a sampling rate of 1000Hz. Impedance was kept below 50 kΩ. Electro-oculogram (EOG) was also recorded from electrodes located above and below the left and right eyes and from the left and right canthus. Data were referenced to the vertex electrode. The data were filtered offline using 0.1Hz high pass and 30Hz low pass cut offs. Visibly noisy channels were removed from the data by hand. The data were then epoched with a time window of -200 to 800 ms pre and post stimulus.

Artifact Rejection

Epochs were excluded from all remaining channels if the signal went above 75μV or below -75μV. Epochs demonstrating increases in amplitude associated with blinks were excluded using the 5 electrodes surrounding the eyes (EGI electrodes; 14, 17, 22, 126 &127), epochs were excluded if they contained signal above 50 μV or below -50μV. Eye movements

were identified by subtracting the signal from the left canthus from the signal at the right canthus, creating a difference wave. Epochs were rejected when activity in the resulting difference wave went above 16 μV or below -16 μV (Woodman & Luck, 2003), corresponding to approximately one degree of eye movement (Luck, 2005).

ERP datasets were excluded on the basis of being contaminated by excessive eye or muscle movements (N = 10). Datasets were also excluded if participants did not understand instructions as reflected in accuracy being below 50% correct (N = 2).

As described below, two ERP waveforms were computed, reflecting the signal contralateral and ipsilateral to the target. There was no difference in the number of trials used to calculate contralateral (Mean = 315.2, s.d = 75.5), or ipsilateral ERPs (Mean = 323.4, s.d = 79.2). Additionally there was no group difference in the amount of trials used to calculate ERPs (High AQ Mean = 630.1, s.d = 177.1), (Low AQ Mean = 645.6, s.d = 124.8).

ERP Processing

Amplitude

In order to calculate the N2pc, the average signal between 180 and 300 ms was calculated from trials during which a correct behavioural response was made. This was obtained from four pairs of electrodes (T7/T8, P3/P4, P07/08 and P7/P8) relative to a 200 ms pre stimulus baseline voltage. The numbers on the EGI cap for these pairs of electrodes are (46/109, 53/87, 59/92 & 66/85). The time window and electrodes used are in line with previous work (Luck et al., 1997). The signal contralateral to a target was acquired by taking the mean amplitude from the four electrodes on the opposite side of the head to the target. Ipsilateral amplitudes were acquired by taking the mean amplitude from the four electrodes on the same side of the head as the target.

Latency

Because latency measures are nonlinear and vulnerable to high levels of measurement error, the jackknife approach was used (Miller, Patterson & Ulrich, 1998; Kiesel, Miller, Jolicoeur & Brisson, 2008, Luck et al., 2009). Latencies were measured from a number of difference waves, computed from a subsample of n – 1 of the individual participants. These were calculated separately for high and low AQ groups. These iterations inflate the t value; therefore, before testing for significance, the t value must be adjusted according to:

$$\text{Adjusted } t = t / (n - 1)$$

Onset latency was calculated with the fractional area latency method, using 15% area latency (Luck et al., 2009) on the N2pc difference wave (Contralateral minus Ipsilateral) between 180 and 300 milliseconds. Kiesel et al., (2008) concluded that the jack knife method combined with fractional area latency is a superior approach to investigate onset latency in difference wave components.

Results

Behavioural Results

As reported in table 1, accuracy was high and did not vary significantly between high and low AQ scorers, $t(20) = 1.8$, $p = .08$, $d = 0.8$. Similarly, median reaction time did not differ between groups, $t(20) = 1.2$, $p = .23$, $d = 0.5$.

N2pc amplitude

N2pc amplitude was analysed using a 2 x 2 repeated measures ANOVA with a within-subjects factor of laterality (contralateral vs ipsilateral) and a between-subjects factor of AQ group. All reported values reflect the Greenhouse-Geisser corrected statistic. Partial eta-

squared was used to report effect size. Guidelines for interpreting partial eta-squared values are: 0.01 = small effect, 0.09 = medium and 0.25 = large (See Cohen, 1988). A highly significant interaction between contraleteral and ipsilateral signal confirmed the presence of a reliable N2pc, F (1, 20) = 27.1, p = <.001, ηp^2 = 0.58. In addition, there was a significant interaction between AQ group and laterality, F (1, 20) = 5.4, p = .03, ηp^2= 0.21. Paired samples t-tests revealed that the difference between the ipsilateral and contralateral signal was significant for both the high AQ group t(9) = 4.1, p = <.001, d = 1.3, and the low AQ group, t(11) = 2.9, p = .02, d = 0.9, but effect sizes indicated that the difference was larger in the high AQ group. In Figure 2, ERPs ipsilateral and contralateral to the appearance of a target are shown separately for high and low AQ scorers. Figure 3 shows the difference wave where a larger N2pc amplitude is evident in the high AQ scorers.

Please insert Figure 2 here

Please insert Figure 3 here

Onset Latency

Latency values were calculated as the time point in which the difference wave (contralateral minus ipsilateral) reached 15% of the area under the curve between 180 and 300 milliseconds.

An independent measures t-test with a between factor of AQ group revealed no significant group difference in the onset of the N2pc, t (20) = .31, p = .76, d = .03. Mean latency values are given in Table 2.

Additional ERP analyses

In order to establish whether the groups differed in any ERP components other than N2pc additional analyses were conducted on earlier and later components of the ERP including P1

and SPCN amplitude. The P1 is an early component, normally peaking around 100 ms. The P1 reflects visual processing and is thought to originate in extra striate cortex (Luck & Kappenman, 2013). The SPCN (sustained posterior contralateral negativity) occurs between 350 and 650 ms and this was the time window used (Jolicoeur, Brisson & Robitaille, 2008). The SPCN represents the difference between the signal recorded from electrodes that are either contralateral or ipsilateral to a target and is interpreted as an electrophysiological marker of working memory maintenance (Luck & Kappenman, 2013).

Peak P1 amplitude (Time window: 70-170ms) was analysed at occipital electrodes (O1/O2 EGI: 72/77) using an independent measures t-test with a between subjects factor of AQ group. Although Figure 3 suggests a potential between group difference in the amplitude of the P1, statistical analysis indicated no signficant difference in P1 amplitude between groups $t(20) = 1.6$, $p = .13$, $d = 0.7$.

Mean SPCN amplitude (350-650 ms) was analysed at all four pairs of electrodes described above using a 2 x 2 mixed measures ANOVA with a within-subjects factor of laterality (contralateral vs ipsilateral) and a between-subjects factor of AQ group. This revealed a main effect of laterality $F(1, 20) = 16.8$, $p = .001$, $\eta^2_p = .46$, showing a clear SPCN in these data. This did not interact with AQ group $F(1, 20) = .48$, $p = .50$, $\eta p^2 = .02$, indicating that SPCN did not differ between the high and low AQ scorers.

These additional analyses confirm that there was no between-group difference in the amplitude of either of the early (P1) or late (SPCN) ERP components confirming that differences between groups were uniquely observed in the N2pc component.

Simon Effect Analysis

A Simon effect analysis was conducted in order to ensure that the laterality of stimuli and responses did not influence N2pc amplitude. For this analysis the magnitude of the N2pc was calculated by subtracting mean ipsilateral amplitude between 200 and 300 ms from mean contralateral amplitude between 200 and 300 ms. These values were calculated separately from trials in which the stimulus hemifield was compatible or incompatible with response side, and were entered into a 2 x 2 ANOVA with compatibility as the within subjects factor and AQ group as the between subjects factor. This analysis revealed no significant difference in N2pc amplitude between trials where appearance of the target and response were compatible or where they were incompatible, $F\ (1, 20) = .01$, $p = .93$, $\eta p^2 = .001$ and no significant interaction between these variables and AQ group, $F\ (1, 20) = .02$, $p = .89$, $\eta p^2 = .001$. This analysis confirms that the Simon effect did not influence N2pc amplitude which is in line with previous work (Cespón, Galdo-Álvarez & Díaz., 2012).

Interim Discussion

The objective of Study One was to establish whether an ERP signature of covert deployment of attention, i.e. the N2pc component, differed between those with either high or low levels of autistic traits. We found a clear between group difference in N2pc amplitude, providing direct evidence for differences in the mechanisms underlying spatial attention in those with high and low levels of autistic traits. In order to be sure that this effect was not driven by differences in other ERP components, and to confirm that N2pc was the only component that differed between the low and high AQ scorers, we also checked for differences between groups in P1 peak amplitude and mean SPCN amplitude. No between group differences were observed in these components.

Remington and colleagues have shown that those with ASC do not show the usual detriment in search tasks under conditions of high perceptual load. The authors suggest that

this is a facet of higher perceptual capacity in individuals with ASC, and one consequence appears to be that those with ASC are able to allocate attention to task-irrelevant items in a scene even at high levels of load (Remington et al., 2009). We (Milne et al., 2013) recently demonstrated that those with high levels of autistic traits showed larger P3b amplitude following the presentation of irrelevant non-target stimuli than those with lower levels of autistic traits, suggesting that there may be reduced suppression of irrelevant or distracting stimuli in those with high levels of autistic traits. N2pc amplitude, as measured here, reflects the processes of both target selection and suppression, so it is not possible to identify whether the larger N2pc amplitude reflects differences in target selection or suppression. However, measuring the amplitude of the P_D (Hickey et al., 2009) may offer a useful insight into this. If our hypothesis that those with high levels of autistic traits show reduced distractor suppression is correct then we would predict that larger N2pc amplitude will be accompanied by reduced P_D amplitude in those with high levels of autistic traits. The aim of study two was therefore to attempt to replicate the finding from study one of increased N2pc in individuals with higher levels of autistic traits, and to establish whether differences in distractor suppression (P_D) and / or target selection (N_T) were also evident in those with more autistic traits.

Study Two

Method

For this study an entirely new cohort of participants was recruited. All first year students at our institution were invited to complete the AQ online. 864 participants completed the AQ; the mean score was 18.6 with a range of 1 - 45. The top and bottom 10^{th} percentiles of the distribution corresponded to AQ scores of 28 and 11 respectively. From this distribution, forty-five participants were invited to take part in the ERP study reported here.

Nine participants were excluded from analysis due to EEG artifacts. This resulted in a final sample of 36, with 17 high AQ (11 female, 6 male) participants and 19 low AQ (15 female, 4 male) participants. The high AQ group had a mean AQ score of 30 (s.d = 3.9, score range = 28 - 40) and a mean age of 21 (s.d = 3.4, range = 18 - 30) the low AQ group had a mean AQ score of 8.5 (s.d = 2.1, score range = 5 – 11) and a mean age of 20 (s.d = 1.5, range = 18 - 23). Age did not significantly differ between groups t (34) = 1.0, p = .33, d = 0.3. Six participants (five in the high AQ group) were left handed. Written informed consent was obtained from all participants and the study received ethical approval from the department of Psychology ethics sub-committee. All participants were invited to declare any personal or close family ASC diagnosis before the study began and none did so. The experimenter was blind to AQ score until post testing.

Design and Stimuli

Stimuli were the same as in study one, with the removal of the grey distractor Ts and the addition of letter positions on the vertical meridian. This was a replication of Hickey et al, (2009) experiment 4. The lateral/vertical organisation (see Figure 4) allowed for the isolation of components related to lateral targets (N_T) and lateral distractors (P_D).

Search arrays were composed of 2 letters: equiluminant green and blue letter T's (measuring 1° of visual angle). The Ts were equidistant from central fixation and from each other (5°) with 2 positions in the vertical meridian (directly above fixation and below: 0° and 180°) and 6 lateral positions (60°, 90°, 120°, 240°, 270° and 300°), 2 above the horizontal meridian, 2 on the horizontal meridian and 2 below. There were 576 trials where a target appeared laterally and 576 trials where a distractor appeared laterally. There were also 576 trials with the target and distractor were presented in opposing lateral positions to elicit the N2pc. Green and blue appeared with equal occurrence in lateral (1/3 of trials) and vertical

positions. The opposing sides set up, as a balanced visual search display was intended to elicit the N2pc (a summation of distractor and target processing).

Please insert Figure 4 here

Procedure

The procedure was the same as in study one. However, participants were now required to respond with the index and middle finger of their dominant hand. This change was made as an improvement on Study One, eliminating the need for Simon effect analysis. EEG recording, pre-processing and artefact rejection were the same as in study one.

EEG Recording and Processing

EEG recording and processing was the same as in Study One.

Artifact Rejection

Artifact rejection procedures were the same as in Study One.

There was no significant difference in the number of trials used to calculate ERPs between contralateral and ipsilateral ERPs for N2pc, (Contralateral Mean = 200.2, s.d = 48.4; Ipsilateral Mean = 202.4, s.d = 37.2), P_D (Contralateral Mean = 161.2, s.d = 52.8; Ipsilateral Mean = 164.7, s.d = 47.1), or N_T (Contralateral Mean = 167.4, s.d = 50.6; Ipsilateral Mean = 159.1, s.d = 51.1). There was also no significant difference in the number of trials used to calculate ERPs between AQ groups for N2pc, (High AQ Mean = 413.4, s.d = 97.2; Low AQ Mean = 396.2, s.d = 78.4), P_D (High AQ Mean = 305.6, s.d = 98.8; Low AQ Mean = 336.5, s.d = 90.6), or N_T (High AQ Mean = 302.7, s.d = 97.1; Low AQ Mean = 318, s.d = 88.1) trials.

ERP Processing

ERP amplitudes were calculated using the same procedure as in study one. For N2pc amplitude the time window used was 180-300 ms; for $N_{T,}$ 175-325 ms and for $P_{D,}$ 230-280 ms (in line with Corriveau et al., 2012; Sawaki & Luck, 2010; Hickey et al., 2009).

N2pc/N_T Amplitude

The signal contralateral to a target was acquired by taking the mean amplitude from the electrodes on the opposite side of the head to the target. Ipsilateral amplitudes were acquired by taking the mean amplitude from the four electrodes on the same side of the head as the target.

P_D Amplitude

The signal contralateral to a distractor was acquired by taking the mean amplitude from the electrodes on the opposite side of the head to the distractor. Ipsilateral amplitudes were acquired by taking the mean amplitude from the four electrodes on the same side of the head as the distractor.

Latency

The same jack knife procedure was used as in study one.

Onset latency was calculated with the fractional area latency method, using 15% area latency (Luck et al., 2009) on the difference wave (Contralateral minus Ipsilateral). For the N2pc difference wave this was between 180 and 300 milliseconds. On the P_D difference wave, between 230 and 280 milliseconds and on the N_T difference wave between 175 and 325 milliseconds.

Results

Behavioural Results

As reported in Table 1, accuracy was high and did not vary significantly between high and low AQ scorers, t (1, 34) = 1.0, p = .32, d = 0.3, similarly median correct-trial reaction times did not differ between high and low AQ scorers, t (1, 34) = .06, p = .95, d = <.01.

Please insert Table 1 here

N2pc Amplitude

N2pc amplitude was analysed using a 2 x 2 repeated measures ANOVA with a within-subjects factor of laterality (contralateral vs ipsilateral) and a between-subjects factor of AQ group. A highly significant interaction between contraleteral and ipsilateral signal confirmed the presence of a reliable N2pc, F (1, 34) = 19.7, p = <.001, ηp^2 = 0.58. In addition, there was a significant interaction between AQ group and laterality, F (1, 34) = 9.1, p = .005, ηp^2= 0.21. This result is consistent with the findings of study one. Paired sample t-tests revealed that the difference between ipsilateral and contralateral signal was significant for the high AQ group t(16) = 4.3, p = .001, d = 1.2, however it was not significant for the low AQ group, t(18) = 1.3, p = .19, d = 0.3. In Figure 5, ERPs ipsilateral and contralateral to the appearance of a target are shown separately for high and low AQ scorers. Figure 6 demonstrates a larger N2pc amplitude in those with high levels of autistic traits.

Onset Latency

An independent measures t-test with a between factor of AQ group revealed no significant group difference in the onset of the N2pc, t (34) = .02, p = .81, d = <.01, again consistent with the findings of study one. The mean values are shown in Table 2.

Please insert Table 2 here

P_D Amplitude

P_D amplitude was analysed using a 2 x 2 repeated measures ANOVA with a within-subjects factor of laterality (contralateral vs ipsilateral) and a between-subjects factor of AQ group. A highly significant interaction between contraleteral and ipsilateral signal confirmed the presence of a reliable P_D, F (1, 34) = 7.2, p = .01, ηp^2= .17. In addition, there was a significant interaction between AQ group and laterality, F (1, 34) = 5.7, p = .02, ηp^2= .15. Paired samples t-test revelead that the difference between ipsilateral and contralateral signal was significant for the low AQ group t(18) = 3.9, p = .001, d = 1.0, but was not significant for the high AQ group, t(16) = .43, p = .67, d = 0.1, suggesting that those with high levels of autistic traits did not show a P_D. In Figure 5, ERPs ipsilateral and contralateral to the appearance of a target are shown separately for high and low AQ scorers. Figure 6 demonstrates a smaller P_D amplitude in those with high levels of autistic traits.

Onset Latency

An independent measures t-test with a between factor of AQ group revealed no significant group difference in the onset of the P_D, t (34) = .10, p = .91, d = <.01. The mean values are shown in Table 2.

N_T Amplitude

N_T amplitude was analysed using a 2 x 2 repeated measures ANOVA with a within-subjects factor of laterality (contralateral vs ipsilateral) and a between-subjects factor of AQ group. A highly significant interaction between contralateral and ipsilateral signal confirmed the presence of a reliable N_T, F (1, 34) = 22.1, p = <.001, ηp^2= .39. There was no significant interaction between AQ group and laterality, F (1, 34) = .18, p = .38, ηp^2= .01. In Figure 5, ERPs ipsilateral and contralateral to the appearance of a target are shown separately for high and low AQ scorers.

Onset Latency

An independent measures t-Test with a between factor of AQ group revealed no significant group difference in the onset of the N_T, t (34) = .61, p = .60, d = 0.2. The mean values are shown in Table 2.

Please insert Figure 5 here

Please insert Figure 6 here

Additional ERP analyses

In order to be sure that the group difference in the ERP was present for the N2pc component only; additional analyses were conducted on earlier and later components of the ERP including P1 and SPCN amplitude.

P1 Amplitude

Peak P1 amplitude (time window: 70-170ms) was analysed at occipital electrodes (O1/O2 EGI: 72/77) using an independent measures t-test with AQ group as a between subjects factor. Peak P1 amplitude did not differ between groups during N2pc trials, t (34) = .57, p = .58, d = 0.2, P_D trials t (34) = 1.1, p = .28, d = 0.4, or N_T trials t (34) = .18, p = .86, d = 0.1.

SPCN Amplitude

Mean SPCN amplitude (350-650 ms) was analysed at all four pairs of electrodes described above using 2 x 2 mixed measures ANOVA's with a within-subjects factor of laterality (contralateral vs ipsilateral) and a between-subjects factor of AQ group. This revealed a main effect of laterality for N2pc F (1, 34) = 11.1, p = .002, ηp^2= .25 and N_T trials, F (1, 34) = 7.3, p = .02, ηp^2= .13, showing a clear SPCN in these data. This did not interact with AQ group F

(1, 34) = <.01, p = .97, ηp^2= <.01 in N2pc or N_T trials F (1, 34) = .42, p = .52, ηp^2= .01, indicating that SPCN did not differ between the high and low AQ scorers.

For P_D trials there was no main effect of laterality F (1, 34) = 2.4, p = .13, ηp^2= .07, which is consistent with expectations as we would not expect to see an SPCN in response to distractors.

General Discussion

The objective of this work was to establish whether an ERP signature of the deployment of covert attention, i.e. the N2pc component, differed between those with either high or low levels of autistic traits. In two separate studies, involving two entirely separate cohorts of participants, we found that N2pc amplitude was significantly larger in individuals with high, rather than low, levels of autistic traits. This finding provides neural evidence that the deployment of attention differs between high and low AQ scorers. Specifically, larger N2pc amplitude suggests more effortful processing, or greater allocation of attentional resources, during target search. Study two indicated that the higher AQ scorers also had no $P_{D,}$ a finding which indicates a lack of distractor suppression in the high AQ scorers. Together, these results show that individuals with higher levels of autistic traits show increased deployment of attention during a spatial search task, most likely as a result of a lack of distractor suppression. No group differences were found in the N_T component, indicating that the neural mechanisms underpinning target selection do not differ between those with high and low levels of autistic traits.

In study one, ERP amplitude was significantly larger when recorded from electrodes contralateral to the target than electrodes ipsilateral to the target in both the high and low AQ scorers. That is, both groups showed a significant N2pc component. However, in study two, the contralateral/ipsilateral difference only reached significance in the high AQ scorers. The

N2pc has been shown to be larger when stimuli are presented in the lower visual field (Luck et al., 1997), therefore the stimuli in study one were always presented below fixation. In study two, the task was modified so that we could measure NT and PD in addition to N2pc. We used an existing paradigm (Hickey et al., 2009), which had previously been used to measure these components, however this second paradigm did not limit stimuli to appearing only in the lower visual field. This may explain why the low AQ group did not show a significant N2pc in these data, especially given that N2pc onset was later (although not-significantly so) in the low AQ group compared to the high AQ group. Importantly, the high AQ group showed a significant N2pc in both study one and study two, providing support for our conclusion that N2pc amplitude is increased in individuals with high AQ scores.

Previous work suggests that those with ASC (Remington et al., 2009) and those with high levels of autistic traits (Bayliss & Kritikos, 2011) have an enhanced perceptual capacity. Ultimately the result of this enhanced capacity appears to be the processing of normally irrelevant distracting items in a visual scene and this could lead to the overwhelming perceptual experience often reported by those with an ASC. Similarly, Adams and Jarrold, (2012) used a flanker paradigm and found that when their task was made more simple for participants (i.e increasing the size of the target), those with an ASC continued to show interference errors from incongruent distracting flankers. Also, we (Milne et al., 2013) recently demonstrated that those with high levels of autistic traits showed a larger response to irrelevant stimuli compared to those with low levels of autistic traits, resulting in less difference between the P3b response to targets and distractors. We suggested that there may be reduced suppression of distractors in those with high levels of autistic traits, a claim which is further supported by the data reported here. The small P_D suggests a lack of active suppression of distractors in those with high levels of autistic traits which may be a consequence of an enhanced perceptual capacity. Our previous study found that the smaller

P3b amplitude was associated with more efficient visual search, which led us to the rather counter-intuitive conclusion that those who are better at visual search are those who are less efficient at filtering out irrelevant stimuli. Therefore we might expect that those with a lack of $P_{D,}$ and who are not suppressing irrelevant information, may be more efficient at visual search, however further data is required to test this suggestion directly.

Further analyses confirmed that the group differences were unique to the N2pc and P_D. P1 amplitude did not differ between the high and low AQ scorers indicating that there was no difference between the groups in terms of the initial sensory encoding of the stimuli. In addition, SPCN did not differ between the groups indicating that post-perceptual processes such as working memory maintenance and representations (Eimer & Kiss, 2010) do not differ between those with high and low AQ scores. Rather, the group differences we report here are restricted to processes that reflect attention deployment to goal relevant stimuli, and active suppression of distractor stimuli.

As discussed by Gregory and Plaisted-Grant (2013), in any study of autistic traits, there is the possibility that those with high AQ scores, particularly above the clinical cut off defined by Baron-Cohen et al., (2001) could meet diagnostic criteria for an ASC. We attempted to mitigate this by asking participants to declare any ASC diagnosis for themselves or a close family member (parent/sibling) with the intention of excluding any participant who did so. None of our participants indicated that either they or any of their first-degree relatives had a diagnosis of ASD, making it likely that our findings do reflect differences in N2pc amplitude on the basis of AQ score alone. Further research is needed to establish whether this finding is replicated in individuals who have a clinical diagnosis of ASC.

In conclusion, here we present data which demonstrates that the amplitude of the N2pc, an ERP component which reflects deployment of covert attention, is significantly

larger in those with high levels of autistic traits compared to those with low levels of autistic traits. In addition, the $P_{D,}$ which reflects active suppression of distractors, is reduced in those with high levels of autistic traits. Reduced distractor suppression in those with increased autistic traits is in-line with previous data showing that children with autism are less able to supress distractors during a flanker task (Adams and Jarrold, 2012), and may reflect increased perceptual capacity in those with high AQ scores (c.f. Kritikos & Bayliss, 2011). Taken together with our previous findings of altered feature based attention in those with high levels of autistic traits (Milne et al., 2013), this work adds to a growing literature demonstrating atypical attentional processes in the autism spectrum. Additionally, the neural atypicalities reported here could ultimately underlie the experience of perceptual overload often reported by individuals on the autism spectrum.

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Table 1. Mean and Standard Deviation for Accuracy and Reaction Time Data for high and low AQ scorers for both study one and two

		Accuracy (%)		Median RT	(ms)
Study One		High AQ (N= 10)	Low AQ (N = 12)	High AQ	Low AQ
	Mean	82.1	87.1	545.5	523.8
	SD	6.5	6.4	38.5	42.5
Study Two		High AQ (N = 17)	Low AQ (N = 19)	High AQ	Low AQ
	Mean	83.7	82.5	506.9	503.6
	SD	6.1	4.7	31.6	32.0

Table 2. Mean and standard deviation for onset latency, shown for high and low AQ scorers for both Study One and Study Two

Onset Latency (ms)		**N2pc**		**P_D**		**N_T**	
		Mean	S.D	Mean	S.D	Mean	S.D
Study One	High AQ	243.3	11.1				
	Low AQ	213.5	7.0				
Study Two	High AQ	227.0	10.3	247.8	7.7	266.0	11.9
	Low AQ	246.2	7.0	241.5	1.2	211.3	2.6

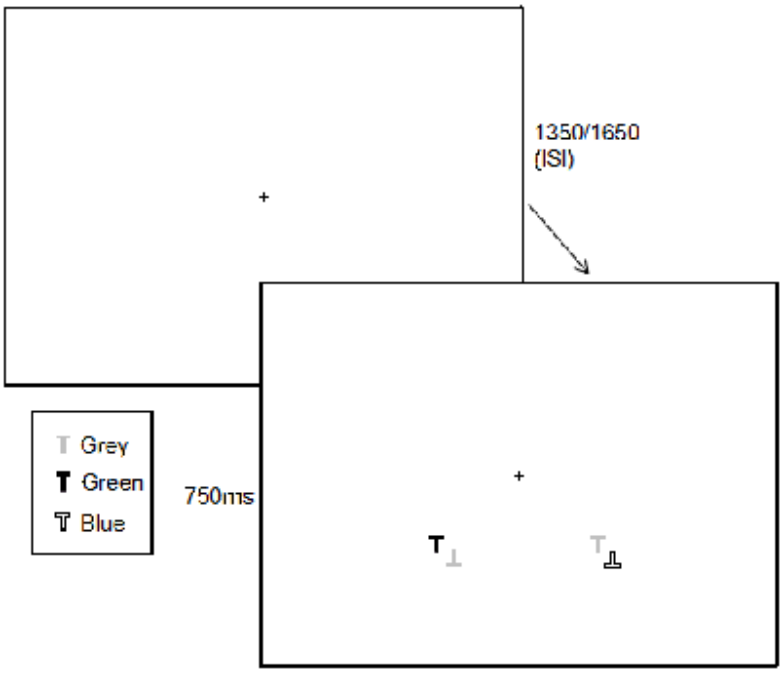

Figure 1. Example of a stimulus array used in study one. In a given trial, either coloured letter could serve as a target while the opposing letter was the distractor.

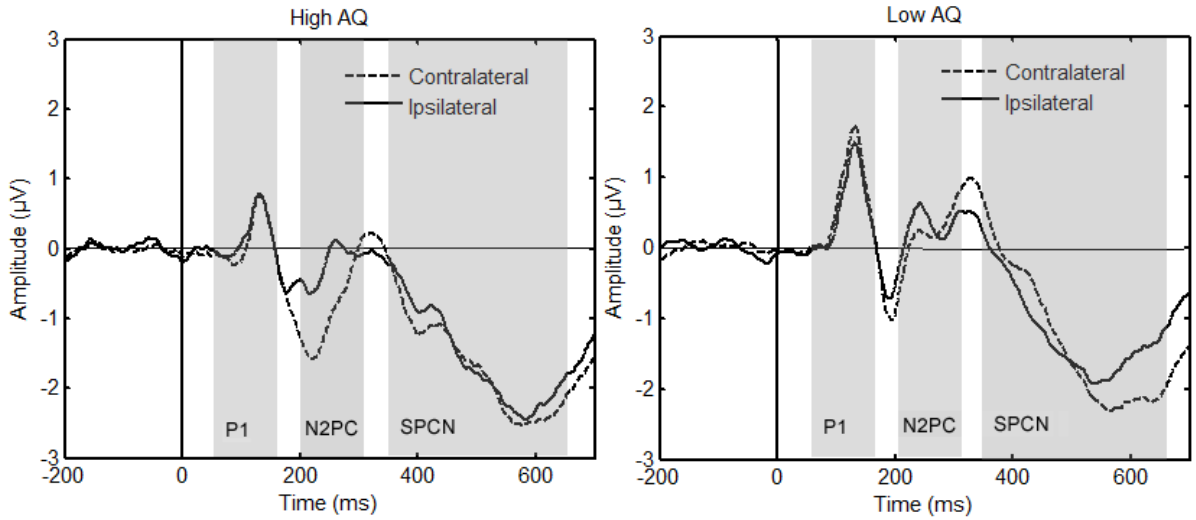

Figure 2. Grand average ERPs obtained from study one shown separately for high and low AQ scorers with the time window for N2PC marked.

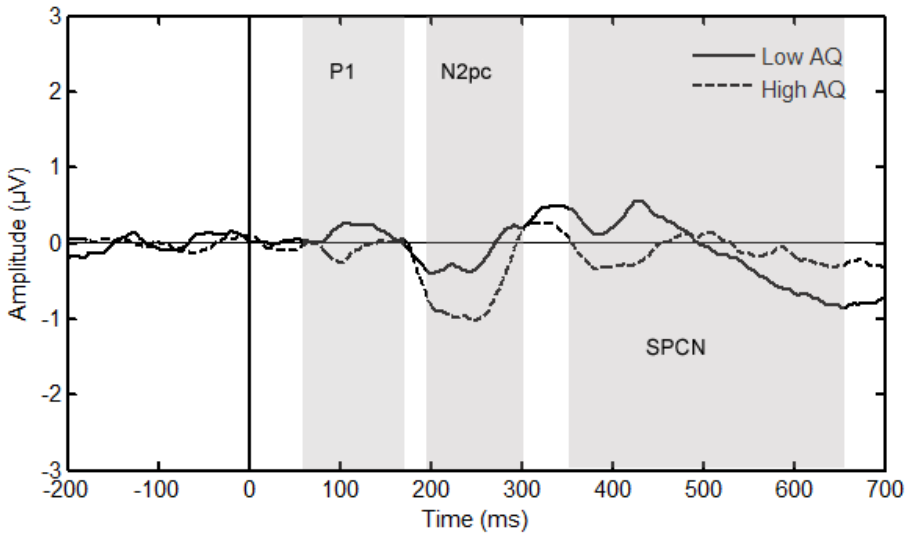

Figure 3. Difference waves (contralateral minus ipsilateral) from study one shown for high (dashed line) and low AQ scorers with time windows for P1, N2pc and SPCN marked.

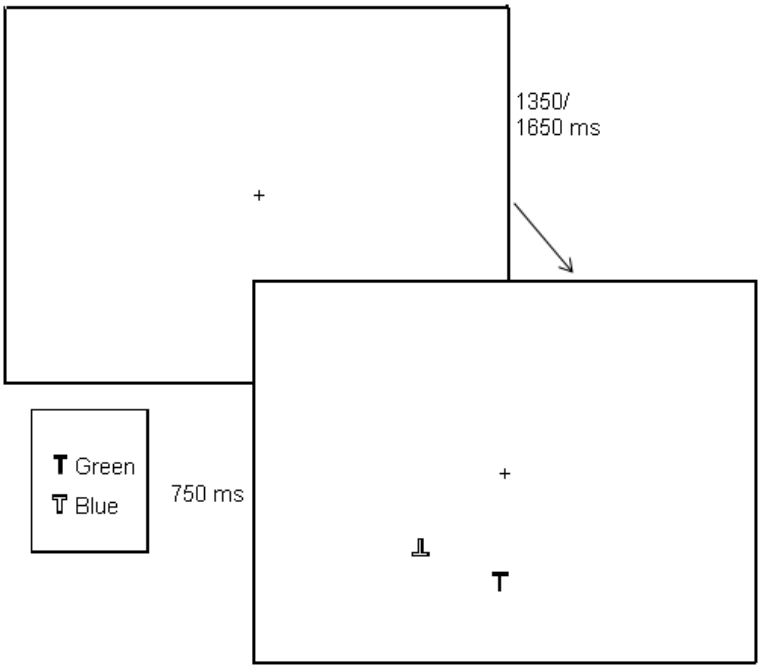

Figure 4. Example of a stimulus array from study two showing the set up with one letter on the vertical meridian. If the target in this example was the green T, we would expect to see a contralateral positivity to the blue distractor T and no lateral response to the target on the meridian.

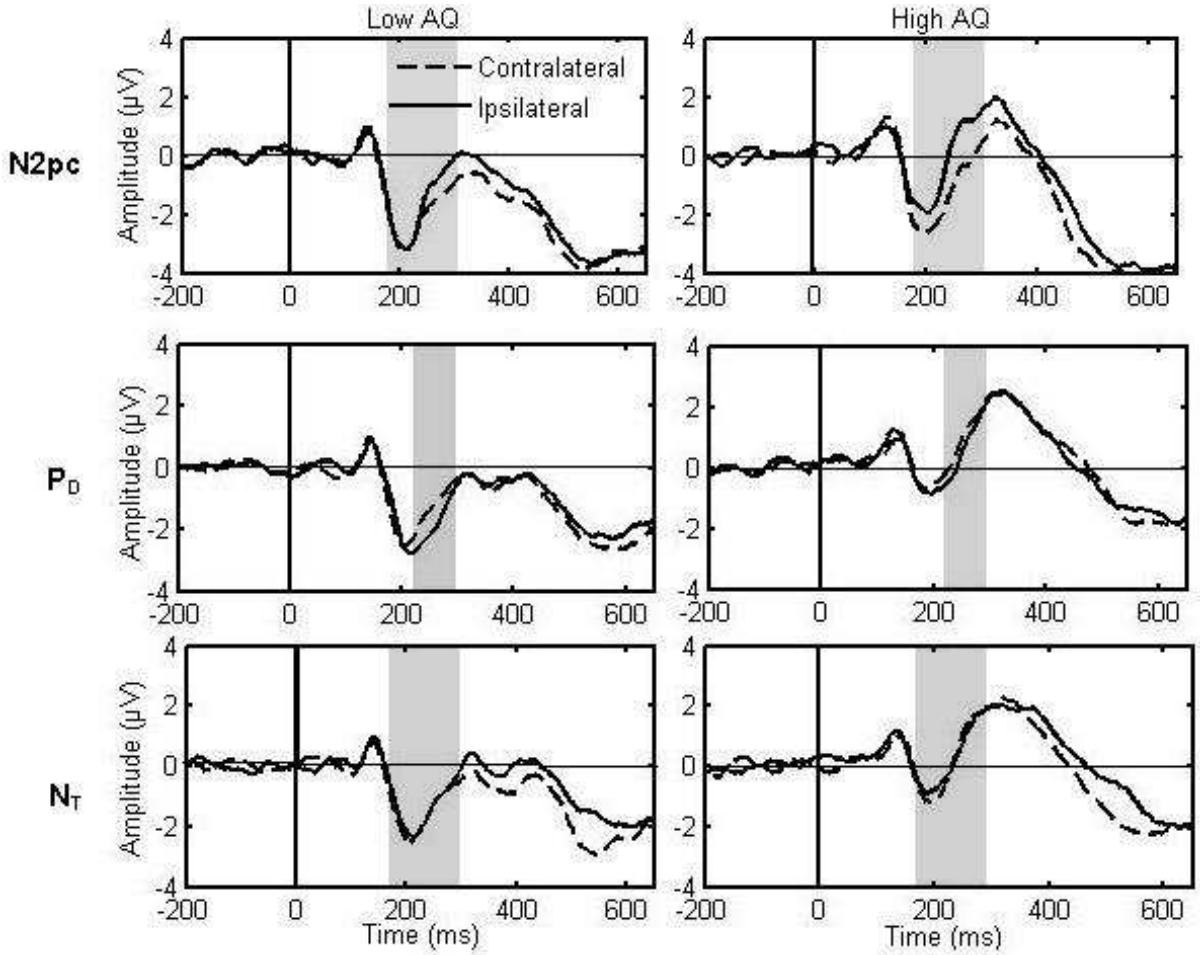

Figure 5. Grand average ERPs from study two; N2pc, P_D and N_T are shown separately for high and low AQ scorers with the time window for the relevant ERP component marked.

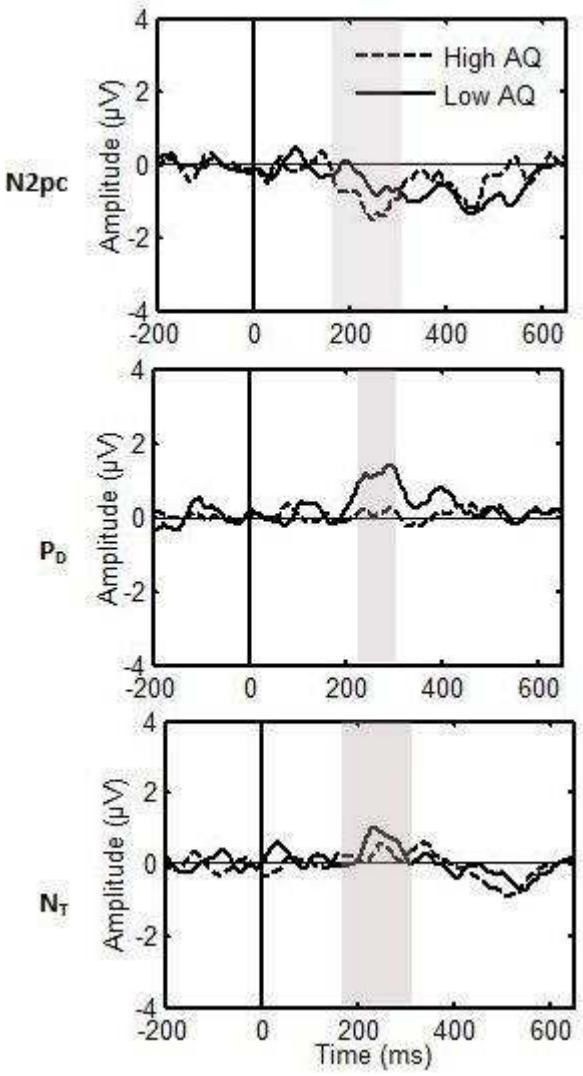

Figure 6. Difference waves from study two (contralateral minus ipsilateral) shown for high (dashed line) and low AQ scorers with the relevant time window marked