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Electrophysiological Correlates of Visual Search in the Autism Spectrum

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Abstract

The thesis examines the neural basis of selective attention in those with high and low levels of self-reported autistic traits. Existing literature suggests that those with an autism spectrum condition (ASC) show atypical selective attention (e.g. Burack 1994), and this has been extended to those with high levels of autistic traits (Bayliss & Kritikos, 2011).

The research presented in the thesis has, for the first time, examined the neural basis of spatial attention in those with high and low levels of autistic traits by measuring the ERP deflections associated with covert attention, target selection and distracter suppression (The N2pc, N_T and P_D).

The results provide evidence of neural differences in spatial attention in those with high levels of autistic traits. Specifically, a larger N2pc suggests greater allocation of attentional resources, and a reduced P_D indicates reduced distracter suppression in those with high levels of autistic traits. 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.

The findings support Remington's suggestion of an enhanced perceptual capacity in ASC (Remington et al., 2009); which would result in the processing of normally irrelevant information. Recent work has extended the possibility of an enhanced perceptual capacity to those with high levels of autistic traits (Bayliss & Kritikos, 2011; Milne et al., 2013), and this is supported by the ERP findings reported in the thesis. The findings may be an important factor in explaining the overwhelming perceptual experience often reported by those on the autism spectrum.

Chapter 1 : Selective Attention and the Autism Spectrum

Autism Spectrum Conditions

Autism spectrum conditions (ASC) is an umbrella term to describe a number of conditions which manifest in social impairments; difficulties in communication; repetitive behaviours and narrow obsessive interests. Throughout this thesis, ASC will be used in lieu of ASD (Autism Spectrum Disorders) as ASC is becoming a more socially desirable and acceptable term (Kenny et al., 2015). Underlying the characteristic repetitive behaviours in ASC, there appears to be fundamental issues with sensory processing, and the importance of this has been recently recognised and incorporated into the diagnostic criteria for ASC in the fifth edition of the diagnostic and statistical manual (DSM-V) (American Psychological Association, 2013). Another feature noted within ASC is atypical attention which has been widely reported; may be linked to the emergence of the core ASC symptoms (Gliga et al., 2015; Keehn, Muller, & Townsend, 2013) and is the focus of this thesis.

First described separately by Leo Kanner (Kanner, 1943) and Hans Asperger (Asperger, 1944), ASCs are heritable neurodevelopmental conditions. The spectrum includes those who would have previously been diagnosed with autism, Asperger's syndrome (AS) or pervasive developmental disorder not otherwise specified (PDD-NOS), recognising that symptom extent and severity varies greatly from individual to individual (American Psychiatric Association, 2013). Previous to this classification, the term AS identified those who show the same impairments as those with autism with an absence of the accompanying language delay and PDD-NOS described those who may not have met all of the criteria for autism. Therefore, one end of the spectrum houses those with typically low functioning autism and the other end houses those who are typically described as high functioning. The epidemiology suggests that ASC is largely genetic (Bailey et al., 1995) with prevalence rates of around 1% in the population (Baird et al., 2006) and 18% for siblings of those with an ASC diagnosis (Ozonoff et al., 2011). Within the spectrum the large degree of variability in symptomatic presentation makes diagnosis more difficult and often early diagnostic opportunities are missed at the high functioning end of the spectrum, resulting in delayed diagnosis often well into school age (Gillberg, Nordin, & Ehlers,

1996). Thus, advancing knowledge of the genetics and neural underpinnings of ASC is crucial to the development of appropriate diagnostic tools.

Autistic Traits in the Typically Developed Population

The term ASC indicates that autistic traits vary on a scale of severity which may also extend into the non-clinical population, with everyone showing some degree of autistic traits (Dawson et al., 2002). Evidence suggests that autistic traits exist on a scale beyond the spectrum of diagnoses (Constantino & Todd, 2003; Wing, 1988), where those on the upper end with the highest levels of autistic traits may possess a clinical diagnosis or may exist below clinical threshold and outside the categorical boundary for diagnosis. There are a number of scales to measure the levels of autistic traits in the general population; the Autism Spectrum Quotient (AQ) (described in detail in Chapter Two) and the Broad Autism Phenotype Questionnaire (BAPQ) are self-report questionnaires commonly used to assess the level of autistic traits in those who do not have a clinical diagnosis (Hurley, et al., 2007; Baron-Cohen et al., 2001). Although autistic traits appear to be continuously distributed within the general population (Constantino & Todd, 2005; Freeth, Bullock, & Milne, 2013; Happé, Ronald, & Plomin, 2006; Hoekstra, Bartels, Verweij, & Boomsma, 2007), they are consistently reported with greater incidence in first-degree relatives of individuals with autism (Bailey et al., 1995) and with a substantial heritability factor (Hoekstra et al., 2007). Piven et al., (1997) found evidence of what is now referred to as the *broader autism phenotype*; reporting higher rates of social and communication deficits and stereotyped behaviour in the relatives of families with more than one case of an ASC. Therefore, those in the broader autism phenotype display milder, non-clinical levels of ASC traits.

Studies described in the later sections of this chapter will highlight support for the existence of a spectrum of traits in ASC and show that measuring autistic traits in the general population and correlating them with performance on tasks is a useful approach in the study of developmental conditions. Recruiting those who are typically developing but report high levels of autistic traits allows researchers to avoid the difficulty around recruiting participants with diagnoses from clinical settings. In addition, comparing the performance of those with high levels of autistic traits to those with low levels of autistic traits could be very informative to research on individual differences.

Theories of ASC

There are a number of explanations that have been proposed as a unifying theory of ASC, however as this section will summarise; attempting to unify all symptoms of ASC in one theory has not been a successful approach. Cognitive theories include postulated impairments in theory of mind, which suggests that an absence of the ability to understand and predict the actions of others is a fundamental deficit within ASC (Baron-Cohen, Leslie, & Frith, 1985). Additionally, impairments in executive function are purported to lead to cognitive dysfunction in ASC (Pennington & Ozonoff, 1996) and mirror neurons were proposed as the problematic elemental neural mechanism for the development of theory of mind and executive function (Williams, Whiten, Suddendorf, & Perrett, 2001). Biological theories include the male brain/systemising theory where Baron-Cohen, (2006), suggests that the ASC processing style is heavily weighted towards the 'male' systemising end of the spectrum. A systemising approach favours events which are more predictable and is problematic for complex social situations.

Weak Central Coherence

The weak central coherence (WCC) account suggests that in ASC, there is a processing bias for local features of a stimulus as a result of impairment in the ability to extract global meaning. Studies that are discussed later in this chapter will highlight the local processing strengths of those with an ASC (See Embedded Figures Task). However, numerous studies have assessed this theory and the general finding is that global processing is intact in ASC (Iarocci et al., 2006; Mottron, Burack, Iarocci, Belleville, & Enns, 2003; Ropar & Mitchell, 2001). Additionally, studies have failed to replicate the finding that those with an ASC are less susceptible to illusions (Milne & Scope, 2008; Ropar & Mitchell, 2001); less susceptibility to illusions would suggest a more local approach to the processing of complex stimuli; consequently these findings do not support the idea of a global impairment proposed by WCC. Furthermore, Mottron et al., (2003) compared 3 different paradigms, finding local task enhancements in ASC but no deficits in global processing. The authors concluded that the notions of global impairment and local bias in WCC need to be re-examined.

Enhanced Discrimination and Reduced Generalisation

Another cognitive theory suggests that those with an ASC may be unable to draw disparate pieces of information together into a whole due to the reduced processing of the similarities between stimuli and situations making items in a scene more discriminate (Plaisted, 2001). O'Riordan, Plaisted, Driver, & Baron-Cohen, (2001) drew from the enhanced local processing aspect of WCC and suggested that superior performance tasks of selective attention may be explained by enhanced discrimination between display items. In 2001, O'Riordan & Plaisted, (2001) manipulated the degree of target and distracter similarity and found that reaction time in ASC was less affected compared to controls, whose reaction time slowed when the targets and distracters were made more similar. This suggests that in ASC there is superior stimulus processing through enhanced discriminatory ability of display items (O'Riordan et al., 2001); however see Hessels, Hooge, Snijders, & Kemner, (2014) for conflicting findings. In support of the idea of enhanced discrimination, Dickinson, Jones, & Milne, (2014) recently reported enhanced orientation discrimination in those with a high level of self-reported autistic traits. However, Brock, Xu and Brooks (2011) tested discrimination thresholds of gratings and found no differences between those with high and low levels of autistic traits and no relation to visual search performance, therefore finding no support for the enhanced discrimination theory.

Enhanced Perceptual Functioning

A third theory, the enhanced perceptual functioning (EPF) model (Mottron et al., 2006) takes concepts from both of the above theories and at present is the best model to explain the diversity of data in ASC. EPF suggests that a local processing bias arises not from a deficit in global processing which has been shown to be typical in ASC, but from superior performance due to enhanced low level perceptual operations (Bertone, Mottron, Jelenic, & Faubert, 2005). Thus, this model emphasises enhanced functioning in ASC rather than a deficit and recent work supports this idea (Smith & Milne, 2009). According to the EPF model, low level perceptual processes operate at a superior level in ASC in comparison to higher order operations. In support of this idea, studies have found atypical early neural activity in ASC, specifically in EEG components arising from in or near the striate and extra-striate cortex (Milne et al., 2009). Altered early processing in ASC could lead to an

atypical relationship between high and low order cognitive processes, resulting in a difficulty to control perceptual processes and ultimately the disruption of behaviour and abilities.

Enhanced Perceptual Capacity

According to load theory (Lavie, 2005) the extent to which irrelevant distracters are perceived depends on whether a task uses up available perceptual capacity or whether resources remain that can be allocated to irrelevant distracter processing. Remington, Swettenham, Campbell, & Coleman, (2009) employed a simple letter detection task and reported that neurotypical adults showed the expected decline in performance as perceptual load increased, however those with an ASC showed no detriment to performance as a function of load, a finding which Bayliss & Kritikos, (2011) recently extended to those who report a high level of autistic traits. Using a simplified version of the task used in Remington et al., (2009), Bayliss and Kritikos, (2011) showed that those with high levels of self-reported autistic traits continued to show interference from a flanking distracter letter, even at higher levels of perceptual load. In addition, Adams & Jarrold, (2012) and Christ, Kester, Bodner, & Miles, (2011) both reported greater interference from incongruent flankers in those with an ASC. Christ et al., (2011) additionally reported that response inhibition, measured using the Stroop Task, was intact in ASC; limiting the impairment in those with an ASC to distracter inhibition. All of this adds to evidence of an enhanced perceptual capacity in those with an ASC. Remington, Swettenham and Lavie, (2012) suggest that a larger perceptual capacity in ASC results in the ability to process more items in parallel, which may ultimately make visual search more efficient. In support of enhanced perceptual capacity, Milne, Dunn, Freeth, & Rosas-Martinez, (2013) reported neural evidence where those with high levels of autistic traits allocated similar resources to both target relevant and target irrelevant items. However, the authors suggest that rather than being able to process more items in parallel; those with an ASC may show a reduced ability to filter out irrelevant stimuli.

Neural Under-Connectivity

The most prominent biological theory of ASC to date proposes that cognitive differences in ASC are a result of long range under connectivity between different brain regions that results in the isolation of brain regions and a deficit in region to

region communication (Brock, Brown, Boucher, & Rippon, 2002). Brock et al., (2002) suggest that WCC is the result of a failure to integrate information from different specialised local networks in the brain; this lack of integration increases as the brain develops and becomes more specialised, meaning brain areas become increasingly isolated. Not all studies support this idea; Keehn et al., (2008) found combined participation of frontal and occipital cortices in ASC suggesting that long distance co-operation may not be deficient. However, this was an fMRI study and only measures neural activity indirectly so should be interpreted with caution. Wass, (2011) reviewed under-connectivity studies and concluded that there is some limited evidence of functional local over connectivity and long distance under connectivity. However, disruptions do not appear to be uniform across the whole brain.

When a number of neurons are activated in the larger receptive fields of higher visual areas, lateral inhibition is required to fine tune the information and focus sensory processes. Importantly, Keita, Mottron, Dawson, & Bertone, (2011) suggest, following a lateral masking paradigm that atypical lateral connectivity may explain visuo-spatial atypicalities in ASC. Using EEG, researchers can look at power in high frequency bands (Gamma 30-100hZ) that is thought to represent binding and using this method one can look at coherence between spatially discrete electrode groupings (Brock et al., 2002). Some EEG studies have shown disordered gamma activity in ASC (Brown et al., 2005; Grice et al., 2001). This method offers promise for identifying atypical brain connectivity and organisation in ASC.

None of the theories described above offer a complete explanation for cognitive and behavioural aspects of ASC, and a more appropriate recent approach has been to address certain aspects of ASC directly with specific hypotheses. Such an approach is advantageous as it will allow researchers to move away from the current heterogeneity within ASC which causes difficulty when attempting to consolidate research findings.

Selective Attention in ASC

The typical visual scene is cluttered with a vast amount of information and without an effective filter to select relevant information the world would be incredibly chaotic. Within the definition of selective attention there are a number of different types of attention which are relevant to the study of ASC. For example,

switching is when focus is changed from one (or a group) of items to another. Cueing is when attention is directed by a cue; broadening or narrowing attention is when the number of items subject to enhanced focus can be increased or decreased. Social attention refers to the selection of social items and joint attention is when two individuals attend to stimuli and to one another. Desimone and Duncan (1995) described two phenomena of visual attention: a limited capacity and selectivity. Only a small amount of information that enters the eye can be used to inform behaviour; and the ability to selectively filter out unwanted information is necessary for efficient functioning. The work which will be described subsequently focuses on the basic selective aspect of attention, suggesting that the chaos resulting from an inefficient selective filter may be evident in the perceptual experience of those with an ASC.

Selective attention can be thought of as a spotlight which enhances detection within its beam (Posner, Snyder, & Davidson, 1980) and broadly speaking, there may be differences in the spread or selectiveness of this spotlight in ASC. Mann & Walker, (2003) found that when compared to a typically developing (TD) group, those with an ASC were slower to respond to a spatial extension of a crosshair from one trial to the next. The authors suggest that, rather than a consistently narrow spotlight (Townsend & Courchesne, 1994), those with an ASC possess an over focused attentional spotlight, resulting in a deficiency in broadening the spread of attention. A similar finding was reported by Holmboe et al., (2010) who used a gap-overlap task, where a peripheral distracter is presented alongside a central stimulus and the time taken to saccade the distracter is measured. They found that infant siblings of those with an ASC took longer to respond to peripheral stimuli compared to controls. Elsabbagh et al., (2015) replicated these findings in infants who were later diagnosed with an ASC; concluding that there may be an inability or a lack of motivation to disengage attention in ASC. This finding ties in with the global processing deficit described by the WCC account, which has also been extended to those who report a high level of autistic traits (Sutherland & Crewther, 2010). In addition, an over focused attentional style could aid in explaining why those with an ASC typically demonstrate exceptional detail level processing and superior performance on some tasks of selective attention.

Embedded Figures Task

Shah & Frith, (1983; 1993) and Jarrold et al., (2005) reported that children with an ASC performed particularly well on the embedded figures task (EFT) when compared to controls matched on non-verbal IQ. The EFT involves the presentation of a simple geometric figure in which participants are asked to find a simple hidden figure. Shah and Frith (1993) suggest that the exceptional performance of those with an ASC on the EFT is due to resistance to the whole picture and tendency to process local constituents. Shah and Frith's (1983) finding was replicated by Jolliffe and Baron-Cohen (1997), who found that both children with a clinical diagnosis of ASC and AS performed significantly better on the EFT. de Jonge, Kemner, & van Engeland, (2006) assessed EFT performance in high functioning individuals with a clinical diagnosis of ASC (HFA) and matched controls; they measured accuracy, reaction time and the number of incorrect attempts made at finding the target; the result showed that clinical participants were faster and needed fewer attempts to find the target. Furthermore, Manjaly et al., (2007) found that those with an ASC were unimpaired on the EFT while their performance on a control task with minimal local search requirements was degraded. This lends support to the idea of weak central coherence (Happe & Frith, 2006).

In addition to being present in those with an ASC diagnosis, those in the general population who report high levels of autistic traits also demonstrate enhanced performance on the EFT (Almeida et al., 2013; Grinter et al., 2009). However, some studies have found no significant difference in EFT performance between ASC and controls (Brian & Bryson, 1996; Kaland, Mortensen, & Smith, 2007; Mottron et al., 2003; Ring et al., 1999). However, it must be noted that Brian and Bryson (1996) did not match the groups on age and Ring et al., (1999) had a sample size of 6. Despite this, both studies do suggest that there is no difference between the groups (not impaired, nor enhanced in ASC). Considering that those with an ASC are characteristically impaired in numerous other cognitive domains, even a typical performance is a surprising result.

In addition to measuring EFT performance, Ring et al., (1999) and Manjaly et al., (2007) used fMRI to test for local-global processing brain differences in ASC and TD groups. Both studies revealed atypical and extra brain region activations associated with completion of the EFT in ASC groups. Manjaly et al., (2007)

reported more involvement of earlier visual areas (extra striate and right calcarine sulcus) in the ASC group as opposed to involvement of higher level areas in the typical group. In addition, Ring et al., (1999) state that the network activated in ASC is not the same as that activated during a typical strategy of serial search. Similarly to Manjaly et al., (2007), Ring et al., (1999) report an increased involvement of earlier object recognition areas in ASC. In addition, more broadly speaking, numerous studies have concluded that there exists a form of hyper activation or hypersensitivity of early visual areas in ASC (Isler et al., 2010; Samson et al., 2011). This brain imaging work supports enhanced discrimination and the enhanced perceptual functioning model.

Visual Search

The embedded figures task is rather complex (Jarrold, Gilchrist, & Bender, 2005) and considerably more research has been conducted into the mechanisms behind visual search, thus visual search is a more robust task for examining atypicalities in ASC.

It has been consistently shown that when compared to controls, those with an ASC are much more rapid and accurate at visual search tasks (Joseph, Keehn, Connolly, Wolfe, & Horowitz, 2009; Kaldy, Kraper, Carter, & Blaser, 2011; O'Riordan, 2004; O'Riordan et al., 2001; Plaisted, O'Riordan, & Baron-Cohen, 1998), see Kaldy, Giserman, Carter, & Blaser, (2013) for a review. More specifically, the superiority of those with an ASC on visual search tasks is more prominent for tasks requiring a more difficult, serial search (Wolfe, Cave, & Franzel, 1989) and in target absent trials (Keehn & Joseph, 2016; Kaldy et al., 2013; Joseph et al., 2009; Kaldy et al., 2011; O'Riordan, 2004; O'Riordan et al., 2001; Plaisted et al., 1998). This superior ability challenged the WCC theory that there is a perceptual deficit in ASC and is in accordance with findings of superior performance in the embedded figures task.

Plaisted et al., (1998) found that children with ASC were more accurate and rapid than controls at a conjunctive visual search task; where the target shares features with one or more distracters. The authors (Plaisted et al., 1998) concluded that those with an ASC could possess superior visuo-spatial skills, resulting in superior performance on more difficult versions of a visual search task. O'Riordan

and Plaisted (2001) presented a simpler conjunctive search task with highly discriminable items and found no difference between their ASC and TD groups, therefore suggesting that when a task is easier, superiority is not apparent. However, Jarrold et al., (2005) demonstrated that the ASC group outperformed controls on a simpler feature search as well as the more difficult conjunctive search.

O'Riordan et al., (2001) followed up Plaisted et al., (1998) by matching ASC and TD children on non-verbal ability to ensure that superiority effects were not a result of higher IQ. Children with an ASC were significantly better at conjunctive search and the superiority was more prominent in target absent trials; a finding which has been replicated a number of times (see Kaldy et al., 2013) for a review. Recently, (Keehn & Joseph, 2016) used eye tracking to investigate saccades during target present and target absent trials; reporting that those with an ASC did not share the left visual field bias during search, which was present in the TD group. The authors suggest that this could be a result of an enhanced perceptual capacity (Remington et al., 2009; 2012) as a larger capacity would mean that those with an ASC would not require a biasing mechanism to complete a search efficiently; meaning that all areas of the search array would be visited faster. This ability would be particularly advantageous in target absent trials, where all areas in an array must be visited to be confident of a decision.

O'Riordan, (2004) demonstrated that adults with ASC showed the same pattern of results as children in previous work, suggesting that atypical processing is persistent through to adulthood. In addition, recent studies have extended (Almeida, et al., 2010; Brock, Xu, & Brooks, 2011; Milne,. Dunn, Freeth, &. Rosas-Martinez, 2013) the visual search advantage to a general population sample with a high number of autistic traits (assessed using the AQ; Baron-Cohen, et al., 2001) and these are summarised in a later section. There are, however, studies with children and adults with ASC (Jarrold et al., 2005; Iarocci & Armstrong, 2014; Keehn et al., 2013) and those with high levels of autistic traits (Gregory and Plaisted-Grant, 2014) which have failed to replicate the superior performance in visual search.

Which Theory Best Explains Superior Visual Search in ASC?

Kaldy et al., (2011) used eye tracking with a sample of 2 year old children and found that the number of items scrutinised by those with an ASC exceeded that

of those who were typically developing. Additionally, as display size increased, the number of items fixated by ASC toddlers increased, whereas TD children scrutinised a fixed small number. This study suggests that perceptual atypicalities are primary in nature and is in line with the EPF model and studies showing early perceptual deficits in ASC. Other eye tracking studies have found that the ASC group made less fixations of the same duration as the TD group (Kemner et al., 2008; Keehn & Joseph, 2016). This finding ties in with enhanced perceptual capacity, which may allow those with an ASC to process more distracters (Milne et al., 2013), resulting in less fixations necessary to locate a target. However, Joseph et al., (2009) reported shorter, rather than fewer fixations which lends support to the enhanced discrimination theory. Though eye tracking studies have revealed inconsistent findings, the fact that the superiority of those with an ASC is reliably seen only in conjunctive tasks (though see Jarrold et al., 2005) and in target absent trials, suggests that the superiority is arising from a cognitive mechanism benefiting more complex search, rather than a quicker motor response per se.

Visual Processing and Autistic Traits

The previous section touched on several studies which have extended findings of atypical perception and attention to those who report high levels of autistic traits, which can be measured using the AQ (Baron-Cohen et al., 2001) or BAPQ (Hurley et al., 2007). These will be summarised together here.

Robertson & Simmons, (2013) reported that atypical sensory responsiveness, as measured by a sensory questionnaire, was more common in those who reported high levels of autistic traits, as measured by the AQ. In terms of low level perceptual processing, high AQ scorers have been shown to perform better on a task of orientation discrimination (Dickinson, Jones & Milne 2014), where those with high levels of autistic traits had a lower threshold to detect orientation changes in gratings.

More complex tasks which have revealed differences between high and low AQ scorers include the embedded figures task (Grinter et al., 2009); block design task (Stewart, Watson, Allcock, & Yaqoob, 2009) and Navon figure task (Sutherland &. Crewther, 2010). In addition, the visual search superiority seen in those with an ASC has been repeatedly extended to those with high levels of autistic traits (Milne et al 2013., Brock, Zu, & Brooks, 2011; Almeida et al., 2010). Almeida et al., (2010)

employed a simple radial frequency (RF) search task, where participants were required to detect a target which was a slightly deformed circle, presented in an array of normal circles. A RF task tests the threshold of recognising deviations from the circular form; the circle can vary by sinusoidal functions with frequency measured in cycles per second. The high AQ group were more efficient, showing that the superiority is present in those with high levels of autistic traits, in simple search tasks. Milne et al., (2013) employed the same conjunctive visual search task as in Plaisted et al., (1998) and also reported superior visual search performance in those with high levels of autistic traits. Those with high levels of autistic traits were less susceptible to an increase in set size, specifically in target absent trials; a finding which is consistent with studies in those with an ASC.

As visual search tasks are empirically more robust than tasks such as embedded figures (Jarrold et al., 2005); subsequent sections will describe the cognitive and neural correlates of visual search in more detail. Describing the altered cognition and neural indices of visual search will aid in explaining attentional atypicalities in ASC and in those with high levels of autistic traits.

The Cognition of Visual Search

Visual search tasks require attention to complete an active search for a pre-specified target in an array of distracters. There are a number of concurrent perceptual and cognitive processes required for a visual search task and studying performance in visual search can provide clues about how the brain co-ordinates these functions. If a search for a target is defined on the basis of one shared feature with distracting stimuli, the search is parallel and unaffected by the number of distracters in the display as all items are processed at the same time (Wolfe et al., 1989). However, if the target shares more than one feature with distracters, the search becomes conjunctive and targets are found only following a serial search which takes more time. In a serial search, attention is directed to one item at a time, allowing each item to be identified in turn (Sternberg, 1966). A longer search is also evident in target absent trials, where Chun & Wolfe, (1996) propose that a threshold of activation is required to end a search. As opposed to target present trials, where search ends when the target is located; a target absent search ends when participants decide to terminate search for the target.

Wolfe and collaborators suggest that in visual search tasks, attention is deployed in a guided search (Wolfe et al., 1989) where stimulus items are attended according to their priority in a parallel search. Treisman and Gelade (1980) proposed that certain visual features are processed early and automatically, for example a highly salient pop-out target; however, without functioning focused attention, features of a stimulus could not be combined together. Therefore Treisman & Gelade's, (1980) feature integration theory suggests that feature dimensions are encoded early in perception and then later combined by focal attention into unitary stimuli. Duncan & Humphreys, (1989) criticised the feature integration theory, stating that search efficiency can only be understood by considering the perceptual similarity of targets and distracters. The more similar targets-distracters and distracters-distracters become to each other, the less efficient search becomes. O'Riordan & Plaisted, (2001) suggest that this target – distracter similarity is the critical defining feature affecting discrimination of targets from distracters. The feature integration, guided search and perceptual similarity theories all contribute significant ideas about visual search and need not be mutually exclusive

Neural Basis of Visual Search

Functional brain imaging studies have revealed a significant amount about the functional correlates of visual search. Visual search appears to use a network of frontal-parietal regions; bottom up processing being carried out by the visual cortices and top down processing carried out using the fronto-parietal network (Keehn et al., 2008). fMRI studies have revealed the participation of specific brain regions in visual search; simple feature search recruits extra striate areas, indicating low level visual processing, whereas the demanding serial search additionally recruits the parietal cortex (Coull, Walsh, Frith, & Nobre, 2003). This supports the feature integration theory; an early pre-attentive stage of processing discriminates the identity of simple features in parallel and a serial attentive process localises features and joins them together (Luck & Hillyard, 1990).

Keehn et al., (2008) found increased occipital activation in ASC during a visual search task, suggesting enhanced bottom up processing. Additionally, intact distributed network activation in ASC suggested intact top down modulation (Keehn et al., 2008). Research has shown that those with an ASC appear to recruit simpler processing strategies during visual search (Jarrold et al., 2005) and this could be

reflected by increased activation of early visual areas (Keehn et al., 2008). Enhanced performance in visual search therefore, could be a reflection of enhanced bottom up processes, where two items appear more distinct, or from altered top down processing, where excitation and inhibition mechanisms are activated in an altered way.

N2pc

The N2pc is an ERP component which has been heavily researched, well characterised and strongly linked to spatial attention; particularly when used to investigate visual search tasks (Sawaki & Luck, 2010; Woodman & Luck, 2003). During visual search tasks, the N2pc is visible as 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). The N2pc appears to reflect early attention processing, specifically low level target-distracter processing in visual search tasks and is apparent in the parietal, occipital (Hopf et al., 2000) and temporal (Luck, et al., 1997) cortices, with a generator source in the striate/extra striate cortex (Luck & Hillyard, 1994). Wijers, Lange, Mulder, & Mulder, (1997) localised the source of the N2pc to the inferior occipito-temporal cortex and Chelazzi and colleagues (Chelazzi, Duncan, Miller, & Desimone, 1998; Chelazzi, Miller, Duncan, & Desimone, 1993, 2001), reported single unit studies with N2pc effects observed in V4 and infero-temporal cortex. Furthermore, Hopf et al., (2006) confirmed activity in V4 and the lateral occipital cortices using fMRI. Therefore the component may be a reflection of ventral stream processing.

The N2pc can be elicited by numerous types of lateral stimuli, including those defined by colour, motion, orientation, size, shape, word/letter identity and even facial expression (For a review see Luck & Kappenman, 2011). Studies have found that N2pc onset can differ based on the salience of a target (Brisson, Robitaille

& Jolicoeur, 2007), and N2pc amplitude is reduced and onset is later in older individuals (Lorenzo-López, Amenedo, & Cadaveira, 2008). Luck, Girelli, McDermott, & Ford, (1997) found that the N2pc was significantly larger and longer lasting for conjunctive search tasks than for feature search tasks and further studies have shown that the amplitude of the N2pc increases with training and improvement on visual search tasks (An et al., 2012; Hamamé, Cosmelli, Henriquez, & Aboitiz, 2011). Sawaki, Luck, & Raymond, (2015) conclude from such findings that a larger N2pc amplitude may reflect the allocation of more focused attention resources.

In summary, the N2pc appears to reflect neural processes occurring during the completion of visual search tasks. The amplitude of the N2pc can increase with increased task difficulty and with practice. Investigating the N2pc in those on the autism spectrum may shed light on the neural processes underlying superior efficiency in visual search. However, the N2pc alone will not shed light on the target and distracter processing elements of a visual search task; for this purpose we can look at the subcomponents of the N2pc.

N2pc, Target Selection and Distracter Suppression

The N2pc is elicited when target discrimination is required. Non-target items can also elicit an N2pc when they are similar to the target item and more focused attention is needed to correctly discriminate a target (Luck & Hillyard, 1994b). Thus, Luck and Hillyard, (1994b) suggested that the N2pc operates a spatial filtering process, including the suppression of irrelevant distracting information and further studies support this claim (Hickey, Di Lollo, & McDonald, 2009; Woodman, Arita, & Luck, 2009). However other studies have found that N2pc amplitude is unaffected by the number of distracters (Eimer, 1996; Hickey, McDonald, & Theeuwes, 2006) and N2pc has been elicited in situations where distracter information was essential for completion of the task (Mazza, Turatto, &. Caramazza, 2009) therefore suppression would be counterproductive. Furthermore, the N2pc has been observed contralateral to targets when distracters and targets are in opposing hemifields' (Eimer, 1996). Eimer (1996) goes on to suggest that the N2pc may reflect the selection of targets and recent work supports this theory (Mazza & Caramazza, 2011; Mazza, Turatto, & Caramazza, 2009; Zhao et al., 2011).

Hickey et al., (2009) were able to separately assess target processing and distracter suppression. By placing one stimulus on the vertical meridian in every trial, Hickey et al. were able to conclude that any lateralised ERP activity reflected the processing of the lateral stimulus. Thus, if the lateral stimulus was a distracter, the lateralised activity would reflect distracter processing and conversely the lateralised ERP activity would reflect a lateral target. Hickey et al., identified the $P_{D,}$ a positive difference between contralateral and ipsilateral waveforms, reflecting the suppression of distracters in space, and the $N_{T,}$ a negative difference between contralateral and ipsilateral waveforms which reflects target selection. Hickey et al., found that the P_D was eliminated when the task was changed to a simple detection task and distracter suppression was unnecessary and other studies have reported a P_D tied to distracter suppression (Burra & Kerzel, 2014; Corriveau et al., 2012; Hilimire, Hickey, & Corballis, 2012; Hilimire, Mounts, Parks, & Corballis, 2009; Kiss, Grubert, Petersen, & Eimer, 2012; Sawaki & Luck, 2010; Sawaki et al., 2015). The idea of separable target-distracter components is supported by a magnetoencephalography study that revealed two temporally and spatially distinct subcomponents of the N2pc; an initial portion reflecting parietal lobe activity and the later portion reflecting neural activity in lateral posterior regions (anterior occipital and posterior infero-temporal areas) (Hopf et al., 2000). It is possible that this distinction is related to the P_D/N_T distinction.

In a recent paper investigating the neural basis of feature-based selective attention, Milne et al., (2013) reported ERP data which revealed differences in resource allocation to irrelevant distracters 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. The paper reported increased P3b amplitude following presentation of distracters 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 distracter stimuli in the high AQ group. Milne et al., (2013) suggest that processing of irrelevant distracters may arise out of an enhanced perceptual capacity (Remington et al., 2009; 2012), which ultimately could underlie superior visual search in those with an ASC. Investigating the amplitude of the P_D will offer a more

direct measure of distracter processing and we may expect to see an attenuated P_D; reflecting reduced distracter suppression in those with high levels of autistic traits. (Hilimire et al., 2009) recently found that N2pc amplitude was reduced when a target and decoy were closer to one another; the authors suggest that this could be the result of more competition and increased distracter suppression; therefore a large P_D could be associated with a smaller N2pc. However, this is the opposite conclusion to Luck & Kappenman (2011) who suggest that a summation of a large P_D and the N2pc will result in a larger N2pc.

Computing the N2pc

As demonstrated in Figure 1.1, the N2pc is observed as more negative voltage at scalp sites contralateral to an attended item relative to scalp sites ipsilateral to an attended item. N2pc amplitude is computed by taking the EEG signal contralateral and ipsilateral to a target and calculating a contralateral-minus-ipsilateral difference wave. The difference between the contralateral and ipsilateral amplitude represents the amplitude of the N2pc.

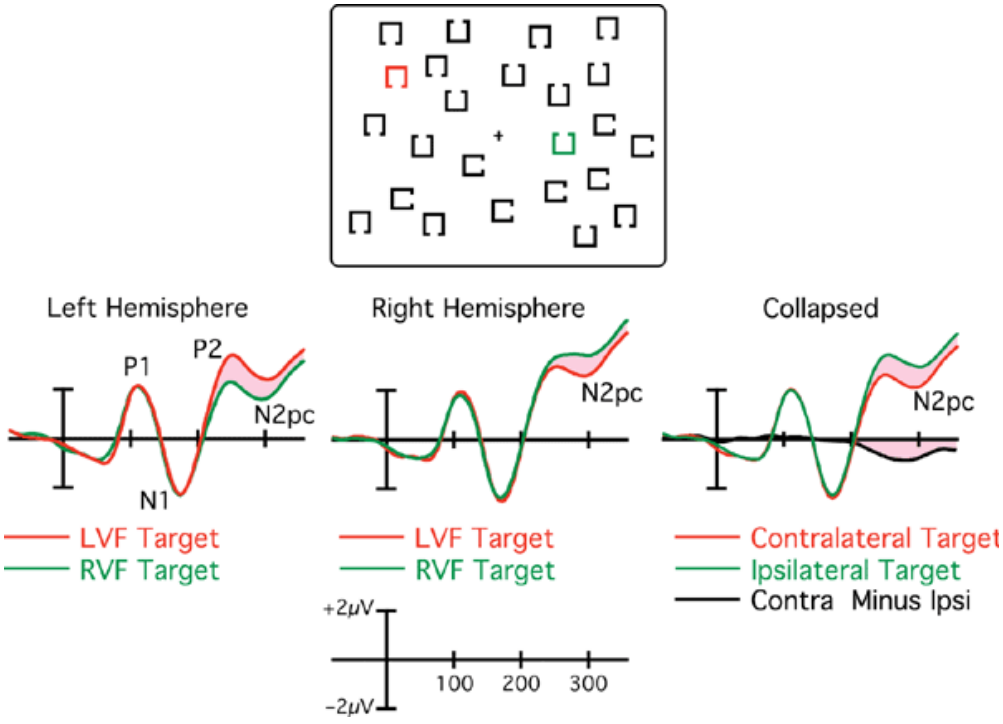


Figure 1.1, from (Luck et al., 2006) displays example waveforms which demonstrate the calculation of the N2pc

The N2pc can be seen as greater negative voltage for right visual field (RVF) targets over the left hemisphere and greater negative voltage for left visual field (LVF) targets over the right hemisphere. The contralateral waveform is the average of RVF

targets in the left hemisphere and LVF targets in the right hemisphere. The ipsilateral waveform is the average of LVF targets in the left hemisphere and RVF targets in the right hemisphere. The N2pc is isolated as the difference between the contralateral and ipsilateral waveform (contralateral minus ipsilateral) and is highlighted.

Summary

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 an ASC demonstrate atypical selective attention when compared to those who are typically developing (Shah & Frith, 1983; Burack, 1994; Plaisted, O'Riordan & Baron-Cohen., 1998). Tasks that are used to assess selective attention in ASC typically involve detecting a target in an array of distracting information. Visual search is one such task which has been widely employed and has consistently revealed superiority in performance in those with an ASC.

ERP research has identified robust neural correlates of selective attention and this research forms an excellent knowledge base from which to explore selective attention in the autism spectrum. Previous work has reported a difference in feature based attention in those with high levels of autistic traits and the work in this thesis aims to establish whether neural indices of spatial attention (N2pc) are also atypical in those with high levels of autistic traits. The N2pc is a particularly appropriate for use in this work as it has strong links to visual search. Therefore, work here will employ established visual search paradigms which elicit the N2pc. 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.

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 an 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, and a reduced P_D amplitude due to a lack of distracter suppression (Milne et al., 2013; Sawaki, Luck & Raymond, 2015). The research presented in this thesis will explore these hypotheses with respect to enhanced visual search performance and enhanced perceptual

capacity with the aim of offering insight into the neural basis of attention in those who report high levels of autistic traits.

Chapter 2 : ERP indices of spatial attention: Investigating the N2pc in those with high and low levels of autistic traits

Introduction

Chapter One described a picture of atypical selective attention in those with autism spectrum conditions. Individuals with ASCs perform atypically in laboratory tasks requiring local visual processing, for example; identifying contrast changes on gratings (Bertone et al., 2005) and in the identification of a target in an array of distracting information (Plaisted et al., 1998; Joseph et al., 2009). It is important to investigate these low level disturbances as they fundamentally alter the quality of information received and may consequently contribute to broad development deficits in autism.

Visual search is a well-documented cognitive task requiring feature and spatial attentional processing. The literature shows that individuals with autism are more efficient at visual search tasks than their typically developing counterparts (Plaisted et al., 1998; Joseph et al., 2009). This has also recently been shown in neurotypical individuals with high numbers of autistic traits (Brock et al., 2011, Milne et al., 2013). The cognitive and electrophysiological aspects of visual search are well understood and due to its high temporal resolution, EEG is an excellent tool to investigate the electrophysiological correlates of visual search in autism. One such correlate is the N2pc ERP component observed in the N2 time range.

The cognitive process considered to be reflected by the N2pc is the lateralized shifting of attention and the selection of a specified target in space (Eimer, 1996; Hopf et al., 2000), encompassing the elimination of competing distracters (Hickey DiLollo & McDonald., 2009; Luck & Hillyard, 1994b). Luck and Hillyard (1994b) found that the N2pc was larger when distracters were presented with a target; suggesting that the N2pc reflects processes occurring during visual search. However, Eimer (1996) found that the N2pc could be elicited in the absence of distracters and therefore it may reflect the processing of target stimuli, independent of distracting information. The N2pc represents the difference between the signals recorded from electrodes that are contralateral or ipsilateral to a target, 200-300 ms post stimulus onset (Woodman & Luck, 1999). When presented with a visual search display, amplitude is enhanced at electrodes contralateral to the side of the target.

Studies have shown that the amplitude of the N2pc increases with training and improvement on visual search tasks (Hamame et al., 2011; An et al., 2012).

In the first study of this thesis, a version of a spatial attention task used by Luck et al., (1997) was used to examine the amplitude of the N2pc component in high and low autism quotient scoring participants. An additional paradigm was used to examine behavioural visual search performance in the same participants (based on Plaisted et al., (1998). Based on previous research discussed in Chapter One, it was predicted that those with high levels of autistic traits would be more efficient at target absent visual search as measured by RT x set size slope (Plaisted et al., 1998; Joseph et al., 2009). It was also predicted that N2pc amplitude would be different in high scoring AQ participants, reflecting the altered allocation of focused attention resources (Luck et al., 1997; Burra & Kurzel., 2013; Sawaki, Luck & Raymond, 2015). The final prediction was a relationship between the amplitude of the N2pc and visual search efficiency, with a larger N2pc amplitude associated with more efficient performance. According to Luck & Hillyard., (1994b) spatial filtering theory, the amplitude of the N2pc should be related to visual search performance. However, the results from Eimer (1996) would suggest no relationship between N2pc amplitude and visual search.

Using the Autism Quotient

As described in Chapter One, the diagnostic criteria in DSM-V has changed to reflect the consensus that ASC symptomology is variable and is best considered on a continuum of severity. Beyond this spectrum are those who have high levels of traits associated with autism but no clinical diagnosis, these people can be described as possessing sub-clinical autistic traits (Ozonoff, Rogers, Farnham, & Pennington, 1993). Baron-Cohen et al., (2001) introduced the Autism Spectrum Quotient (AQ) which reflects the continuum with a view that the whole population possesses a certain level of autistic traits.

The AQ is a 50 item self-administered questionnaire which measures the degree to which an adult reports features of the core autistic phenotype (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, Baron-Cohen et al., (2001) identified an upper cut-

off score on the AQ of 32, above which participants' were more likely to have a clinical diagnosis of ASC. Examples of questions for each sub scale can be seen in Table 2.1 and the complete AQ can be seen in Appendix B (Page 127).

The AQ has satisfactory test-retest reliability (Hoekstra, Bartels, Cath, & Boomsma, 2008; Baron-Cohen et al., 2001) and is good at differentiating between high functioning adults with autism and neuro-typical controls (Wouters & Spek, 2011). 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). The AQ has five subscales, described by Baron-Cohen et al., (2001) and found to have a high internal consistency. However, factor analysis studies have been conducted and suggest altered subscales for the AQ. Hoekstra et al., (2008) suggest that the AQ is actually composed of two subscales; social interaction and attention to detail and Austin, (2005) suggests that there are three subscales; social skills, detail/patterns and communication/mind reading.

Table 2.1 Example questions from each of the five subscales of the AQ

Subscale	**Question**
Social Skills	'I prefer to do things with others rather than on my own'
Attention Switching	'I frequently get so absorbed in one thing that I lose sight of other things'
Attention to detail	'I usually notice car number plates or other strings of information'
Communication	'I enjoy social chit chat.'
Imagination	'When I am reading a story, I can easily imagine what the characters might look like.'

Before using the AQ to recruit participants for studies there are a number of questions and issues which should be adequately addressed. Firstly, it is crucial that the sample of participants with subclinical autistic traits is a sample in its own right and the results cannot be directly extrapolated to autism. Conducting studies using

this sampling method, we are able to describe the cognitive and neural profile of people who express certain levels of autistic traits, without a clinical diagnosis.

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 and consequently confound the study. Gregory & Plaisted-Grant, (2013) cautioned the use of the AQ as a proxy for autism after repeatedly failing to replicate visual search results in those with high levels of autistic traits and any conclusions made should consider this point. All participants in the studies of this thesis were invited to declare any ASC diagnosis for themselves or a close family member, with the intention of excluding any participant who did so.

Ethical Considerations

The ShARL group at Sheffield University hold large databases with between 600 and 1200 participants, detailing scores on the autism quotient; gender, email address and course information. The first cohort was collected in 2011 and has been collected at the beginning of the academic year, every year since. This has received ethical approval from the Department of Psychology ethical committee at the University of Sheffield.

There are clearly ethical issues raised with the notion of inviting participants to further study based on their score on a screening test. The Autism Quotient is not suitable for detecting autism, rather it is used to establish the prevalence of autistic-like traits in the typical population and every individual is thought to show these traits to a greater or lesser degree. For the purposes of the studies in this thesis, the AQ was referred to as a questionnaire that measures traits and preferences; this allowed the experimenter to explain why only certain people were invited to take part in further studies and prevented anxiety surrounding the use of the word autism. Participants were told on initial completion of the questionnaire that they may be invited to participate in future studies, however it was not specified whether this would be because of particularly high or low scores. Furthermore, the experimenter was not aware at the point of testing whether the participant had a high or low score on the AQ. The study was described as a study looking at the neural correlates of visual search and autism or autistic traits was not mentioned at any point.

Any participants who raised concerns about the questionnaire or a potential diagnosis were directed towards a supervisor and the relevant welfare support team. Written informed consent was obtained from all participants and the study received ethical approval from the department of Psychology ethics sub-committee. The experimenter was always blind to the AQ score of the participant until after the testing session.

Participants

Participants were recruited on the basis of their level of self-reported autistic traits as measured by the autism-spectrum quotient [AQ, Baron-Cohen et al., (2001), see below]. 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 17.7 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 recruited to take part in the study. Seventeen of these were high AQ scorers (AQ $\geq$27) and seventeen were low AQ scorers (AQ $\leq$10). All participants had normal or corrected-to-normal vision and were aged between 18 and 40 years old. The mean age for the high AQ group was 23 and for the low AQ group was 22; there was no significant group difference in age, t = (32) .75, p = .46, d = 0.3. All participants were invited to declare any ASC diagnosis before the study began and none did so. The sample consisted of 19 females and 17 males with 10 females and 7 males in the high AQ group and 9 females, 8 males in the low AQ group.

Methodology

Stimuli and Procedure

Computer based stimuli were created using Adobe Photoshop 7.0. Presentation of all stimuli was controlled by E-Prime2 run on a 12 inch desktop PC and displayed on a 14.5 inch CRT monitor (both 800*600 resolution). Participants sat 70cm from the screen and completed two search tasks. The spatial attention task was designed to elicit the ERP components of interest and was a replication of Luck et al., (1997) with elements from Hickey et al., (2009) in Chapters 3 and 4. The second task was a visual search task, based on Plaisted et al., (1998). ERP and

behavioural data was analysed from the spatial attention task and only behavioural responses were analysed from the visual search task.

Spatial Attention Task (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. 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 Ts always occurred equally in green/blue, left/right and upright/inverted. The letter Ts were 0.6° high and 0.5° wide.

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 always 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. In this study the task consisted of 900 trials and 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. 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. Next to each coloured T was a grey distracter T, presented in the same luminance range as the green and blue T, at a distance which ranged from 0.7° to 1.6° (measured centre to centre – see Figure 2.1a).

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. The

experiment was split into 6 blocks of 150 trials with an opportunity for an unlimited break following each block.

Visual Search Task (Based on Plaisted et al., 1998)

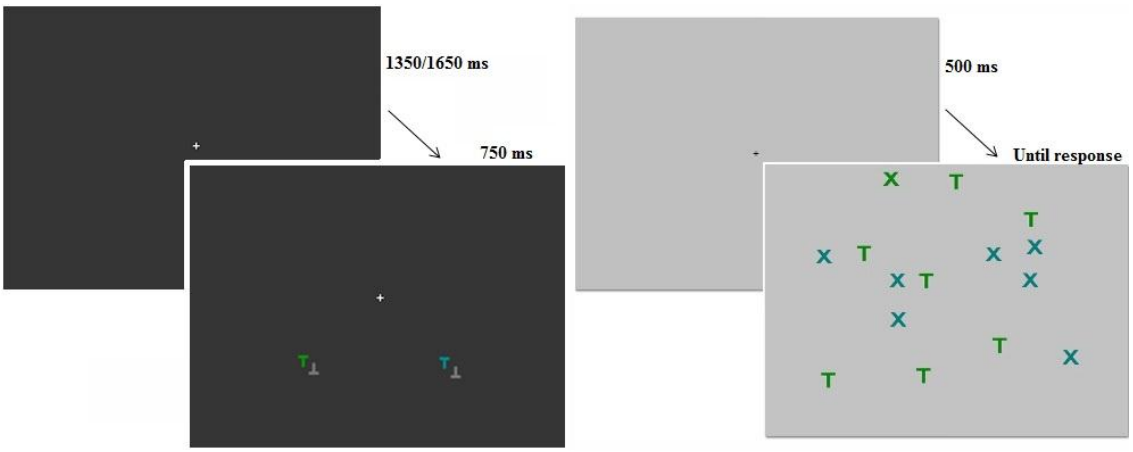
Participants were required to state the presence or absence of a pre-specified target (green X). Targets were defined by a conjunction of both colour and form. Stimulus arrays contained 5, 15 or 25 letters (equiluminant blue Xs or green Ts); presented on a light grey background with a black fixation cross. In 50% of the trials a target (green X) was also present. Each letter measured approximately 1° of visual angle, and the size of the entire stimulus array did not exceed 25° of visual angle in Chapters Three and Five or 18° of visual angle in Chapter 3. The luminance of each letter was within 3% of 18cd/$m^{2.}$ 120 trials were presented, 40 of each set-size. Set size and target presence was randomly occurring.

Each trial began with the presentation of a fixation cross which remained on screen for 500ms. After this, the search array appeared on-screen until the participant made their response. Twelve practice trials, with feedback on accuracy and reaction time was given prior to the 120 experimental trials, which were all presented in one block. No feedback was given during experimental trials. Responses were made by pressing the left-hand key to indicate that the target was present and the right-hand key to indicate target absence. Participants were instructed to press each button with the index finger of their right and left hands. In Chapter 4, participants were instructed to use their dominant hand to respond, using the index finger to indicate that the target was present and the middle finger to indicate target absence.

The participants began with the spatial attention task followed by the visual search task.

Figure 2.1 a&b Stimulus organisation and presentation for both tasks. The target in the spatial attention task was defined by colour in each block. In the visual search task the target was always a green X.

2.1a Spatial attention task stimuli example **2.1b** Visual search task stimuli example



The spatial attention task (3.1a) used to elicit ERPs was a replication of Luck et al., (1997) with two equiluminant letter Ts in opposing lateral positions, accompanied by one grey distracter T. Fixation was a white cross, displayed for 1350 or 1650 milliseconds, followed by a stimulus display for 750ms. The letters always appeared below fixation. The visual search task (3.1b) was a replication of Plaisted et al., (1998) with equiluminant green Ts and blue Xs as distracters and a green X as the target. Fixation appeared for 500ms, followed by a display of 5, 15 or 25 letters which could have the target present or absent. The stimuli display would remain until participant response.

EEG Recording and Data 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. Data were referenced to the vertex electrode online. The data were filtered offline using 0.1Hz high pass and 30Hz low pass cut offs, visibly bad channels were removed from the data by the experimenter. The data were then epoched with a time window of -200 to 800 ms pre and post stimulus.

Visibly noisy channels were removed from each dataset by the experimenter; these are defined as channels whose signal regularly passed into the boundaries of other channels. 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. Since eye movements can affect the amplitude of the N2pc (Luck et al., 1997), any lateral 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)

Artifact Rejection

ERP datasets were excluded if there were fewer than 150 trials contributing to the contralateral or ipsilateral ERP following all artifact rejection procedures (n=10). Datasets were also excluded if participants did not understand instructions as reflected in accuracy being below 50% correct (n=1). For ERP analyses this resulted in a final sample of 23, with 11 high AQ (5 female, 6 male) participants and 12 low AQ (7 female, 5 male) participants. The high AQ group had a mean AQ score of 31 (sd = 2.7, score range = 28 - 37) the low AQ group had a mean AQ score of 8.5 (sd = 1.6, score range = 6 - 10). As described in Chapter Two, two ERP waveforms were computed, reflecting the signal contralateral and ipsilateral to the target. The mean number of trials used to calculate these two ERPs was 315 and 323 respectively with no difference in the number of trials used between high and low AQ scorers for contralateral t (21) = .67, p = .51, d = 0.3, or ipsilateral t (21) = .92, p = .42, d = 0.3 trials.

Table 2.2 Total usable ERP trials by AQ group

	High AQ	Low AQ
Mean	606	663
Range	313-833	388-862

ERP Processing

ERP data was extracted from four pairs of electrodes (T7/T8, P3/P4, P07/08 and P7/P8; EGI electrodes 46/109, 53/87, 59/92 and 66/85) for all ERP analyses. In chapters 4 and 5, a further analysis on P_D and N_T amplitude was conducted on data extracted from P07/08 (EGI: 59/92) in accordance with analyses conducted by

Hickey et al., (2009). An additional P1 analysis was conducted using occipital electrodes corresponding to O1 and O2 (EGI: 72 & 77).

All ERPs were obtained relative to a 200 ms pre stimulus baseline voltage, from trials during which a correct behavioural response was made

N2pc Amplitude

N2pc amplitude was quantified as the mean voltage between 180 and 300 ms (Luck et al., 1997). 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 electrodes on the same side of the head as the target. The amplitude of the N2pc was represented by the degree to which the voltage in the selected latency range was different for contralateral versus ipsilateral signals when a target was presented with a lateral distracter.

P1 Amplitude

P1 amplitude was quantified as the maximum (peak) positive amplitude reached between 70 and 170 milliseconds, calculated and reported separately for all of the above stimulus set ups. In accordance with previous ERP analyses, the amplitude was quantified from the signal both contralateral and ipsilateral to targets.

SPCN/P300 Amplitude

In all study chapters, SPCN amplitude was calculated as the average signal between 350 and 600 ms and was obtained from four pairs of electrodes (T7/T8, P3/P4, P07/08 and P7/P8). The amplitude of the SPCN was quantified from the signal both contralateral and ipsilateral to targets (N2pc, N_T) or distracters (P_D). The amplitude of the P300 was calculated as the absolute amplitude of contralateral and ipsilateral trials combined, within this time window.

ERP Onset Latency

Because latency measures are nonlinear and vulnerable to high levels of measurement error, the Jack-knife approach was used (Kiesel, Miller, Jolicœur, & Brisson, 2008; Luck et al., 2009; Miller, Patterson, & Ulrich, 1998). 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.

ERP Analyses

Analyses of ERP amplitudes were conducted by entering mean values from contralateral and ipsilateral sites into a repeated-measures ANOVA as a within factor, with a between-subjects factor of AQ group. All reported values reflect the Greenhouse-Geisser corrected statistic (Jennings & Wood, 1976). Analysis of onset latency was conducted by entering the latency values into an independent-measures T-Test with a between-subjects factor of AQ group.

Simon Effect

The present experiment was set up with responses from index fingers of both hands. In order to discount any laterality effect the N2pc amplitude for trials where the hand response was the same side as the target stimulus and the hand to respond was the opposite side to the target stimulus were extracted and statistically compared.

Results

Behavioural Results

Spatial Attention Task Accuracy and Reaction time

Two participants were excluded from behavioural analyses due to poor accuracy (<50%). As reported in Table 2.2, accuracy was high and did not vary significantly between high and low AQ scorers, t (30) = 1.2, p = .27, d = 0.4. Similarly median correct-trial reaction times did not differ between high and low AQ scorers, t (30) = .43, p = .67, d = 0.2. The same analysis was conducted using only the participants who were included in ERP analyses. This revealed no difference between groups in terms of accuracy t (20) = 1.8, p = .08, d = 0.8, or median reaction

time, t (20) = 1.2, p = .23, d = 0.5. To take any speed/accuracy trade-offs into account an inverse efficiency score was calculated. The inverse efficiency score did not vary significantly between groups when all participants were included t (30) = .45, p = .66, d = 0.2, nor when the same analysis was conducted only on those included in the ERP analysis, t (20) = 1.2, p = .22, d = 0.5.

Table 2.2 Median and standard deviation for accuracy and reaction time data.

	Accuracy %		Median RT (ms)	
	High AQ (N=17)	**Low AQ (N=15)**	**High AQ**	**Low AQ**
Mean	78.3	85.9	540.5	535.1
SD	16.3	6.3	42.7	44.4

Visual Search Accuracy

Mean accuracy in visual search was high (92%, s.d = 19). A mixed-measures ANOVA (2x3x2) with a between-subjects factor of AQ group revealed a significant difference in accuracy between different set sizes F (2, 60) = 16.0, p = <.001, ηp^2 = .35, and between target absent and present trials, F (1, 30) = 26.6, p = <.001, ηp^2 = .47. There was a significant two-way interaction between set size and target presence F (2, 60) = 18.3, p = <.001, ηp^2 = .39. As displayed in Figure 3.2, accuracy decreased as set size increased in target present trials, but there was no effect of increasing set size on accuracy in target absent trials. The two-way interactions between set size and AQ group F (2, 60) = 2.6, p = .20, ηp^2 = .05, and target presence and AQ group F (1, 30) = .03, p = .90, ηp^2 = .00, were not significant. Finally, the test revealed no main effect of AQ group on accuracy F (1, 30) = .63, p = .43, ηp^2 = .02.

Figure 2.2 a&b Accuracy plots for present **(a)** and absent **(b)** trials in the visual search task. Showing all 3 set sizes and 2 AQ groups. The maximum accuracy for each variable was 20.

Figure 2.2a Target Present Accuracy

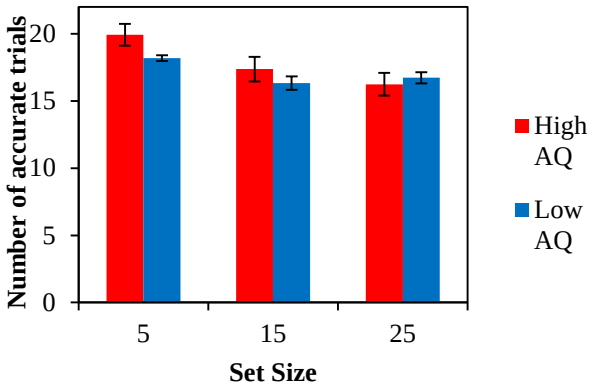
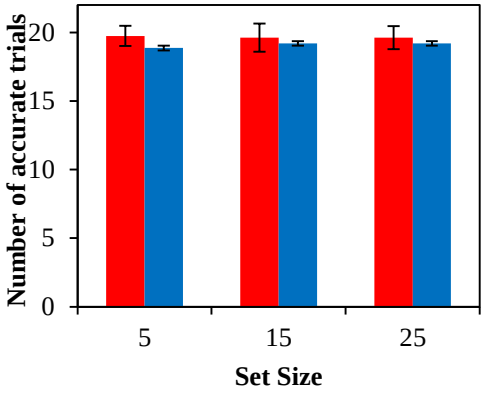


Figure 2.2b Target Absent Accuracy



Search Reaction Time

Reaction times three standard deviations above and below the mean for each individual were discarded; this resulted in the removal of an average 6 data points per participant (Range = 0-24). Mean reaction time data for each set size and target present and absent trials were entered into a mixed-measures (2x3x2) ANOVA with a between-subjects factor of AQ group and within-subject factors of target presence (2) and set size (3). As expected, reaction times were significantly slower in absent trials compared to present trials F (1, 30) = 67.1, p = <.001, ηp^2= .69; there was a highly significant effect of increasing set size on reaction time F (2, 60) = 192.0, p = <.001, ηp^2= .87 and there was a significant two-way interaction between set size and target presence F (2, 60) = 31.5, p = <.001, ηp^2= .51. As shown in Figure 2.3, increasing set size had more of a slowing effect on target absent trials. However, there was no significant two-way interaction between AQ group and set size F (2, 60) = .02, p = .98, ηp^2= .00 or between AQ group and target presence F (1, 30) = .06, p = .81, ηp^2= .00. Finally, there was no significant interaction between display size, target presence and AQ group F (2, 60) = 1.4, p = .27, ηp^2= .04 and there was no main effect of AQ group on reaction time F (1, 30) = .47, p = .50, ηp^2 = .02.

Figure 2.3 a&b Graphs showing the mean visual search scores for both target absent and target present trials and both AQ groups, error bars display the standard error (+/-1).

Figure 2.3a – Target Present Trials

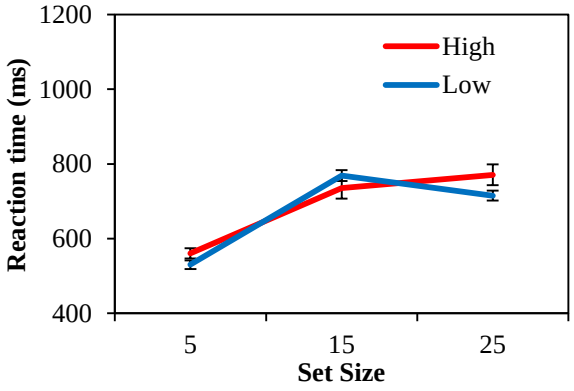
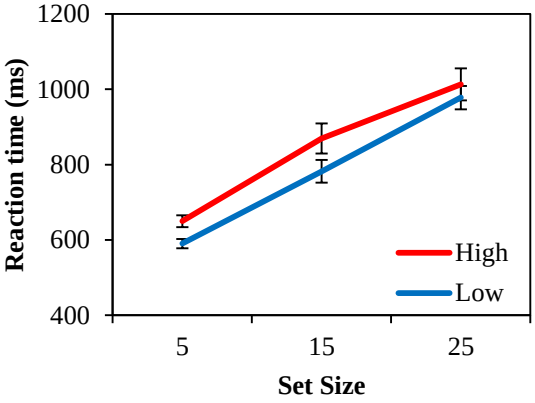


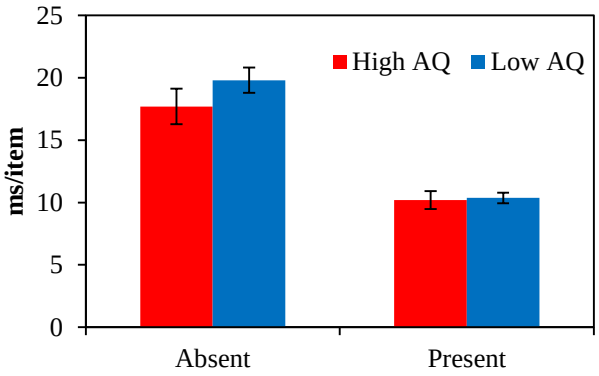
Figure 33b – Target Absent Trials



Visual Search Efficiency

Slopes of the RT x set size function were calculated by performing a linear regression with display size as the independent variable and reaction time as the dependent variable on the same data as the analysis above. Slopes were calculated separately for absent and present trials and compared in a (2x2) repeated-measures ANOVA with a between-subjects factor of group (high or low AQ) and a within-subjects factor of target presence (present or absent). As expected, slopes were significantly steeper when a target was absent (mean = 17.8 ms/item, s.d = 7.0) than when the target was present (mean = 10.9 ms/item, sd = 3.3), F (1, 28) = 38.6, p = <.001, ηp^2= .63. As shown in figure 3.4, in target absent trials, high (mean = 17.2 ms per item, s.d = 7.9) and low (mean = 18.6 ms per item, sd = 5.9) AQ scorers demonstrated a very similar search efficiency. The analysis showed that there was no significant interaction between AQ group membership and search efficiency F (1, 30) = 2.3, p = .14, ηp^2= .08 confirming the results from the ANOVA reported above. Therefore both groups were equally influenced by an increase in set size across both present and absent conditions.

Figure 2.4 Graph showing the mean RT x set size slope for both target present and absent trials and both AQ groups. Standard error bars (+/- 1) are displayed.



Performance on the visual search task was as expected; participants made more errors and were slower in trials where the target was absent and where the set size was larger. However, contrary to previous work, (Plaisted et al., 1998; Joseph et al., 2009; Brock et al., 2011; Milne et al., 2013), there was no difference in visual search accuracy, reaction time or efficiency between those with high and low levels of autistic traits.

ERP Results

N2pc Amplitude and Autistic Traits

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 (See Figure 2.5). 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. Furthermore, there was no main effect of group F (1, 20) = 0.7, p = .43, ηp^2= .03, indicating that absolute amplitude within the N2pc time window did not differ between groups. In Figure 2.6, ERPs

ipsilateral and contralateral to the appearance of a target are shown separately for high and low AQ scorers. Figure 2.7 shows the difference wave where a larger N2pc amplitude is evident in the high AQ scorers and Figure 2.8 demonstrates topographical distribution in the N2pc time range.

N2pc Latency and Autistic Traits

As described in Chapter 2 (Page 29), latency values were calculated as the time point at which the difference wave (contralateral minus ipsilateral) reached 50% of the peak amplitude between 180 and 300 milliseconds.

An independent-measures T-Test on mean onset latency, with a between factor of AQ group revealed no significant group difference in the onset of the N2pc, t (20) = .37, p = .72, d = .03.

Table 2.3 Mean and standard deviation for the N2pc onset latency for high and low AQ scorers

	Mean (ms)	S.D
High AQ	243.3	11.1
Low AQ	213.5	7.0

Figure 2.5 Grand average ERP, for all participants, showing data extracted from 4 pairs of electrodes (P3/4, P7/8, P07/08. T3/4). The N2pc is evident in the diversion between the contralateral and ipsilateral signal between 200 and 300 milliseconds

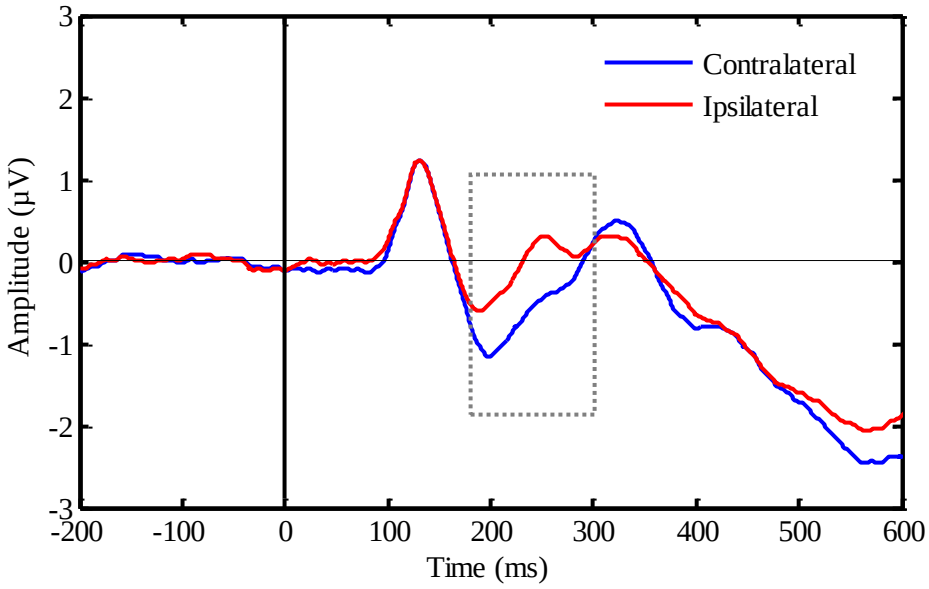


Figure 2.6 Grand average ERPs shown separately for high and low AQ scorers showing data extracted from 4 pairs of electrodes (P3/4, P7/8, P07/08. T3/4). The N2pc is evident in the diversion between the contralateral and ipsilateral signal between 200 and 300 milliseconds

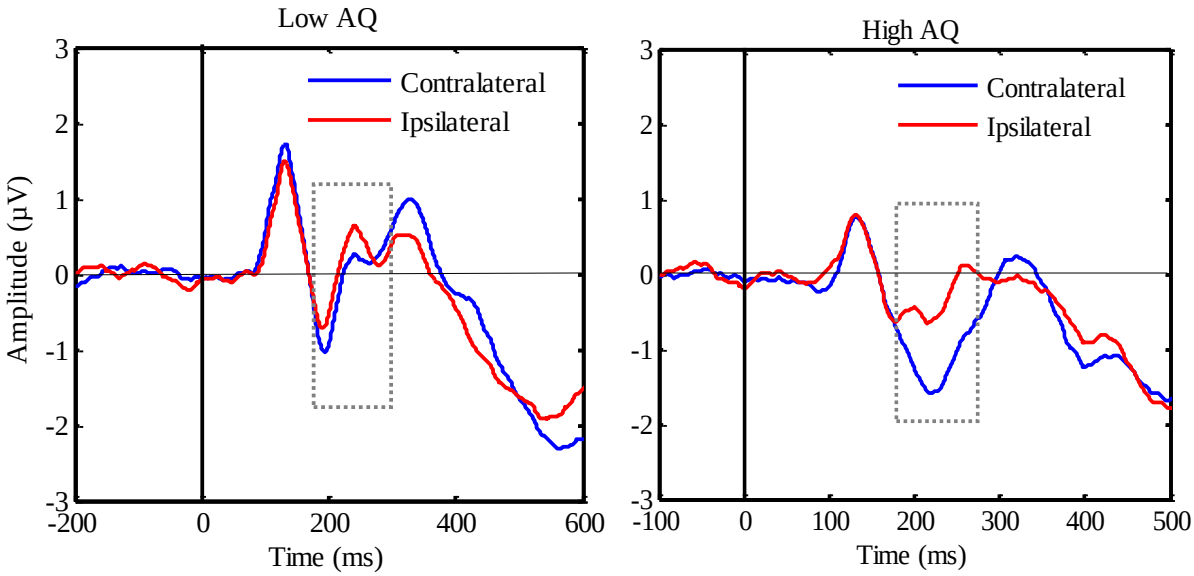


Figure 2.7 N2pc Difference waves (contralateral minus ipsilateral) for high and low AQ groups. The N2pc is the negative going signal between 200 and 300 milliseconds.

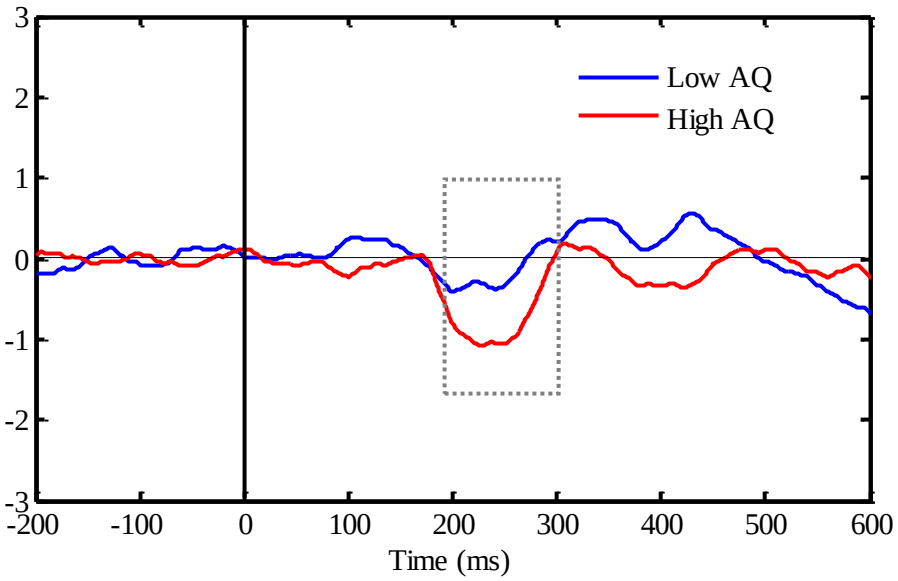
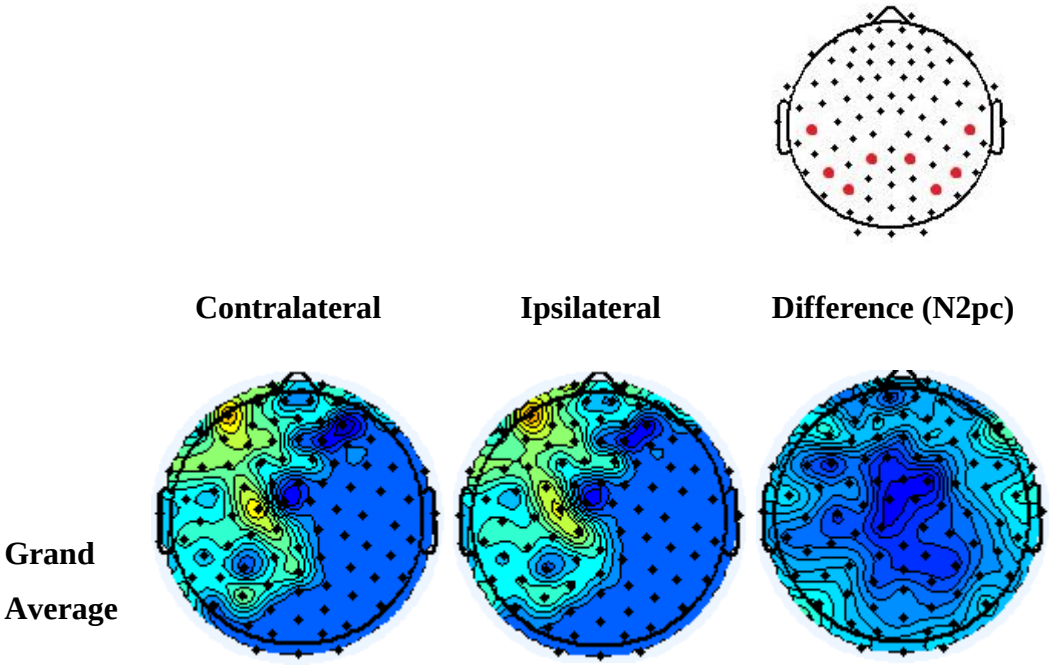
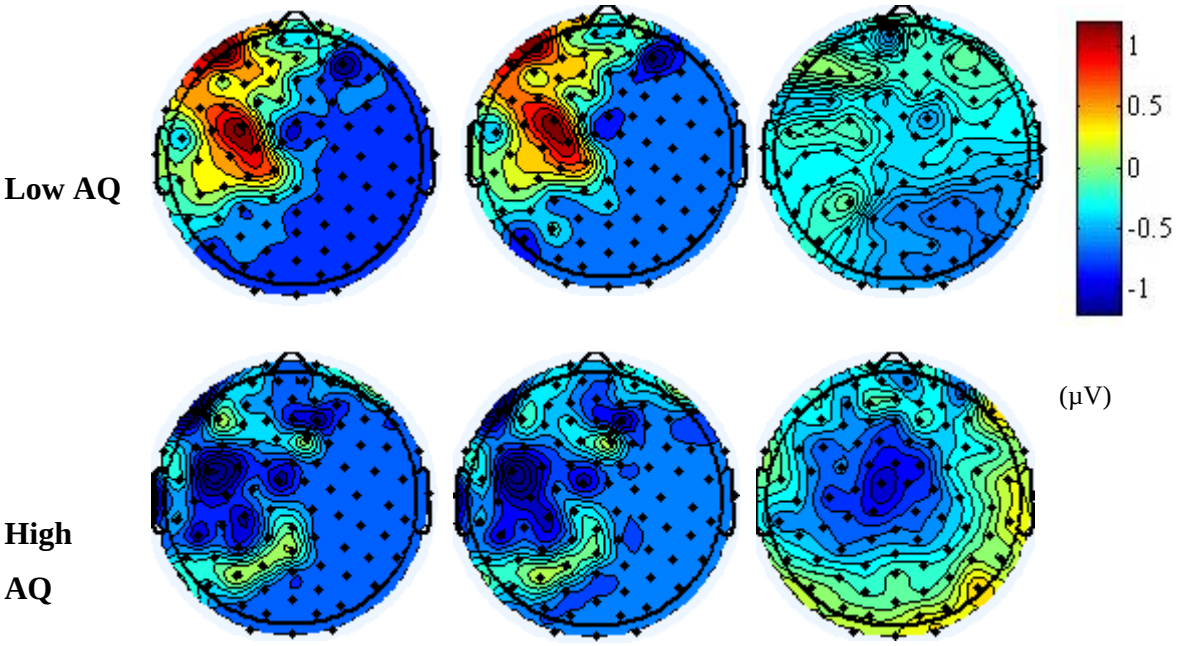


Figure 2.8 Topographic plots of the N2pc showing mean amplitude across the scalp between 180 and 300 milliseconds. A scalp map displays the electrodes used to extract data.





The topographic plots display the mean amplitude across the scalp during the 180-300 millisecond N2pc time window; contralateral to the target; ipsilateral to the target and the difference (contralateral minus ipsilateral). The contralateral plots show more negativity than the ipsilateral plots and this is reflected in negativity in the difference (contralateral minus ipsilateral) plots. The negativity is occipital-parietal in those with low levels of autistic traits and more central-parietal in those with high levels of autistic traits.

N2pc Amplitude and Visual Search Efficiency

In order to establish whether N2pc amplitude predicted visual search efficiency a linear regression was conducted with the (RT x set size) slope value for absent trials entered as the dependent variable and N2pc amplitude as the independent variable and another analysis with present trials entered as the dependent variable and N2pc amplitude as the independent variable. The analysis was conducted only on participants included in ERP analyses above. The analyses indicated that N2pc amplitude did not significantly predict visual search efficiency in either absent, $R^2 = .04$, $F(1, 20) = .78$, $p = .39$ or present $R^2 = .05$, $F(1, 20) = .02$, $p = .90$ trials.

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, 2011). The SPCN (sustained posterior contralateral negativity) occurs between 350 and 650 ms and this was the time window used (Jolicœur, 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, 2011).

P1 Amplitude and Autistic Traits

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.

SPCN Amplitude and Autistic Traits

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, η^2_P = .46, showing a clear SPCN in these data. This did not interact with AQ group F (1, 20) = .48, p = .50, ηp^2= .02, indicating that SPCN did not differ between the high and low AQ scorers. Furthermore, there was no main effect of group F (1, 20) = .72, p = .41, ηp^2= .04, indicating that absolute amplitude within the SPCN time-window, which broadly corresponds to the P3 time window (Robitaille et al., 2007), did not differ between the two groups either.

These additional analyses confirm that there was no between-group difference in the amplitude of either of the early (P1) or late (P3, SPCN) ERP components confirming that differences between groups were uniquely observed in the N2pc component.

Congruency

An additional analysis was conducted to assess whether the congruency of orientation had an effect on reaction times or the amplitude of the N2pc. Congruent trials were defined as those where the two coloured T's were the same *orientation* and incongruent trials where the T's were in opposing orientations.

The experiment was set up with 900 trials, however due to a mistake in design there were an unequal number of congruent (390) and incongruent (510) trials. Incongruent trials were randomly removed on a participant by participant basis in order to match the number with the congruent trials and ensure that ERPs were based on equal numbers of trials.

Accuracy

A repeated-measures ANOVA (2x2) with a between-subjects factor of AQ group revealed no significant difference in accuracy between congruent and incongruent trials F (1, 30) = 1.6, p = .22, ηp^2= .05. The interaction between display size and AQ group was also non-significant F (1, 30) = .38, p = .54, ηp^2= .01. Finally, the test revealed no main effect of AQ group on accuracy F (1, 30) = 3.5, p = .07, ηp^2= .11.

Reaction Time

Median (correct) reaction time data for congruent and incongruent trials was entered into a repeated-measures (2x2) ANOVA with a between-subjects factor of AQ group. As expected the reaction times were significantly slower in incongruent trials compared to congruent trials F (1, 30) = 17.3, p = <.001, ηp^2= .37. However, there was no significant two-way interaction between AQ group and congruency F (1, 30) = .48, p = .50, ηp^2= .02. And there was no main effect of AQ group on reaction time F (1, 30) = .59, p = .45, ηp^2= .02.

N2pc Amplitude

N2pc amplitude for congruent and incongruent trials were entered into a 2x2 repeated-measures ANOVA with a between factor of AQ group. This revealed no significant difference in N2pc amplitude between congruent and incongruent trials F (1, 20) = 1.2, p = .29, ηp^2= .05. There was also no significant interaction between congruency and AQ group F (1, 20) = .45, p = .51, ηp^2= .02. However, as expected, there was a significant main effect of AQ group on congruency F (1, 20) = 5.4, p = .03, ηp^2= 0.21, reflecting the main finding of a larger N2pc in those with high levels of autistic traits.

Simon Effect

In the Simon effect, response time is faster when the stimulus position corresponds to the location of the response hand (Wascher, 2005). For example in

this study when the letter T is on the left and is upright, requiring a left button press, or on the right side of fixation and inverted, requiring a right button press. Incompatibility of response and target has enlarged amplitudes in the N2 (N270) time range and decreased P300 amplitude, suggesting interference of response action with perception (Valle-Inclán, 1996). For this study it was necessary to conduct a Simon effect analysis as both hands were used for responses and this analysis can assess whether matching laterality of stimuli and response hand influenced the amplitude of the N2pc.

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, ηp^2= .001 and no significant interaction between these variables and AQ group, F (1, 20) = .02, p = .89, ηp^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).

Discussion

This study revealed a significantly larger N2pc in those with high levels of autistic traits. However, there was no difference between those with high and low levels of autistic traits in any other ERP measures, nor in behavioural performance in the spatial attention task or the visual search task.

The behavioural results presented here do not support the previous literature which shows enhanced visual search performance in individuals with high levels of autistic traits. This study found no difference in visual search reaction time or efficiency between high and low AQ scorers, in neither target present or absent trials. Previous studies have found that those with a diagnosis of an ASC are typically more accurate and faster at conjunctive visual search tasks (Plaisted et al., 1998; Joseph et al., 2009). Milne et al., (2013) and Brock et al., (2011) have extended this finding to

those with high levels of autistic traits; however the present study and the studies summarised by Gregory and Plaisted-Grant (2013) do not support these findings.

One potential reason for discrepancy between these findings is task difficulty. The RT x set size functions in the present study created search slopes that were approximately half of the typical slope values in a visual search task. In a previous study (Milne et al., 2013) mean slope values were 32.7ms/item for absent trials and 13.1/item for present trials. In the present study the mean slope value was 17.8ms per item for absent trials and was 10.9ms per item in present trials. Slope values typical of a conjunctive search task in present and absent trials are 20-30ms/item and 30-60ms/item respectively (Wolfe, 1998, Joseph et al., 2009). The low slope values in the present study suggest that the task was easy for the sample of participants in the present study; especially given that the slopes are in the expected range of a feature search rather than a conjunctive search. Plaisted et al., (1998) developed their visual search task for use with children; therefore it may have been too easy for adults in the present study. This is an important finding as the literature seems to suggest that ASC superiority is only evident in difficult tasks that require more demanding processing (Remington, Swettenham & Lavie, 2012).

This does not explain how a very similar task (Milne et al., 2013) could find behavioural differences between the groups. The visual search task employed in both Milne et al., (2013) and the present study was a replication of Plaisted et al., (1998) with a slightly narrower visual angle to accommodate the use of a smaller screen in the present study (Plaisted = approximately 33°, present study = 25°, Milne et al., = 17°). The visual angle of the array can be defined as the proportion of the visual field occupied by an image when viewed from a particular distance (Murray, Boyaci, & Kersten, 2006). The task was extremely similar to one used in a previous study (Milne et al., 2013) which found that those with high levels of autistic traits were more efficient in more difficult trials, where the target was absent. Again, the only difference in the task was the overall visual angle of the display. In the former study (Milne et al. 2013) there were the same amount of letters in a smaller visual angle, therefore the letters were more crowded. This could have resulted in more interference in the attentional lens and more difficulty when the participants' were identifying a target.

N2pc Amplitude

It was predicted that a difference in the allocation of spatial attention would be reflected in the amplitude of the N2pc. The study revealed a significant difference N2pc amplitude between individuals with high and low levels of autistic traits, where those with higher levels of autistic traits had a larger N2pc amplitude. Further analyses on ERPs earlier and later in the visual evoked potential confirmed that this effect was unique to the N2pc. In addition, no difference in the onset of the N2pc was reported. The absence of any difference in the visual search rates of the two groups and of any relationship between the N2pc and visual search efficiency suggests that the N2pc may not reflect a process integral to the completion of a conjunctive visual search task, with the need to filter distracters (Eimer, 1996).

A further analysis broke the experiment down into congruent and incongruent trials, to investigate whether matching orientation in the target and distracter had an impact on N2pc amplitude. As expected, there was slowed reaction time in the incongruent trials, but no significant effect of congruency on the amplitude of the N2pc, which is consistent with previous work (Pagano & Mazza, 2013).

The N2pc appears to reflect the allocation of focused attention (Burra & Kurzel., 2013; Sawaki, Luck & Raymond, 2015) and the larger N2pc in those with high levels of autistic traits suggests enhanced orienting of attention to the pre-specified target (Eimer, 1996; (Clark et al., 2015). This could be because those with high levels of autistic traits find the task more difficult; however this is not reflected in behavioural performance or suggested by the previous literature. Hamame et al., (2011) and An et al., (2012) both reported a larger N2pc with practice on a visual search task, where participants' reaction time improved across sessions and N2pc amplitude also increased. In addition, Hamame et al., (2011) found that perceptual sensitivity (d') increased with increasing N2pc amplitude, supporting the claim that the N2pc is involved in more attentional focus on a trained target and could be involved in increased sensitivity to stimuli in trained visual fields. The authors (Hamame et al., 2011) suggest that the increase in N2pc amplitude reflects a weighting mechanism which operates between sensory and attentional levels and enhances the target by facilitating the selective treatment of the target amongst distracters.

In the present study large N2pc amplitude was not accompanied by more efficient behavioural performance in the ERP task or visual search task. A large N2pc in those with high levels of autistic traits could be due to the freeing up of more visual processing resources as a consequence of a higher perceptual capacity (Remington et al., 2009, 2012). A larger perceptual capacity would result in distracter processing even at high levels of perceptual load (Remington et al., 2009) and in the ERP task presented here, increased distractibility could offset any superiority in efficiency when a participant with high levels of autistic traits or ASC (Remington et al., 2009) is still processing the distracter letter. A lack of distracter suppression could ultimately increase the need for target enhancement, reflected in a larger N2pc amplitude. The suggestion that those with high levels of autistic traits are not suppressing distracting information can be investigated directly using ERPs. The second study of this thesis will seek to do this by isolating the two subcomponents of the N2pc which were described in Chapter One. We might expect to see a group difference in the amplitude of the P_D, the ERP reflecting distracter suppression (Hickey et al., 2009).

In conclusion, there were no differences in visual search accuracy, reaction time or efficiency between those with high and low levels of autistic traits. This may be due to the task being too simple for the participants. This study revealed that the N2pc was larger in those with high levels of autistic traits, potentially reflecting enhanced focusing of attention and altered processing of distracters. The next study of this thesis will investigate this finding by breaking down the N2pc into its target and distracter specific subcomponents. The findings and implications of study one will be discussed further in Chapter 5.

Chapter 3 : ERP correlates of spatial selective filtering in those with high self-reported levels of autistic traits

Introduction

The previous chapter presented evidence of altered allocation of spatial processing in those with high levels of autistic traits. Though the groups did not differ in their behavioural performance, the conclusions were based on ERP data demonstrating an augmented N2pc in those with high levels of autistic traits when compared to those with fewer autistic traits. This study will focus on two subcomponents of the N2pc which have recently been described (Hickey et al., 2009) and were introduced in Chapter one; the P_D and N_T.

Distracter suppression appears to be atypical in ASC. Using a modified visual search task, Burack (1994) found that individuals 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 distracter letters were presented within the window as opposed to outside of the window, participants with ASC showed a greater increase in response time than typically developing controls. Burack (1994) suggested that this reflects an "inefficient attentional lens" in autism and subsequent studies have supported this claim (Mann & Walker, 2003; Smith & Milne, 2009). Remington et al., (2009) demonstrated that those with ASC show strong interference from distracting flanker letters especially at high levels of perceptual load, a finding they consider to reflect greater perceptual capacity in those with ASC. Bayliss and Kritikos (2011) extended this finding to those with high self-reported levels of autistic traits. Overall these studies provide evidence for atypical processing of distracters in ASC and in those with high levels of autistic traits.

Milne et al., (2013) reported electrophysiological data which revealed differences in resource allocation to irrelevant distracters between those with high and low levels of autistic traits. Specifically, they found that those with more autistic traits had a larger P3b response to irrelevant stimuli compared to those with fewer autistic traits. This suggests that those who are high in autistic traits pay more attention to task irrelevant items in a scene than those who possess fewer autistic traits. This dovetails with Remington et al's., (2012) suggestion that individuals with autism have enhanced perceptual capacity. Enhanced attention to irrelevant items and

superior performance on selective attention tasks could both arise as a corollary of this enhanced perceptual capacity (Remington et al., 2009; 2012).

The N2pc has been shown to be composed of two subcomponents; the N_T reflecting target selection and the P_D reflecting distracter suppression (Hilimire et al., 2012; Hilimire, Mounts, Parks, & Corballis, 2011; Sawaki, Geng, & Luck, 2012; Sawaki & Luck, 2011; Hickey et al., 2009; Sawaki and Luck, 2010). Sawaki and Luck (2010) found that the P_D was elicited when a salient irrelevant singleton was presented to participants; therefore the P_D appears to reflect active suppression processes.

The present study will employ the visual search task used in Milne et al., (2013), a replication of Plaisted et al., (1998), which revealed that high AQ scorers were more efficient at absent trial visual search compared to the low scorers. The N2pc will be re-measured and a new procedure will allow investigation of the correlates of target and distracter processing separately in the form of the N2pc subcomponents P_D and N_T. This will allow links to be more directly drawn with suggestions of reduced attentional filtering (Remington et al., 2009; Milne et al., 2013).

Based on study one it was predicted that N2pc amplitude would be larger in individuals scoring higher on the AQ when compared to low scoring individuals. Based on the previous literature it was predicted that those with high levels of autistic traits would show an attenuated P_D positivity reflecting reduced suppression of distracters, and an N_T that was predicted to be similar between high and low AQ groups. Finally, based on the previous literature a group difference in visual search performance could be expected, but based on the first study in this thesis, there may not be a difference in visual search performance between those with high and low levels of autistic traits.

Experiment Two: The neural correlates of target and distracter processing in those with high or low levels of autistic traits

Participants

To recruit participants for experiment two a new AQ distribution was obtained. All first year students were invited to complete the AQ online. As it was

the beginning of a new academic year, the database recruited for study two was composed of an entirely different cohort of students than the database recruited for study one (Chapter Three). 610 participants completed the AQ; the mean score was 19.1 with a range of 2 - 47. None of the participants recruited for Experiment 2 had participated in Experiment 1. The top and bottom 10^{th} percentiles of the distribution corresponded to AQ scores of 27 and 12 respectively. From this distribution, forty-one participants took part in the ERP study reported here. Twenty-one of these were high AQ scorers (AQ $\geq$27) and twenty were low AQ scorers (AQ $\leq$12). All participants had normal or corrected to normal vision and were aged between 18 and 44 years old. The sample consisted of 21 females and 20 males and gender balance was roughly equated in the high and low AQ groups.

All procedures were carried out in line with BPS guidelines (outlined in Chapter One) and the study received ethical approval from the departmental ethical review committee.

Methodology

Stimuli

Spatial Attention Task (Based on Luck et al., 1997 and Hickey et al., 2009)

Participants completed a spatial attention task which is detailed in Chapter 2 (Page 24) with the addition of letter positions on the vertical meridian. This task consisted of 840 trials and was based on Hickey, DiLollo and McDonald, (2009) and Luck et al., (1997).

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 280 trials where a target appeared laterally and 280 trials where a distracter appeared laterally. This was a replication of Hickey, DiLollo and MacDonald, (2009) *experiment 4* with fewer trials. There were also 280 trials where the target and distracter were presented on opposing lateral positions to elicit the N2pc. Thus, there were a total of 840 trials in the spatial attention task.

Green and blue appeared with equal occurrence in lateral (1/3 of trials) and vertical positions. The lateral/vertical organisation (see Figure 3.1) was the critical set up and allowed for the isolation of components related to lateral targets (N_T) and lateral distracters (P_D). The opposing sides set up, as a balanced visual search display was intended to elicit the N2pc (a summation of distracter and target processing).

Visual Search Task

The visual search task used in this study was the same as in Milne et al., (2013) which previously highlighted differences in performance between high and low AQ scorers. This task had the same parameters described in Chapter 2 (Page 26) but had a narrower visual angle, not exceeding 18° of visual angle.

In the first study of this thesis, the visual search task in Milne et al., (2013) was used but modified to match the spread of the letters (visual angle) with Plaisted et al., (1998). The modified task found no difference in visual search performance whereas the task used previously (Milne et al., 2013) did. Therefore, this study switched to the visual search task used in Milne et al., (2013).

Procedure

The participants began with the spatial attention task followed by the visual search task.

Spatial Attention Task

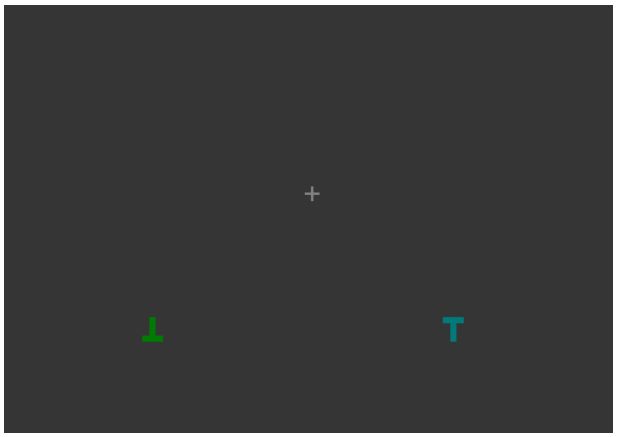
The procedure is fully detailed in Chapter 2 (Page 25). Participants pressed a response key with their left index finger if the target was upright and with their right index finger if the target was inverted. The experimental session contained 6 blocks of 140 trials.

Visual Search Task

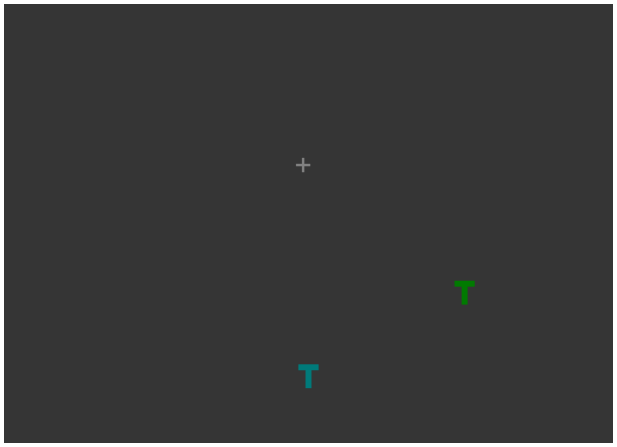
The procedure for this task was common across the thesis and is detailed in Chapter 2 (Page 26).

Figure 3.1 Letter Ts could appear above, below, or in line with fixation, in two of eight possible positions. The three ERPS were elicited by separate trials which were presented in three different critical manipulations (for the purposes of this illustration assume that the blue T is the target):

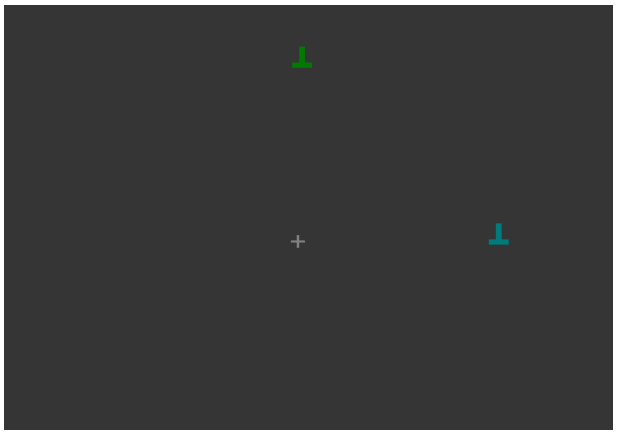
a. Two opposing lateral letter Ts, intended to elicit the *N2pc*



b. One lateral distracter presented with a target (defined by colour) on the vertical meridian, intended to elicit the P_D.



c. One lateral target (defined by colour) presented with a distracter on the vertical meridian, intended to elicit the N_T.



Data Processing and Analysis

Data Collection and Pre-Processing

The EEG system is described in Chapter 2 (Page 27). The artifact rejection procedure is detailed in Chapter 2 (Page 28).

Data Exclusion

ERP datasets were excluded if there were less than 80 trials contributing to the contralateral or ipsilateral ERP, resulting in the exclusion of 5 datasets. One dataset was excluded because the participant demonstrated a misunderstanding of instructions and this was reflected in their task accuracy. For ERP analyses this resulted in a final sample of 27, with 12 high AQ (8 female, 4 male) participants and 15 low AQ (8 female, 7 male) participants. The high AQ group had a mean AQ score of 32 (score range = 27 - 44) the low AQ group had a mean AQ score of 9 (score range = 6 - 12).

N2pc Trials

Only trials where there were two lateral letter Ts were used to extract N2pc data. The mean number of trials used to calculate the contralateral and ipsilateral ERPs was 103 and 96 respectively with no difference in the number of trials used between high and low AQ scorers for contralateral t (25) = 1.4, p = .16, d = 0.5, or ipsilateral t (25) = 1.5, p = 14., d = 0.6 waveforms.

P_D Trials

Only trials where there were there was a lateral distracter and a target on the vertical meridian were used to extract P_D data. The mean number of trials used to calculate the contralateral and ipsilateral ERPs was 92 and 89 respectively with no difference in the number of trials used between high and low AQ scorers for contralateral t (25) = .62, p = .14, d = 0.2, or ipsilateral t (25) = .57, p = .15, d = 0.2 waveforms.

N_T Trials

Only trials where there were there was a lateral target and a distracter on the vertical meridian were used to extract N_T data. The mean number of trials used to calculate the contralateral and ipsilateral ERPs was 102 and 100 respectively with no difference in the number of trials used between high and low AQ scorers for

contralateral t (25) = .72, p = .14, d = 0.3, or ipsilateral t (25) = .64, p = .12, d = 0.2 waveforms.

Information about final usable trials for all ERPs is shown in table 3.1.

Table 3.1 Mean and range of usable trials for each ERP component and AQ group, following data exclusion

		Mean	Minimum	Maximum
	P_D	181	152	198
	N_T	202	155	232
	N2pc	199	150	225
High AQ	P_D	189	161	198
	N_T	212	170	222
	N2pc	189	184	225
Low AQ	P_D	178	152	195
	N_T	192	155	232
	N2pc	210	167	216

ERP Processing

N2pc Amplitude

N2pc amplitude was quantified as the mean voltage between 180 and 300 ms (Luck et al., 1997). 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 electrodes on the same side of the head as the target. The amplitude of the N2pc was represented by the degree to which the voltage in the selected latency range was different for contralateral versus ipsilateral signals when a target was presented with a lateral distracter.

P_D Amplitude

P_D amplitude was quantified as the mean voltage between 230 and 280ms (Hickey et al., 2009; Sawaki & Luck, 2010) in the critical stimulus organisation, when the lateral letter was ignored. The contralateral signal was acquired by taking the mean amplitude from the electrodes on the opposite side of the head to the distracter. Ipsilateral amplitudes were acquired by taking the mean amplitude from electrodes on the same side of the head as the distracter. The amplitude of the P_D was represented by the degree to which the voltage in the selected latency range was different for contralateral versus ipsilateral signals when a lateral distracter was presented with the target on the vertical meridian.

N_T Amplitude

N_T amplitude was quantified as the mean voltage between 175-325ms (Corriveau et al., 2012; Hickey et al., 2009) in the critical stimulus organisation, when the lateral letter was attended. 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 electrodes on the same side of the head as the target. The amplitude of the N_T was represented by the degree to which the voltage in the selected latency range was different for contralateral versus ipsilateral signals when a lateral target was presented with a distracter on the vertical meridian.

Behavioural Data Exclusions

Behavioural visual search data from 2 participants was excluded from analysis because of a clear misunderstanding of instructions reflected in low accuracy. For visual search analyses this left a sample of 39 with 20 high AQ scorers (10 male) and 19 low AQ scorers (9 male). Data from two participants was excluded from N2pc behavioural analyses because of extreme outlying reaction times, for N2pc behavioural analyses this resulted in a final sample of 38 with 20 high AQ scorers (10 male) and 18 low AQ scorers (9 male).

Results

Behavioural Results

Spatial Attention Task Behavioural Results

Four participants were excluded due to low accuracy. As reported in table 3.2, accuracy was high and did not vary significantly between high and low AQ scorers, t (35) = .24, p = .84, d = 0.06. Similarly median correct-trial reaction times did not differ between high and low AQ scorers, t (35) = .89, p = .38, d = 0.3. The same analysis was conducted using only the participants who were included in ERP analyses. This revealed no difference between groups in terms of accuracy t (25) = .26, p = .80, d = .08, or median reaction time t (25) = .22, p = .83, d = 0.09. The inverse efficiency score was calculated and did not vary significantly between groups when all participants were included t (38) = .24, p = .81, d = 0.08, nor when the same analysis was conducted only on those included in the ERP analysis, t (25) = .21, p = .84, d = 0.08.

Table 3.2 Mean and standard deviation for accuracy and reaction time data.

	Accuracy %		Median RT (ms)	
	High AQ (N=20)	**Low AQ (N=17)**	**High AQ**	**Low AQ**
Mean	88.1	86.8	512.53	509.31
SD	6.9	6.7	39.28	38.15

Visual Search Accuracy

Mean accuracy in visual search (91%, S.D = 4.9) was high. A repeated-measures ANOVA (2x3x2) with a between-subjects factor of AQ group revealed a significant difference in accuracy between different set sizes F (2, 78) = 16.6, p = <.001, ηp^2= .30 and between target absent and present trials, F (1, 39) = 93.3, p = <.001, ηp^2= .71. There was a significant two-way interaction between set size and target presence F (2, 78) = 27.4, p = <.001, ηp^2= .41, however the two-way interactions between set size and AQ group F (2, 78) = 2.1, p = .13, ηp^2= .05 and target presence and AQ group F (1, 39) = 1.8, p = .19, ηp^2= .04 were not significant.

Finally, the test revealed no main effect of AQ group on accuracy F (1, 39) = .07, p = .79, ηp^2= .00. The mean number of accurate trials for each AQ group, set size and absent and present trials are shown in figure 3.2.

Figure 3.2 a&b Accuracy plots for present **(a)** and absent **(b)** trials, 3 set sizes and 2 AQ groups. The maximum accuracy for each variable was 20.

Figure 3.2a Present

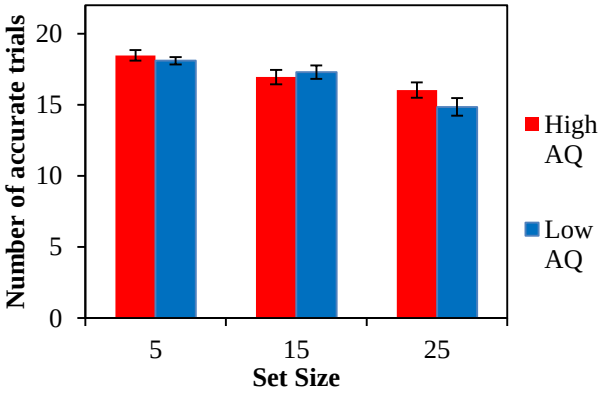
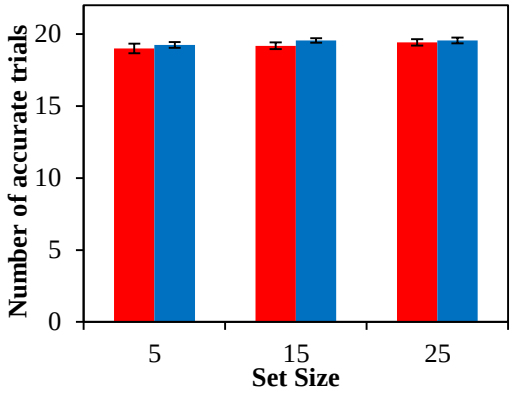


Figure 3.2b Absent



Visual Search Reaction Time

Reaction times three standard deviations above and below each participants individual mean were discarded; this resulted in the removal of an average 4 data points per participant (Range = 0-36). Mean reaction time data for each set size and target present and absent trials were entered into a mixed-measures (3x2x2) ANOVA with a between-subjects factor of AQ group. As expected the reaction times were significantly slower in absent trials compared to present trials F (1, 39) = 30.7, p = <.001, ηp^2= .44; there was a highly significant effect of increasing set size on reaction time F (1, 39) = 151.4, p = <.001, ηp^2= .80 and there was a highly significant two-way interaction between set size and target presence F (2, 74) = 6.2, p = .003, ηp^2= .15. There was no significant two-way interaction between AQ group and set size F (2, 74) = .43, p = .65, ηp^2= .01 or between AQ group and target presence F (1, 37) = .99, p = .33, ηp^2= .04. There was no significant three way interaction between set size, target presence and AQ group F (1, 39) = .28, p = .76, ηp^2= .00. Finally, there was no significant main effect of AQ group on visual search reaction time F (1, 39) = 1.3, p = .27, ηp^2= .032.

Figure 3.3 Graphs showing the mean visual search scores for both target absent and target present trials and both AQ groups, error bars display the standard error.

Figure 3.3a – target present trials

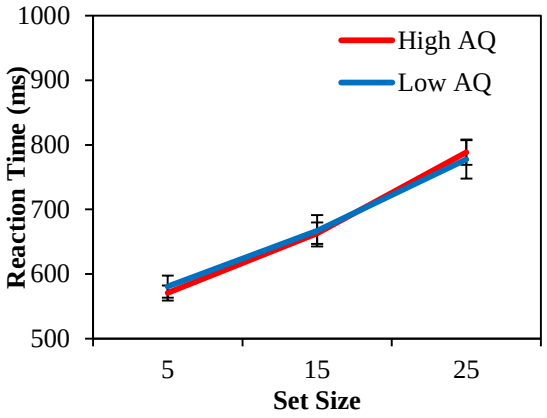
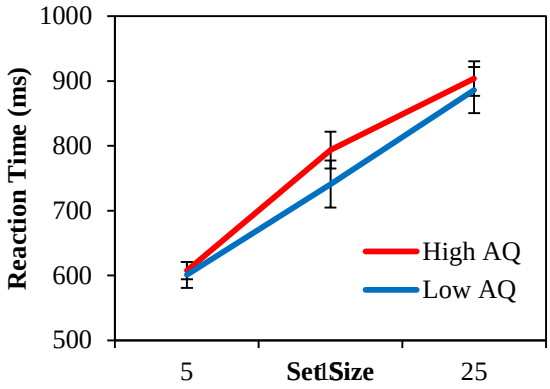
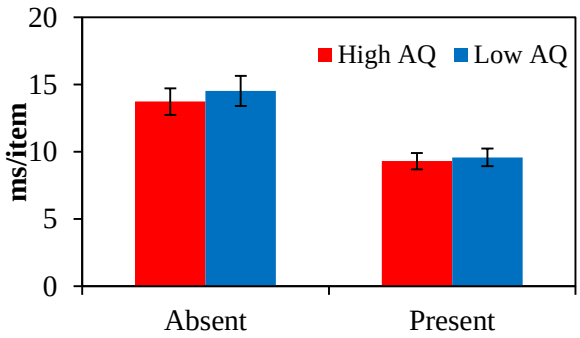


Figure 3.3b – target absent trials



Slopes of RT x set size were calculated by performing a linear regression of each participant's raw (correct) visual search data and compared in a mixed model repeated-measures ANOVA with a between-subjects' factor of group (high or low AQ) and a within-subjects' factor of target presence (present or absent). As expected, slopes were significantly steeper when a target was absent than when the target was present F (1, 37) = 22.8, p = <.001, ηp^2= .38. As shown in figure 3.4, in target absent trials, high and low AQ scorers demonstrated very similar search efficiency. A two-way ANOVA showed that there was no significant interaction between AQ group membership and search efficiency F (1, 37) = .02, p = .89, ηp^2= .0, confirming the results from the ANOVA reported above. Therefore both groups were equally influenced by an increase in set size across both present and absent conditions.

Figure 3.4 Graph showing the median RT x set size slope for both target present and absent trials in the visual search task, and both AQ groups. Standard error bars (+/- 1) are displayed.



Event Related Potentials

N2pc Amplitude and Autistic Traits

N2pc amplitude was analysed 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. All reported values reflect the Greenhouse-Geisser corrected statistic. Partial eta-squared was used to report effect size. A highly significant main effect of laterality confirmed the presence of a reliable N2pc, F (1, 25) = 40.1, p = <.001, ηp^2= .62 (See Figure 3.5). In Figure 3.6, ERPs ipsilateral and contralateral to the appearance of a target are shown separately for high and low AQ scorers. As previously reported in Chapter 2, the data show larger N2pc amplitude in those with high levels of autistic traits, however in contrast to the data presented in Chapter Three, this difference was not statistically significant, F (1, 25) = 2.8, p = .12, ηp^2= .14, (see Figure 3.7). Furthermore, there was no main effect of group F (1, 25) = .36, p = .56, ηp^2= .01, indicating that absolute amplitude within the N2pc time window did not differ between groups. Figure 3.8 displays the topographic distribution in the N2pc time window.

Figure 3.5 Grand average ERP, for all participants, showing data extracted from 4 pairs of electrodes (P3/4, P7/8, P07/08. T3/4). The N2pc is evident in the diversion between the contralateral and ipsilateral signal between 200 and 300 milliseconds

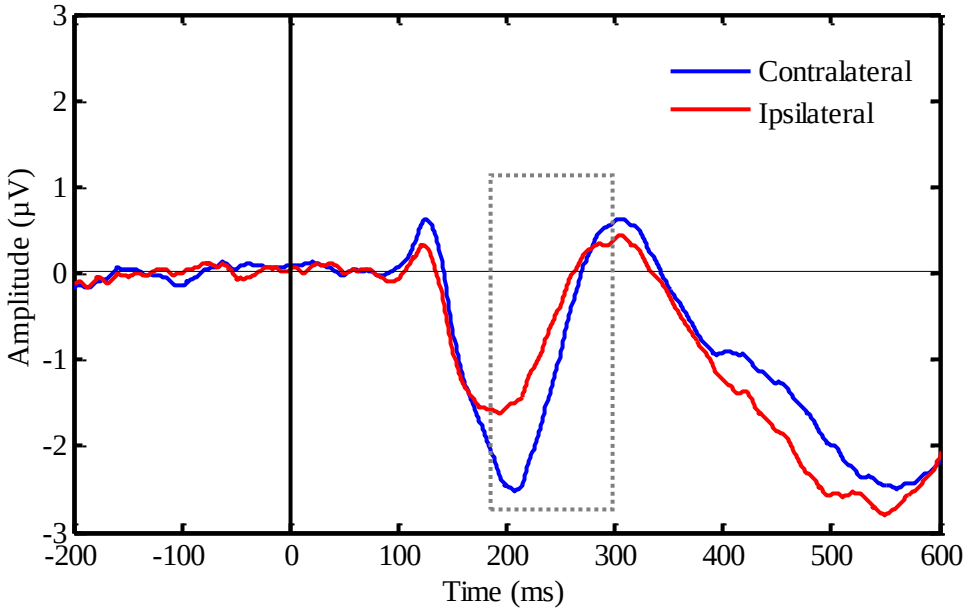


Figure 3.6 Grand average ERPs shown separately for high and low AQ scorers showing data extracted from 4 pairs of electrodes (P3/4, P7/8, P07/08. T3/4). The N2pc is evident in the diversion between the contralateral and ipsilateral signal between 200 and 300 milliseconds

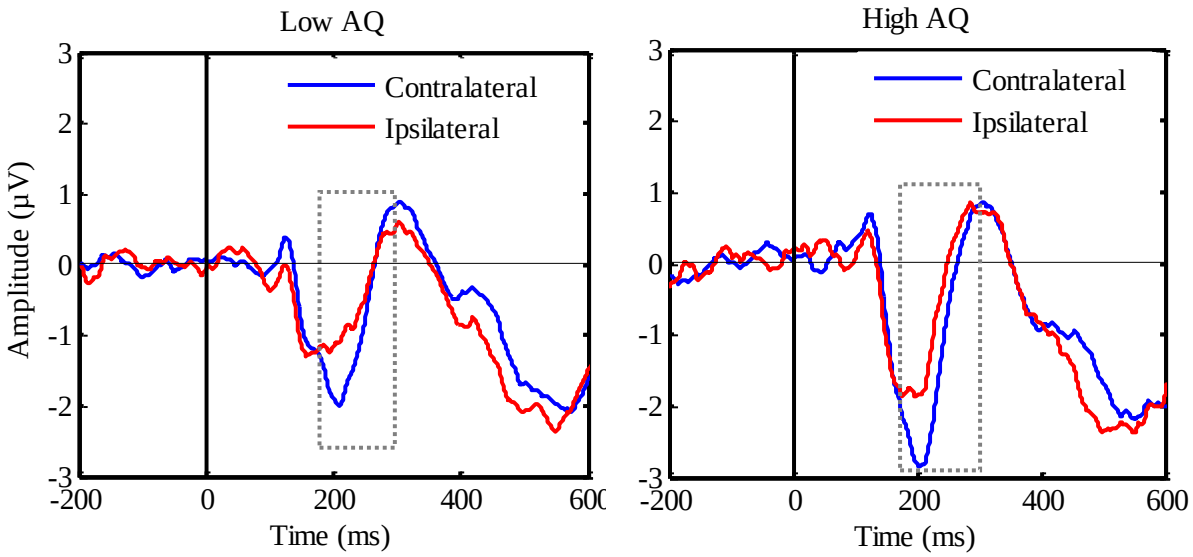


Figure 3.7 N2pc Difference waves (contralateral minus ipsilateral) for high and low AQ groups. The N2pc is the negative going signal between 200 and 300 milliseconds.

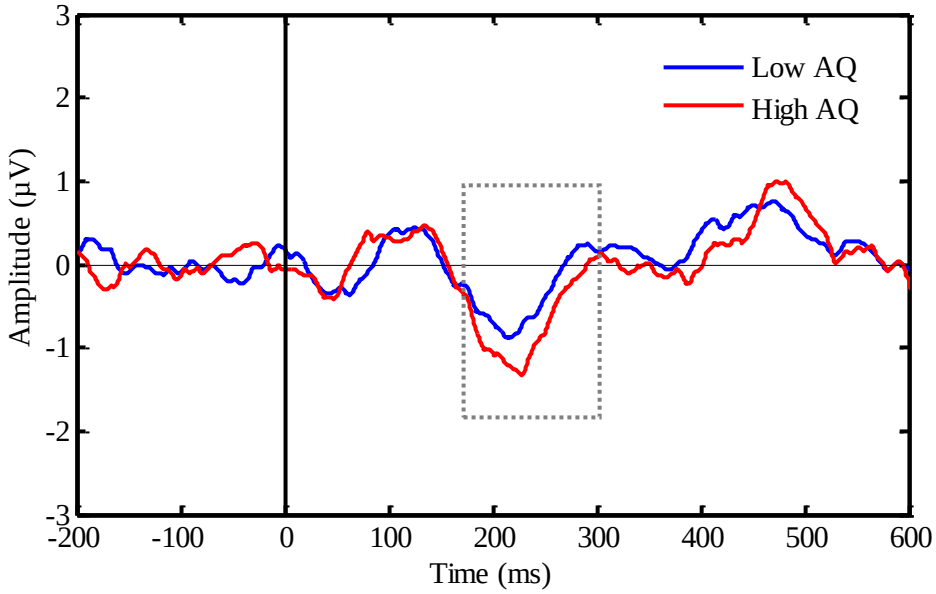
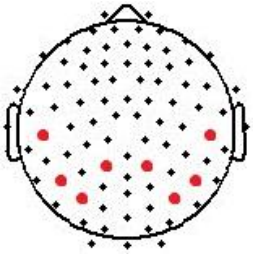
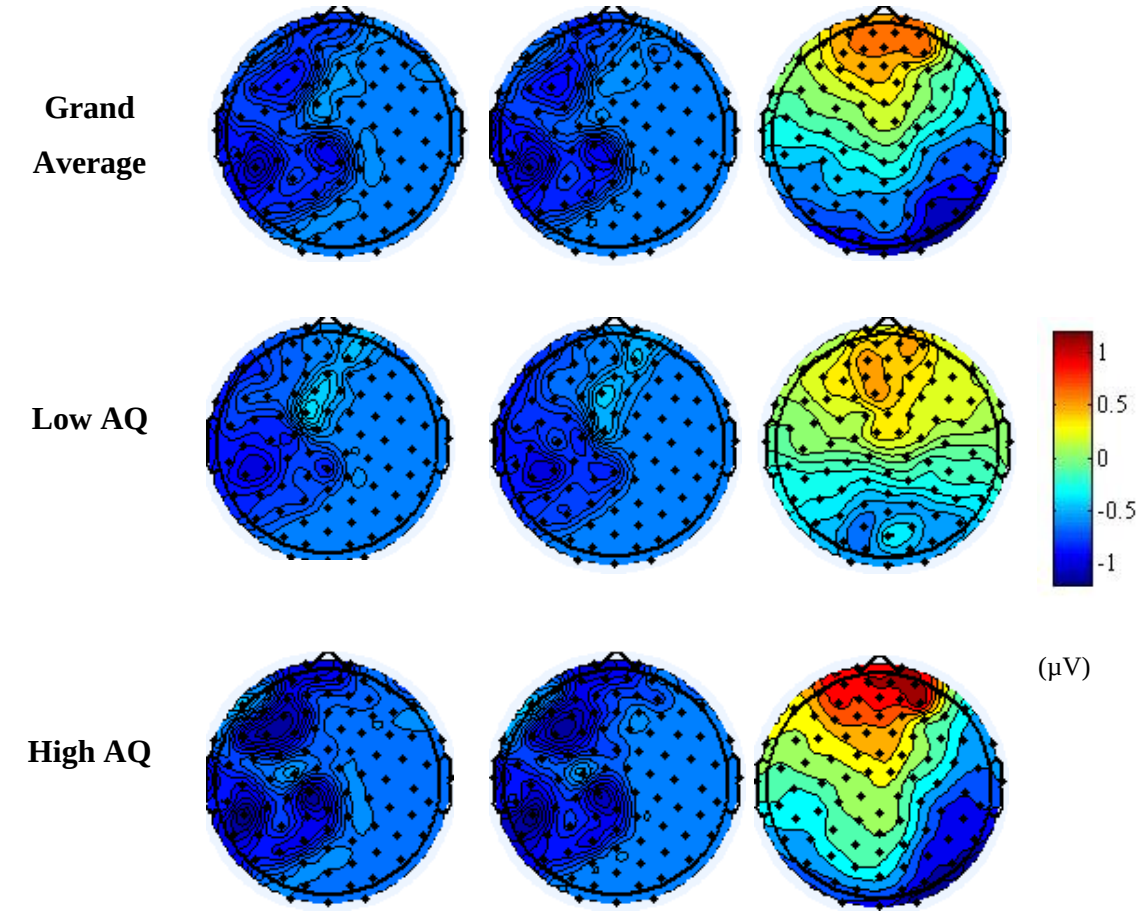


Figure 3.8 Topographic plots of the N2pc showing mean amplitude across the scalp between 200 and 300 milliseconds. A scalp map displays the electrodes used to extract data.





The topographic plots display the mean amplitude across the scalp during the 180-300 millisecond N2pc time window; contralateral to the target; ipsilateral to the target and the difference (contralateral minus ipsilateral). The contralateral plots show more negativity than the ipsilateral plots and this is reflected in negativity in the difference (contralateral minus ipsilateral) plots.

Distracter Suppression and Autistic Traits

P_D amplitude was investigated by way of 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. Figure 3.9 shows the ERPs obtained from contralateral and

ipsilateral sites relative to the appearance of the target; although there does not appear to be a clear P_D in this figure, there was a significant effect of laterality, F (1, 25) = 8.3, p = .00, ηp^2= .25. As shown in Figures 3.10 and 3.11, those with high levels of autistic traits demonstrated a smaller P_D amplitude compared to those with fewer autistic traits, although this was not statistically different, F (1, 25) = 3.3, p = .08, ηp^2= .12. Furthermore, there was no main effect of group F (1, 25) = .38, p = .54, ηp^2= .02, indicating that absolute amplitude within the P_D time window did not differ between groups. Figure 3.12 displays the topographic distribution in the P_D time window.

For the N2pc analyses in this thesis, four pairs of electrodes have been used for analyses and this was continued with analyses of P_D reported above. However, as signal can vary between electrode sites, the analysis was also conducted at electrodes used by Hickey et al., (2009); P07 and P08 (EGI: 66 & 85). A significant main effect of laterality confirmed the presence of a reliable P_D, F (1, 25) = 14.8, p = .001, ηp^2= .37. The interaction with AQ group was not significant F (1, 25) = 2.3, p = .14, ηp^2= .09. Furthermore, there was no main effect of group F (1, 25) = .46, p = .50, ηp^2= .02, indicating that absolute amplitude within the P_D time window did not differ between groups.

Figure 3.9 Grand average ERP, for all participants, showing data extracted from 4 pairs of electrodes (P3/4, P7/8, P07/08. T3/4). The P_D is evident in the slight diversion between the contralateral and ipsilateral signal between from 230 milliseconds.

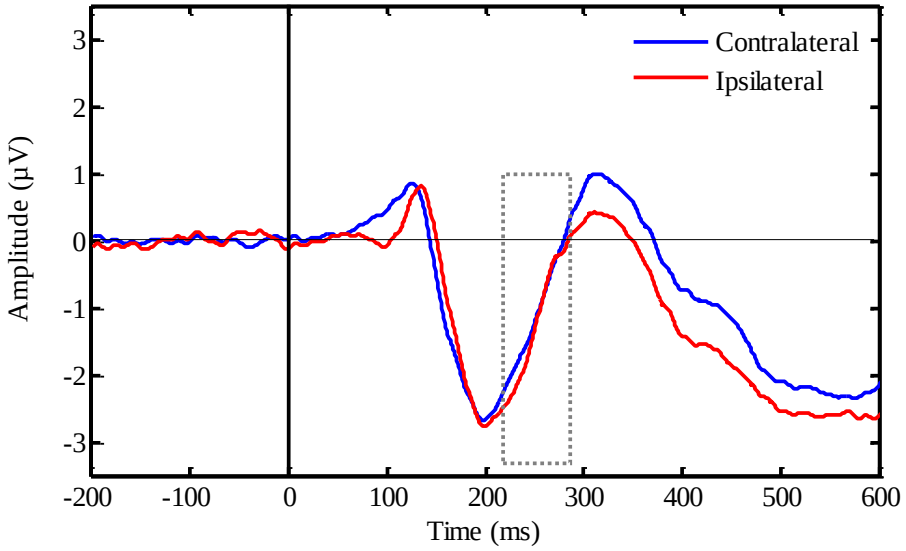


Figure 3.10 Grand average ERPs shown separately for high and low AQ scorers showing data extracted from 4 pairs of electrodes (P3/4, P7/8, P07/08. T3/4).

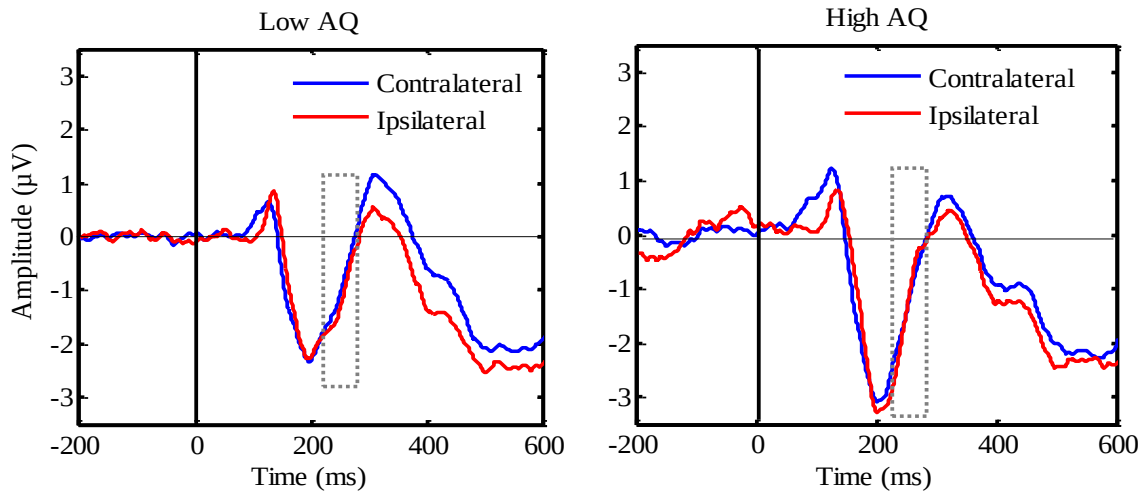


Figure 3.11 P_D difference waves (contralateral minus ipsilateral) for high and low AQ groups. The P_D is the positive going signal between 230 and 280 milliseconds.

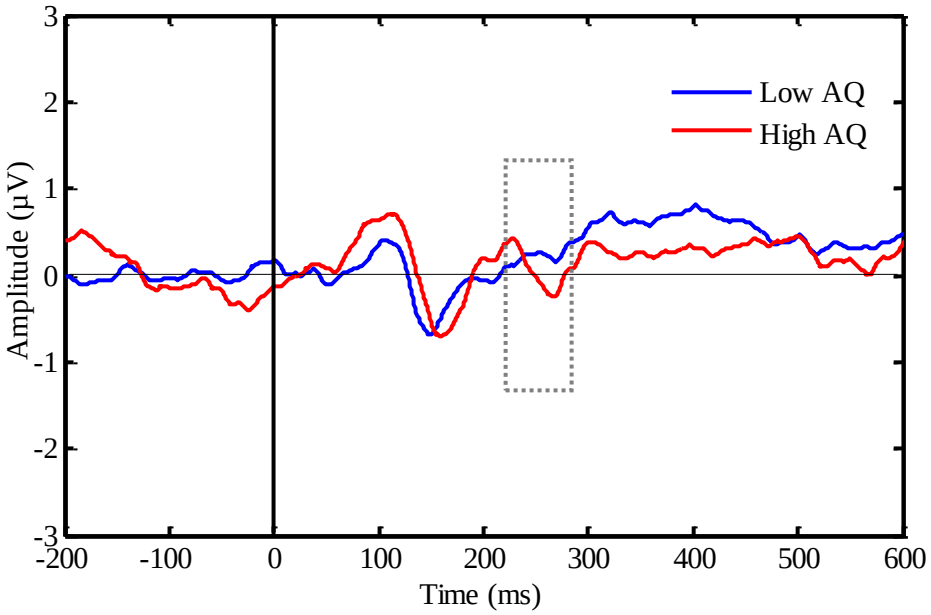
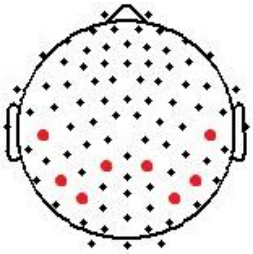
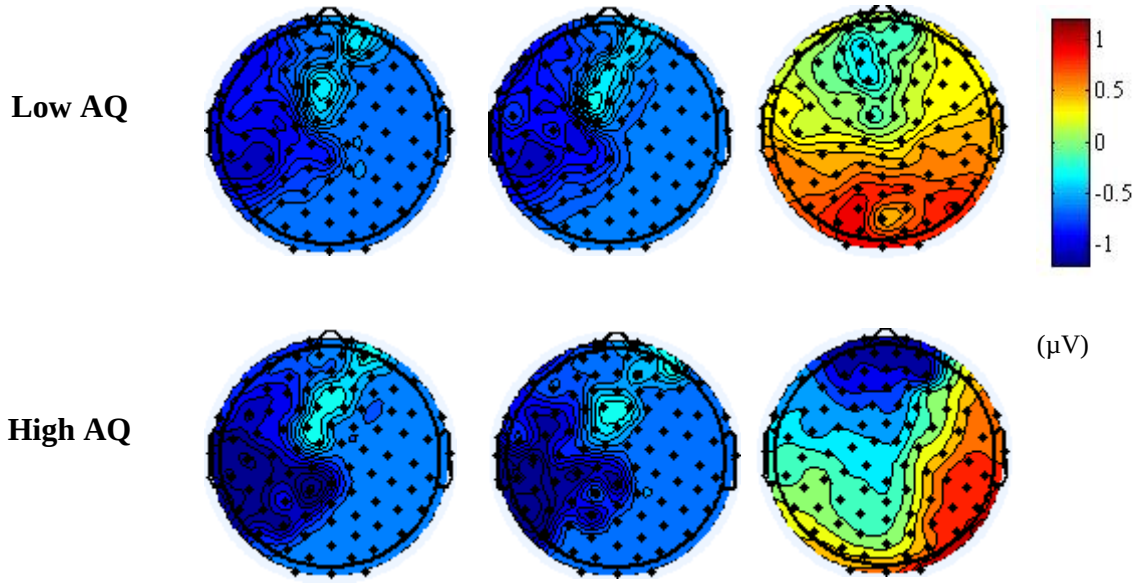


Figure 3.12 Topographic plots of the P_D showing mean amplitude across the scalp between 230 and 280 milliseconds. A scalp map displays the electrodes used to extract data.



P_D (230 - 280ms)	**Contralateral**	**Ipsilateral**	**Difference**
Grand Average			



The topographic plots display the mean amplitude across the scalp during the 230-280 millisecond P_D time window; contralateral to the target; ipsilateral to the target and the difference (contralateral minus ipsilateral). The ipsilateral plots show more negativity than the contralateral plots and this is reflected in positivity in the difference (contralateral minus ipsilateral) plots. The positivity has more spread across the scalp in those with low levels of autistic traits.

Target Processing and Autistic Traits

N_T amplitude was investigated by way of 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. Figure 3.13 shows the ERPs obtained from contralateral and ipsilateral sites relative to the appearance of the target. A significant main effect of laterality confirmed the presence of a reliable N_T, F (1,25) = 6.5, p = .018, ηp^2= .23. There was no significant interaction between AQ group and N_T amplitude, F (1, 25) = .00, p = .99, ηp^2= 0, as shown in Figure 3.14. Furthermore, there was no main effect of group F (1, 25) = .37, p = .55, ηp^2= .02, indicating that absolute amplitude within the N_T time window did not differ between groups. In Figure 3.15 difference waveforms obtained by subtracting the amplitude at ipsilateral sites from that at contralateral sites are shown for both high and low AQ scorers. Figure 3.16 shows the topographic distribution in the N_T time window.

This analysis was also conducted at electrode sites used by Hickey et al., (2009) to display ERP data; P07 and P08 (EGI: 66 & 85). There was no significant main effect of laterality at these sites, F (1, 25) = 2.0, p = .20, ηp^2= .08. There was no

significant interaction between AQ group and N_T amplitude, F (1, 25) = .37, p = .56, ηp^2= .02. Furthermore, there was no main effect of group F (1, 25) = .36, p = .56, ηp^2= .01, indicating that absolute amplitude within the N_T time window did not differ between groups.

Figure 3.13 Grand average ERP waveform. The N_T is evident in the diversion between the contralateral (blue) and the ipsilateral signal (red).

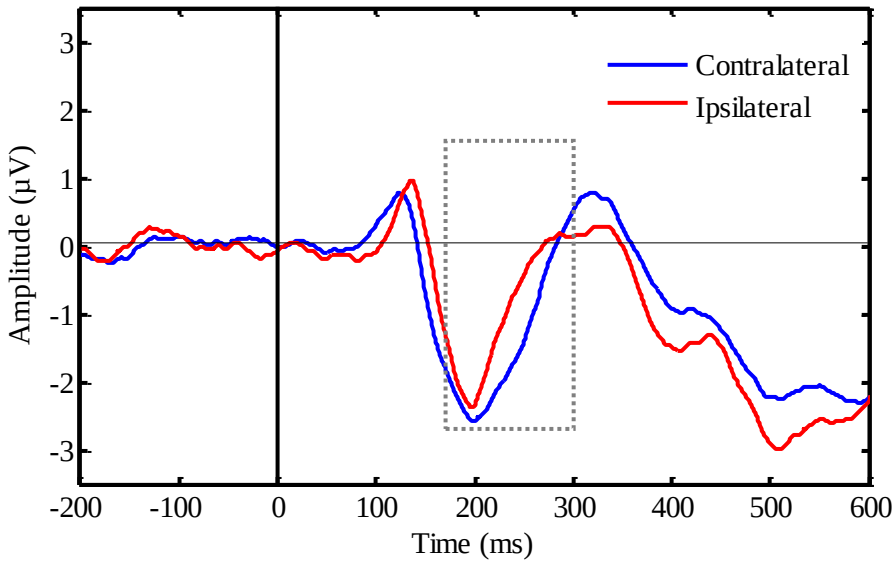


Figure 3.14 Grand average ERPs shown separately for high and low AQ scorers showing data extracted from 4 pairs of electrodes (P3/4, P7/8, P07/08. T3/4). The N_T is evident in the diversion between the contralateral and ipsilateral signal between 200 and 300 milliseconds

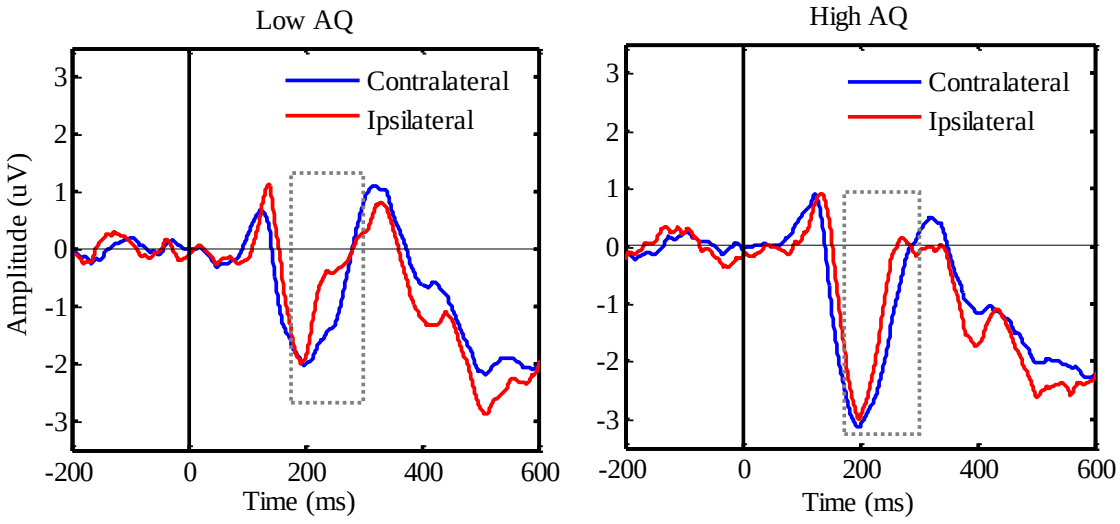


Figure 3.15 N_T difference waves (contralateral minus ipsilateral) for high and low AQ groups. The N_T is the positive going signal between 230 and 280 milliseconds.

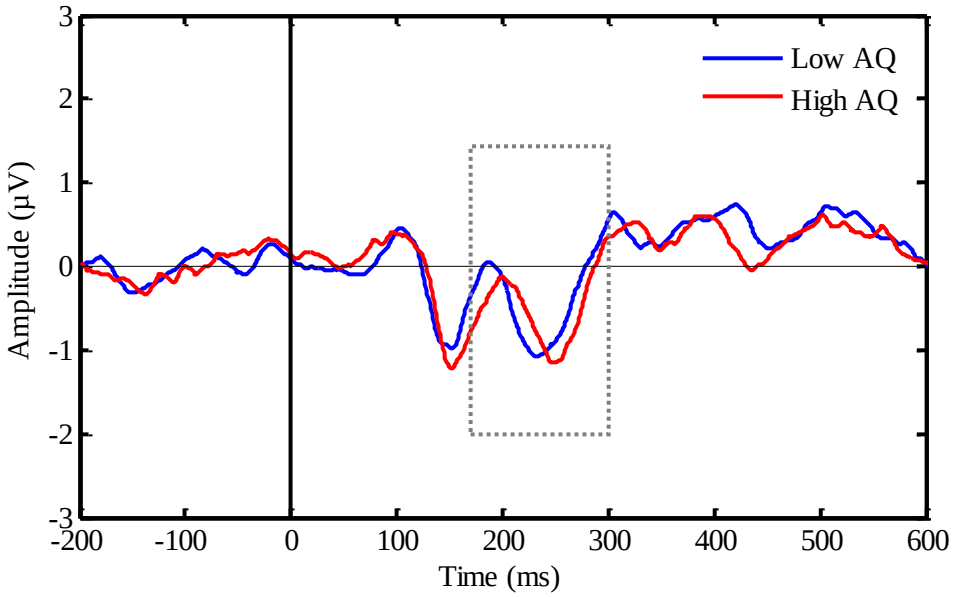
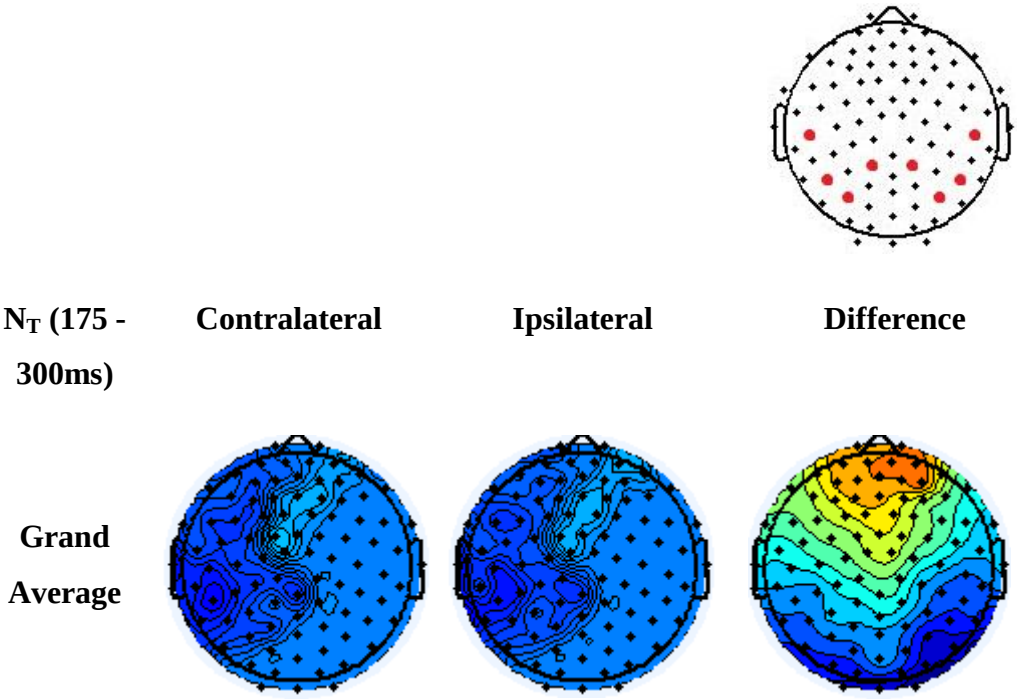
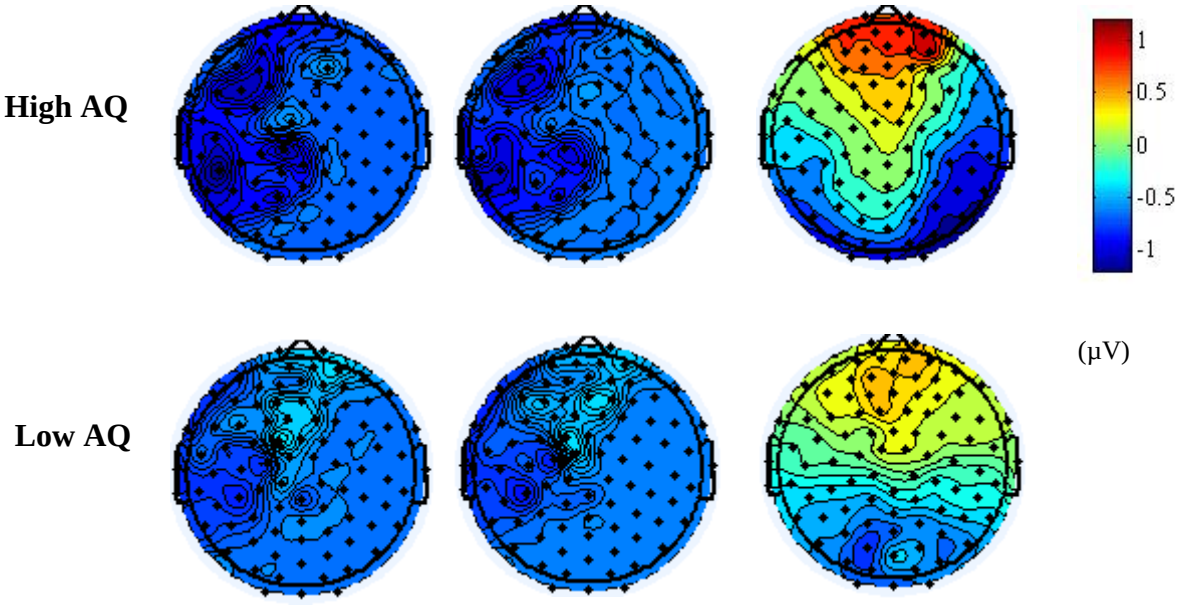


Figure 3.16 Topographic plots of the N_T showing mean amplitude across the scalp between 175 and 300 milliseconds. A scalp map displays the electrodes used to extract data.





The topographic plots display the mean amplitude across the scalp during the 180-300 millisecond N_T time window; contralateral to the target; ipsilateral to the target and the difference (contralateral minus ipsilateral). The contralateral plots show more negativity than the ipsilateral plots and this is reflected in negativity in the difference (contralateral minus ipsilateral) plots. The N_T negativity appears much more pronounced in those with high levels of autistic traits but there was no significant amplitude difference between groups.

ERP Amplitude and Visual Search Efficiency

In order to establish whether N2pc amplitude predicted visual search efficiency. linear regressions were conducted with the (RT x set size) slope value for absent or present trials entered as the dependent variable and ERP amplitude as the independent variable. The analyses indicated that N2pc amplitude did not significantly predict visual search efficiency in absent R^2 = .02, F(1, 25) = .43, p = .52, or present, R^2 = .01, F(1, 25) = .29, p = .60 trials. There was also no significant relationship between P_D amplitude and absent R^2 = .04, F(1, 25) = .00, p = .95 or present R^2 = .03, F(1, 25) = .24, p = .63, trials. And no significant relationship between N_T amplitude and efficiency in absent R^2 = .04, F(1, 25) = .20, p = .66, or present R^2 = .04, F(1, 25) = .05, p = .83 trials.

ERP Latency and Autistic Traits

The method of calculating latency values is described in the method section of Chapter 2 (Page 29).

An independent-measures T-Test conducted separably for each ERP component, with a between factor of AQ group revealed no significant difference in the onset of

the N2pc, t (25) = .32, p = .75, d = 0.1, as shown in Figure 3.6. As shown in Figures 3.6 and 3.12, onset latency did not differ between groups for the P_D, t (25) = 1.6, p = .12, d = 0.6, or the N_T, t (25) = 1.2, p = .24, d = 0.5.

Table 3.3 Mean and standard deviation for onset latency shown for the N2pc, P_D and N_T and both AQ groups

Onset Latency (ms)	N2pc		P_D		N_T	
	Mean	S.D	Mean	S.D	Mean	S.D
High AQ	268.4	9.5	252.6	6.1	266.32	6.9
Low AQ	267.4	5.6	248.6	5.6	269.9	7.8

Additional ERP Analyses

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

P1 Amplitude and Autistic Traits

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 (25) = .23, p = .82, d = .08, P_D trials t (25) = .70, p = .49, d = 0.3, or N_T trials t (25) = 2.0, p = .06, d = 0.8.

SPCN Amplitude and Autistic Traits

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, 25) = 11.8, p = .002, ηp^2= .32 and N_T trials, F (1, 25) = 11.6, p = .002, ηp^2= .32, showing a clear SPCN in these data. This did not interact with AQ group F (1, 25) = .08, p = .79, ηp^2= .00in N2pc or N_T trials F (1, 25) = .10, p = .75, ηp^2= .00, 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, 25) = .52, p = .48, ηp^2= .02, which is consistent with expectations as we would not expect to see an SPCN in response to distractors.

There was no main effect of group for N2pc, F (1, 25) = 2.1, p = .20, ηp^2= .08, P_D, F (1, 25) = 2.7, p = .11, ηp^2= .10, or N_T trials, F (1, 25) = 3.7, p = .08, ηp^2= .11, indicating that absolute amplitude within the SPCN time-window, which broadly corresponds to the P3 time window (Robitaille et al., 2007), did not differ between the two groups for N2pc, P_D or N_T trials.

Congruency

An additional analysis was conducted to assess whether the congruency of orientation had an effect on reaction times or the amplitude of the N2pc. Congruent trials were defined as those where the two coloured T's were the same *orientation* and incongruent trials where the T's were in opposing orientations.

Accuracy

A repeated-measures ANOVA (2x2) with a between-subjects factor of AQ group revealed that participants were less accurate in congruent trials, F (1, 35) = 29.7, p = <.001, ηp^2= .46. The interaction between display size and AQ group was not significant F (1, 35) = 2.9, p = .10, η^2_P = .08. Finally, the test revealed no main effect of AQ group on accuracy F (1, 35) = .03, p = .86, η^2_P = .00.

Reaction time

Reaction times three standard deviations above and below the mean for each individual were discarded; this resulted in the removal of zero data points for any participant or congruency condition. Median (correct) reaction time data for congruent and incongruent trials were entered into a repeated-measures (2x2) ANOVA with a between-subjects factor of AQ group. As expected the reaction times were significantly slower in incongruent trials compared to congruent trials F (1, 35) = 168.2, p = <.001, ηp^2= .83. However, there was no significant two-way interaction between AQ group and congruency F (1, 35) = .33, p = .96, ηp^2= .00. And there was no main effect of AQ group on reaction time F (1, 35) = .04, p = .85, η^2_P = .00.

N2pc Amplitude

N2pc amplitude for congruent and incongruent trials was entered into a 2x2 repeated-measures ANOVA with a between factor of AQ group. This revealed no significant difference in N2pc amplitude between congruent and incongruent trials F (1, 25) = .03, p = .87, η^2_P = .00. There was also no significant interaction between congruency and AQ group F (1, 35) = 2.1, p = .16, ηp^2= .06. Finally, there was no significant main effect of AQ group on congruency F (1, 25) = 2.8, p = .12, ηp^2= 0.1.

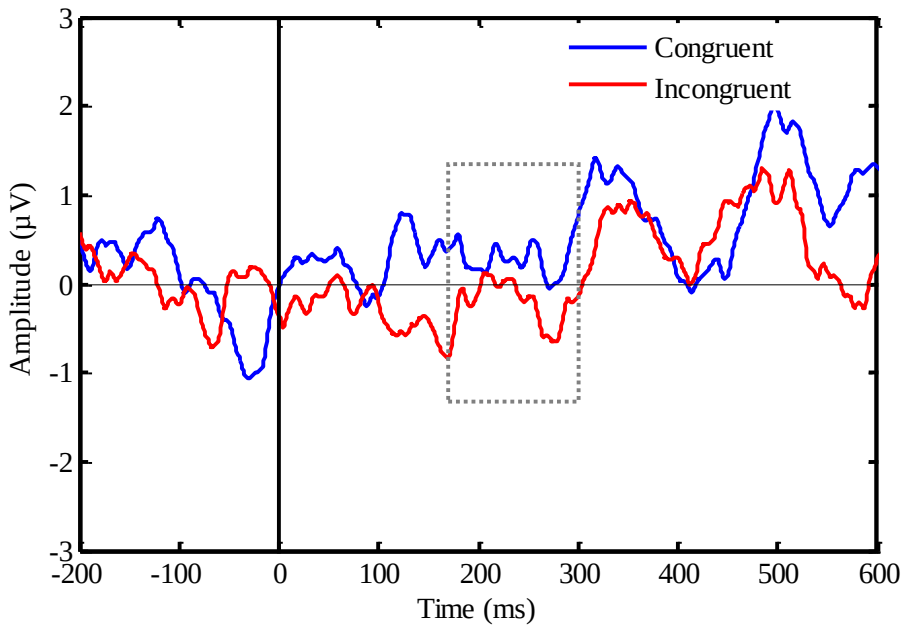
P_D Amplitude

P_D amplitude for congruent and incongruent trials was entered into a 2x2 repeated-measures ANOVA with a between factor of AQ group. This revealed no significant difference in P_D amplitude between congruent and incongruent trials F (1, 25) = .34, p = .57, η^2_P = .02. There was also no significant interaction between congruency and AQ group F (1, 25) = .01, p = .94, ηp^2= .00. Finally, there was no significant main effect of AQ group on congruency F (1, 25) = 3.3, p = .08, ηp^2= .12.

N_T Amplitude

N_T amplitude for congruent and incongruent trials was entered into a 2x2 repeated-measures ANOVA with a between factor of AQ group. This revealed a significant difference in N_T amplitude between congruent and incongruent trials F (1, 25) = 9.7, p = .006, η^2_P = .34, as shown In Figure 3.15, incongruent trials were associated with a larger N_T. There was no significant interaction between congruency and AQ group F (1, 25) = .1.7, p = .21, ηp^2= .08. Finally, there was no significant main effect of AQ group on congruency, F (1, 25) = .00, p = .99, ηp^2= 00.

Figure 3.17 Displays the difference wave (contralateral minus ipsilateral) for both congruent and incongruent conditions. In the N_T time window (highlighted), the signal was more negative for trials where the orientation of the target and distracter were incongruent.



Discussion

The aims of this chapter were to measure visual search in those with high and low levels of autistic traits, using a slightly altered visual search task; to investigate whether the finding of a large N2pc amplitude in those with high levels of autistic traits can be replicated and to probe this effect further by measuring the N_T and P_D and comparing amplitude between those with high levels of autistic traits

Similarly to Chapter three, the present study found no difference in visual search efficiency between those with high and low levels of autistic traits, in neither target present or absent trials. In addition, there was no difference in N2pc, P_D or N_T amplitude between those with high and low levels of autistic traits. Finally, ERP amplitude was not related to visual search efficiency.

Though previous literature tells a strong story of enhanced visuo-spatial abilities in autism, there are few behavioural studies so far that have replicated this effect in the broader autism phenotype. In this study, the similarity in search slopes between the AQ groups suggests that the visual search task was not revealing any

difference in the deployment of attention between those with high and low levels of autistic traits. Though a recent study extended the visual search advantage to those with high levels of autistic traits using the same task as that used in the present study (Milne, Dunn, Freeth & Rosas-Martinez, 2013), the present data cannot support the conclusion that those with high AQ scores show enhanced visual search performance compared to those with low AQ scores. It is unclear why the task used has not replicated the results from Milne et al., (2013) given that the same task, procedure and a similar sample were used. In the previous chapter it was suggested that crowding of letters in Milne et al., (2013) could have resulted in more interference in the attentional lens and more difficulty when the participants' were identifying a target, when compared to the task used in Chapter 2. This possibility was tested directly in a follow-up study where participants were presented with arrays from both visual search tasks in the same block of trials. The study found that the visual search task in Chapter 2, with the wider visual angle, was in fact more difficult than the task used by Milne et al., (2013) and in the present Chapter. More details are given in appendix A (Page 123).

In support of study one, the results also revealed no significant relationship between N2pc amplitude and visual search efficiency. Thus the data so far suggests that N2pc indices do not predict visual search efficiency and this is in line with Eimer (1996) who suggests that the N2pc reflects target selection.

N2pc amplitude did not differ between those with high and low levels of autistic traits in the present study, nor did the amplitude of the P_D, perhaps a result of the reduced number of trials presented. Though as predicted, those with high levels of autistic traits did not differ from those with fewer autistic traits in the amplitude of the N_T. Additional ERP analyses also found no relationship between the P1 or SPCN and AQ group. The SPCN is enhanced negativity contralateral to a target and is thought to reflect working memory maintenance and representations (Eimer & Kiss, 2010). Therefore, as expected, the SPCN was not elicited in trials where the lateral latter was a distracter. An unexpected finding was a significant difference between the contralateral and ipsilateral signal during the P1 time window, in N_T trials. This could be capturing the N1 (140-200 ms) which we could expect to be enhanced contralateral to a target when presented with an irrelevant distracter (Eimer, 1994).

Eimer (1994) suggests that this may reflect a sensory gating mechanism, preventing the overload of unnecessary information.

The congruency analysis once again revealed slower reaction times in incongruent trials and no relationship between congruency and N2pc amplitude or any relationship with AQ group. In addition there was no difference in P_D amplitude associated with congruency, nor any relationship with AQ group. The analysis did reveal that the N_T was larger for incongruent trials; however this did not differ between groups. A larger N_T for incongruent trials is consistent with previous work, showing a greater negativity for incongruent trials for the N2 (Clayson & Larson, 2011; Groom & Cragg, 2015).

Though this study found no difference in N2pc or P_D amplitude between those with high and low levels of autistic traits; both results showed a tantalising trend. It seems there were not enough trials in the present study to be confident about the data. Therefore, the study will be replicated with a significant increase in the number of trials.

Chapter 4 : Electrophysiological evidence for reduced selectivity in those with high levels of autistic traits compared to those with low levels of autistic traits

Introduction

The first study of this thesis presented electrophysiological data demonstrating that ERP indices of spatial attention differ in those with high levels of autistic traits when compared to those with low levels of autistic traits. Study one showed that the amplitude of the N2pc was significantly larger in those with high levels of autistic traits, with an effect size of 0.2 (ηp^2). Study two was not significant with an effect size of 0.1. Guidelines for interpreting partial eta-squared values are: 0.01 = small effect, 0.09 = medium and 0.25 = large (See Cohen, 1988). In addition, study two investigated this finding by measuring the amplitude of the two subcomponents of the N2pc which reflect distracter and target processing; the P_D and N_T (Hickey et al., 2009). This revealed that P_D amplitude did not differ in those with high levels of autistic traits (ηp^2= .12), nor did the amplitude of the N_T (ηp^2= 0).

The present study sought to strengthen the paradigm employed in study two by once again measuring the amplitude of the N2pc, P_D and N_T with a different sample and significantly more trials.

It was predicted that N2pc amplitude would be larger in individuals scoring higher on the AQ when compared to low scoring individuals. It was predicted that those with high levels of autistic traits would show an attenuated P_D, reflecting reduced suppression of distracters. In addition, the N_T was predicted to be similar between high and low AQ groups. . Finally, based on the previous literature a group difference in visual search performance could be expected, but based on the first and second study in this thesis, there may not be a difference in visual search performance between those with high and low levels of autistic traits.

Experiment Three: Is reduced selectivity in those with high levels of autistic traits compared to those with low levels of autistic traits a consistent and reliable finding?

Participants

To recruit participants for this study a new AQ distribution was obtained. All first year students were invited to complete the AQ online. As it was the beginning of a new academic year, the database recruited for experiment three was composed of an entirely different cohort of students than the database recruited for experiment one. 864 participants completed the AQ; the mean score was 18.6 with a range of 1 - 45. None of the participants recruited for this study had participated in any previous studies. 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. Twenty-one of these were high AQ scorers (AQ $\geq$28) and twenty-four were low AQ scorers (AQ $\leq$11). All participants had normal or corrected to normal vision and were aged between 18 and 31 years old. The sample consisted of 30 females and 15 males with 17 female and 7 male low AQ scorers; 13 female and 8 male high AQ scorers.

Methodology

Stimuli and Procedure

Stimuli and presentation were the same as in Chapter 3; however there was a significant increase in the number of trials, with 1728 trials presented. All stimuli were presented with the same procedure as described in Chapter 2 (Page 25).

Spatial Attention Task

There were 576 trials where a target appeared laterally and 576 trials where a distracter appeared laterally (Hickey et al., 2009). There were also 576 trials with letter Ts in opposing lateralised positions (Luck et al., 1997).

Visual Search Task

The visual search task used in this study was the same as in Chapter Three.

Procedure

The participants began with the P_D/N_T trials which were mixed into the same blocks. This was followed by the N2pc trials in a separate set of blocks, finally followed by the visual search task.

Spatial Attention Task

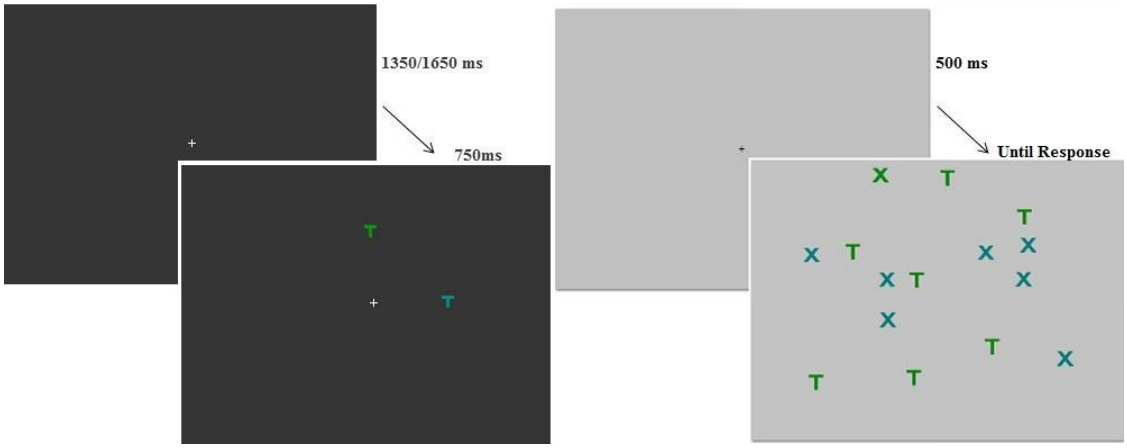
The procedure for this task was the same as in Chapter Four. However participants were required to respond with their dominant hand only as in Luck et al., (1997). The participants used their index finger to indicate that the target T was upright and the middle finger was used to indicate that the target T was inverted.

Visual Search Task

The procedure for this task was the same as in study one.

Figure 4.1 a&b Stimulus organisation and presentation for both tasks. The target in the spatial attention task was defined by colour in each block. In the visual search task the target was always a green X.

Figure 4.1a Spatial attention task stimuli **Figure 4.1b** Visual search task stimuli



The spatial attention task (5.1a) used to elicit ERPs was a replication of Luck et al., (1997) with two equiluminant letter Ts in opposing lateral positions (N2pc) or with one letter on the vertical meridian (P_D, N_T). Fixation was a white cross, displayed for 1350 or 1650 milliseconds, followed by a stimulus display for 750ms.. The visual search task (5.1b) was a replication of Plaisted et al., (1998), previously used in Chapter 3, with equiluminant green Ts and blue Xs as distracters and a green X as the target. Fixation appeared for 500ms, followed by a display of 5, 15 or 25 letters which could have the target present or absent. The stimuli display would remain until participant response.

Data Processing and Analysis

Power Analysis

Power analysis for a two-way ANOVA with 2 groups was conducted in G*Power to determine a sufficient sample size using an alpha of 0.05, a power of 0.95, and a medium effect size based on study one (f = 0.27), (Faul et al., 2013). Based on the aforementioned assumptions, the desired sample size is 32.

ERP Data Pre-Processing

The EEG system and data pre-processing was the same as detailed in Chapter 2. The N2pc, P_D and N_T were quantified in the same way as in Chapter 2 and 3.

Data Exclusion

Whole ERP datasets were excluded if there were less than 150 trials contributing to the contralateral or ipsilateral signal of any ERP component, resulting in the exclusion of 9 datasets. This resulted in a final sample of 36 for ERP analyses with 17 high AQ scorers (6 male, 11 female) and 19 low AQ scorers (4 male, 15 female). The high AQ group had a mean AQ score of 30 (sd = 3.9, range = 28-40) the low AQ group had a mean AQ score of 8.6 (sd = 2.1, range = 5-11).

Behavioural visual search data from 1 participant was lost, however this participant was retained in all N2pc analyses. For visual search analyses this left a sample of 42 with 17 high AQ scorers (6 male) and 18 low AQ scorers (4 male). No data were excluded from analysis of behavioural performance in the spatial attention task.

As described in Chapter 2 (Page 29), two ERP waveforms were computed, reflecting the signal contralateral and ipsilateral to the target.

N2pc Trials

Only trials where there were two opposing lateral letter Ts were used to extract N2pc data. The mean number of trials used to calculate the contralateral and ipsilateral ERPs was 202 and 200 respectively with no difference in the number of trials used between high and low AQ scorers for contralateral t (34) = .74, p = .47, d = 0.2, or ipsilateral t (34) = .74, p = .46, d = 0.2 waveforms.

P_D Trials

Only trials where there were there was a lateral distracter and a target on the vertical meridian were used to extract P_D data. The mean number of trials used to calculate the contralateral and ipsilateral ERPs was 161 and 164 respectively with no difference in the number of trials used between high and low AQ scorers for contralateral t (34) = .54, p = .59, d = 0.2, or ipsilateral t (34) = .52, p = .61, d = 0.2 waveforms.

N_T Trials

Only trials where there were there was a lateral target and a distracter on the vertical meridian were used to extract N_T data. The mean number of trials used to calculate the contralateral and ipsilateral ERPs was 167 and 159 respectively with no difference in the number of trials used between high and low AQ scorers for contralateral t (34) = .67, p = .51, d = 0.2, or ipsilateral t (34) = .92, p = .42, d = 0.3 waveforms. Information about final usable trials for all ERPS is shown in table 4.1.

Table 4.1 Mean and range of usable trials for each ERP component, following data exclusion

		Mean	Minimum	Maximum
	P_D	371	300	493
	N_T	376	303	493
	N2pc	402	303	530
High AQ	P_D	385	304	450
	N_T	366	303	493
	N2pc	416	306	500
Low AQ	P_D	365	300	493
	N_T	388	304	459
	N2pc	388	303	530

Results

Behavioural Results

Spatial Attention Task Accuracy and Reaction Time

Mean accuracy in the spatial attention task (83%, s.d = 5.4) was high and did not vary significantly between high and low AQ scorers, t (1, 43) = .77, p = .45, d = 0.2, similarly median correct-trial reaction times did not differ between high and low AQ scorers, t (1, 43) = .35, p = .73, d = 0.1. Both analyses were conducted only for participants who were included in final ERP analyses and no differences were found between groups for accuracy, t (1, 34) = 1.0, p = .32, d = 0.3, or median reaction time, t (1, 34) = .06, p = .95, d = 0.0.

Table 4.2 Mean and standard deviation for accuracy and reaction time data for the spatial attention task

	Accuracy %		Median RT (ms)	
	High AQ (N=20)	**Low AQ (N=17)**	**High AQ**	**Low AQ**
Mean	83.7	82.5	506.9	503.6
SD	6.1	4.7	31.6	32.0

Visual Search Accuracy

Mean accuracy in visual search (90%, s.d = 5.7) was high. A repeated-measures ANOVA (2x3x2) with a between-subjects factor of AQ group revealed a significant difference in accuracy between different set sizes, F (2, 84) = 31.5, p = <.001, ηp^2= .43 but no significant difference between target absent and present trials, F (1, 42) = 1.9, p = .17, ηp^2= .04. There was no significant two-way interaction between display size and target presence, F (2, 84) = .01, p = .92, ηp^2= 0, additionally, the two-way interactions between display size and AQ group, F (2, 84) = 1.8, p = .19, ηp^2= .04 and target presence and AQ group, F (1, 42) = .01, p = .94, ηp^2= 0, were not significant. Finally, the test revealed no main effect of AQ group on accuracy, F (1, 42) = .20, p = .67, ηp^2= .01. This suggests that accuracy decreased as

set size increased, as shown in figure 4.2. However there was no effect of any other variables on accuracy in the visual search task.

Figure 4.2 a&b Accuracy plots for present **(a)** and absent **(b)** trials, 3 set sizes and 2 AQ groups with standard error bars (+/-1). The maximum accuracy for each variable was 20.

Figure 4.2a Target Present Trials

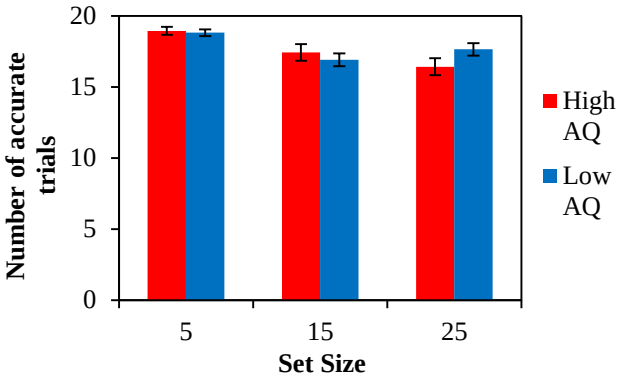
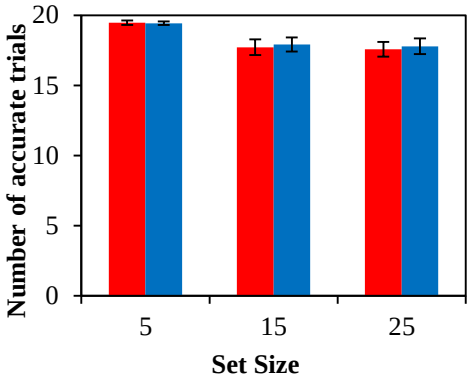


Figure 4.2b Target Absent Trials



Visual Search Reaction Time

Reaction times three standard deviations above and below each participants individual mean were discarded; this resulted in the removal no data points. Mean reaction time data for each display size and target present and absent trials were entered into a mixed-measures (3x2x2) ANOVA with a between-subjects factor of AQ group. As expected the reaction times were significantly slower in absent trials compared to present trials, F (1, 42) = 10.1, p = .002, ηp^2= .20. As shown in Figure 4.3 there was a highly significant effect of increasing set size on reaction time, F (2, 84) = 111.3, p = <.001, ηp^2= .73 and there was a significant two-way interaction between set size and target presence, F (2, 84) = 3.3, p = .04, ηp^2= .07. There was no significant two-way interaction between AQ group and set size, F (2, 84) = .15, p = .86, ηp^2= 0 or between AQ group and target presence, F (1, 42) = 1.1, p = .31, ηp^2= .03. There was no significant three way interaction between display size, target presence and AQ group, F (2, 84) = 1.9, p = .16, ηp^2= .04. Finally, there was no significant main effect of AQ group on visual search reaction time, F (1, 42) = .17, p = .69, ηp^2= 0.

Figure 4.3 a&b Graphs showing the mean visual search scores for both target absent and target present trials and both AQ groups, error bars display the standard error (+/-1).

Figure 4.3a – Target Present Trials

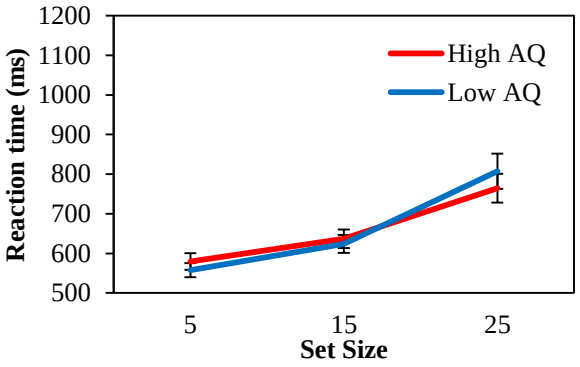
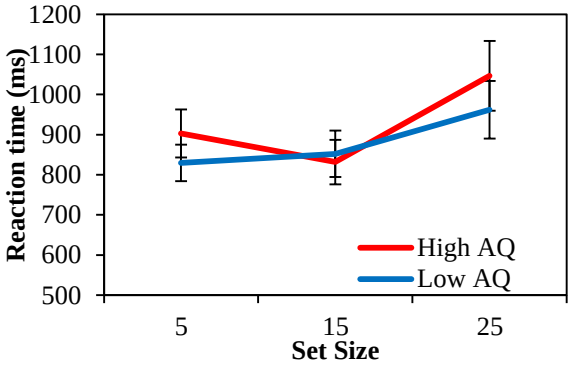


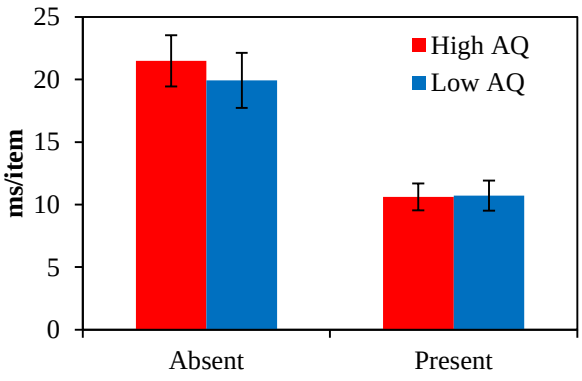
Figure 4.3b – Target Absent Trials



Visual Search Efficiency

As expected, slopes were significantly steeper when a target was absent than when the target was present, F (1, 42) = 85.0, p = <.001, ηp^2= .67. A two-way ANOVA showed that there was no significant interaction between AQ group and search efficiency F (1, 42) = 69, p = .41, ηp^2= .02, confirming the results from the ANOVA reported above. Therefore both groups were equally influenced by an increase in set size across both present and absent conditions (See Figure 4.4).

Figure 4.4 Graph showing the mean RT x set size slope for both target present and absent trials and both AQ groups. Standard error bars are displayed (+/-1).



Event Related Potentials

N2pc Amplitude and Autistic Traits

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. A highly significant interaction between contralateral and ipsilateral signal confirmed the presence of a reliable N2pc, F (1, 34) = 19.7, p = <.001, ηp^2 = 0.58 (See Figure 4.5). 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. Furthermore, there was no main effect of group F (1, 34) = 1.9, p = .17, ηp^2= .05, indicating that absolute amplitude within the N2pc time window did not differ between groups. In Figure 4.6, ERPs ipsilateral and contralateral to the appearance of a target are shown separately for high and low AQ scorers. Figure 4.7 shows the difference wave where a larger N2pc amplitude is evident in the high AQ scorers and Figure 4.8 demonstrates topographical distribution in the N2pc time range.

Figure 4.5 Grand average ERP, for all participants, showing data extracted from 4 pairs of electrodes (P3/4, P7/8, P07/08. T3/4). The N2pc is evident in the diversion between the contralateral and ipsilateral signal between 200 and 300 milliseconds.

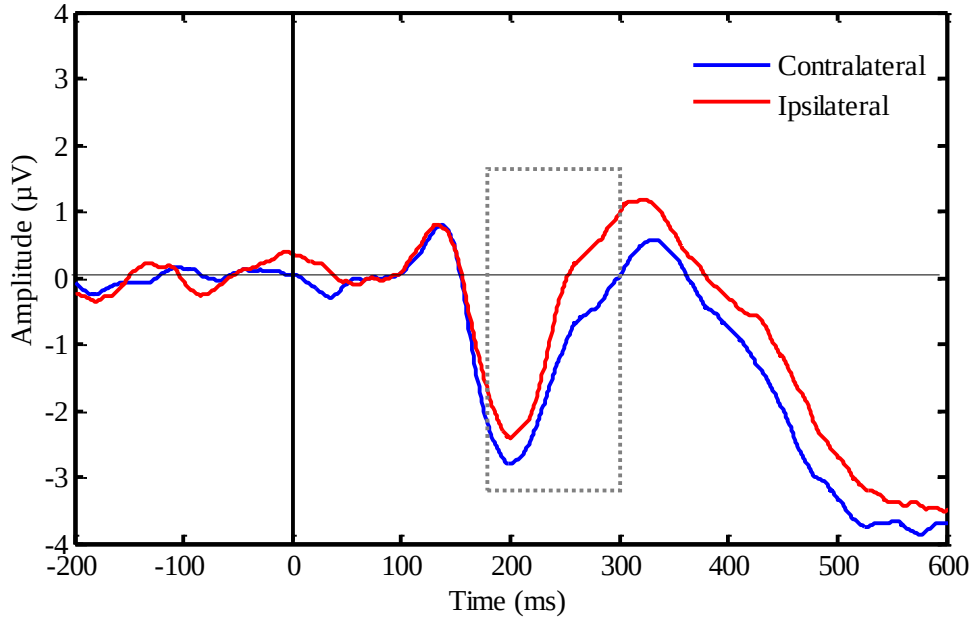


Figure 4.6 Grand average ERPs shown separately for high and low AQ scorers showing data extracted from 4 pairs of electrodes (P3/4, P7/8, P07/08. T3/4). The N2pc is evident in the diversion between the contralateral and ipsilateral signal between 200 and 300 milliseconds.

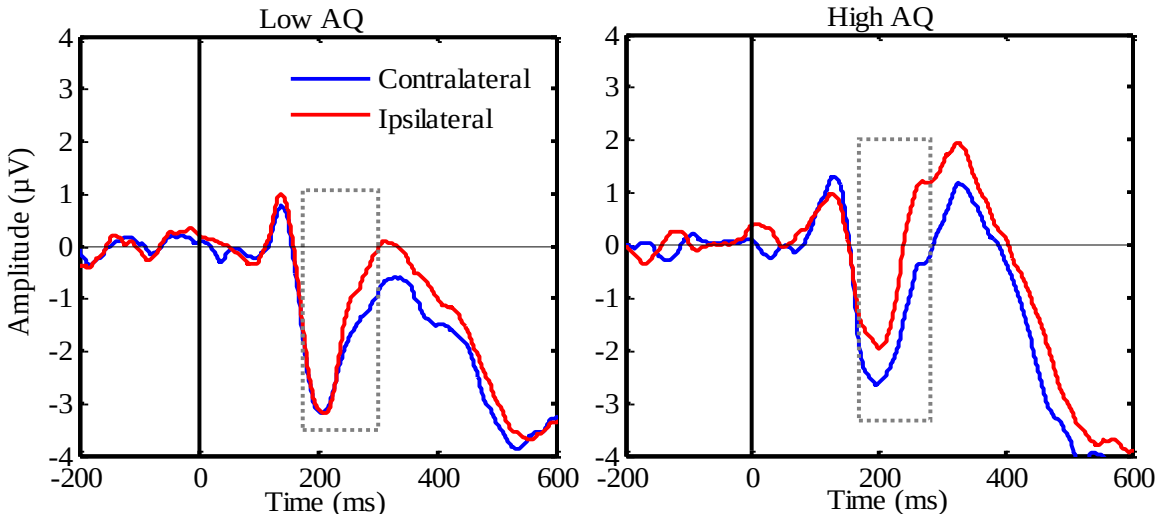


Figure 4.7 N2pc difference waves (contralateral minus ipsilateral) for high and low AQ groups. The N2pc is the negative going signal between 200 and 300 milliseconds.

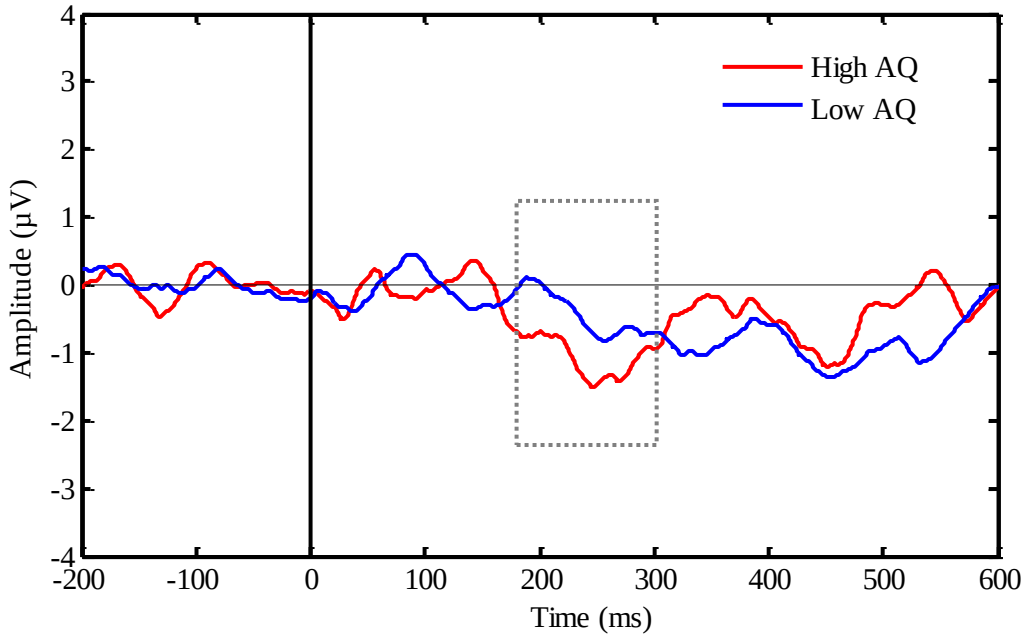
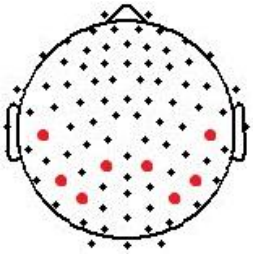
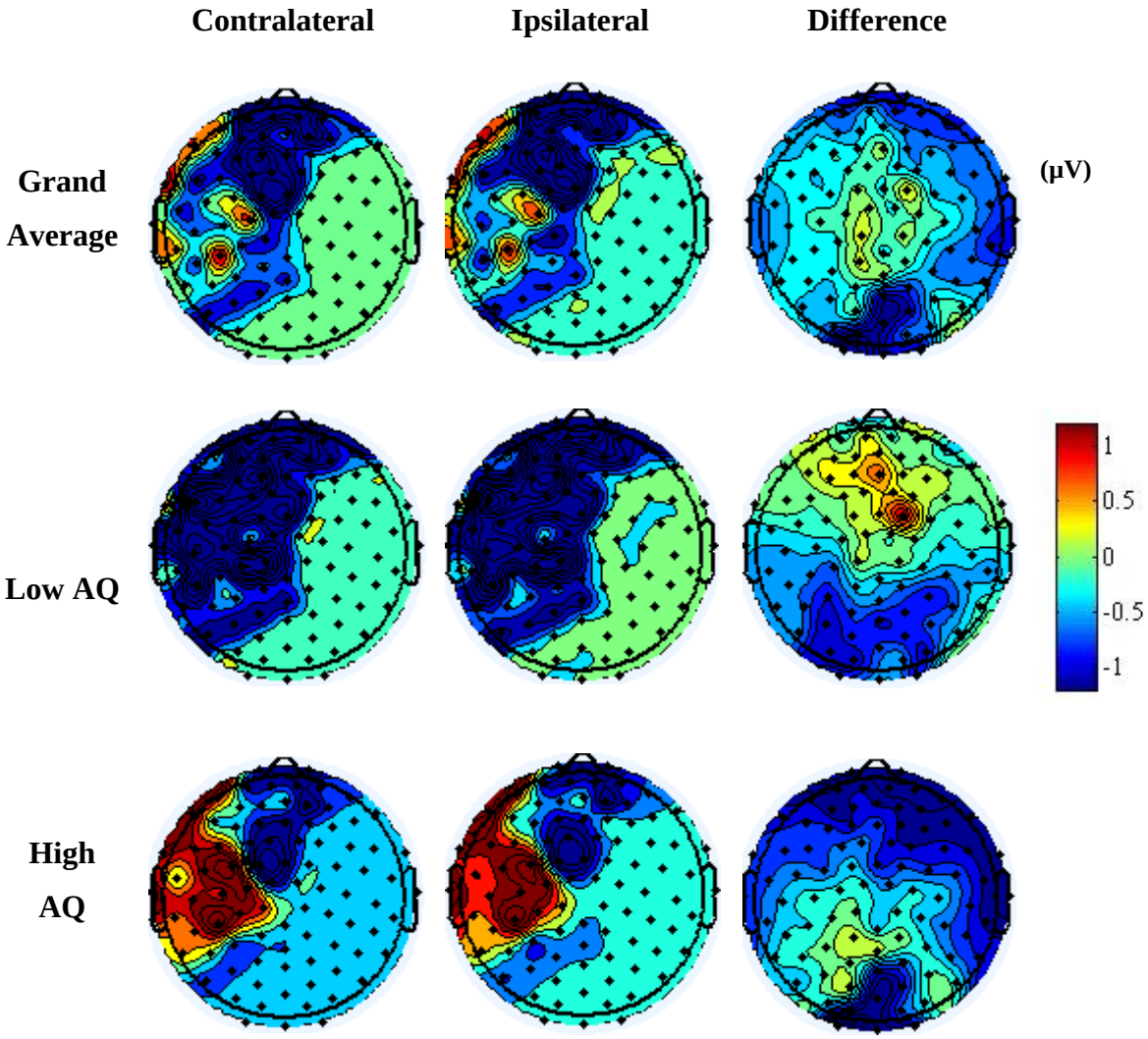


Figure 4.8 Topographic plots of the N2pc showing mean amplitude across the scalp between 200 and 300 milliseconds. A scalp map displays the electrodes used to extract data.



N2PC (200 - 300ms)



The topographic plots display the mean amplitude across the scalp during the 180-300 millisecond N2pc time window; contralateral to the target; ipsilateral to the target and the difference (contralateral minus ipsilateral). The contralateral plots show more negativity than the ipsilateral plots and this is reflected in negativity in the difference (contralateral minus ipsilateral) plots. There was a significant difference in N2pc amplitude between groups and though both groups appear to show an occipital-

parietal source, those with high levels of autistic traits also show a large negativity over temporal sites.

Distracter Suppression and Autistic Traits

P_D amplitude was investigated by way of 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. Figure 4.9 shows the ERPs obtained from contralateral and ipsilateral sites relative to the appearance of the target. A highly significant main effect of laterality confirmed the presence of a reliable P_D, F (1, 34) = 7.2, p = .01, ηp^2= .17. In Figure 4.10, ERP waveforms are shown separately for high and low AQ scorers. A significant interaction between laterality and AQ group suggested a significant difference in P_D amplitude between those with high and low levels of autistic traits, F (1, 34) = 5.7, p = .02, ηp^2= .15 (see Figure 4.11). Paired sample t-tests revealed that the difference between ipsilateral and contralateral signal was significant for the low AQ group t(18) = 3.9, p = .001, d = 0.2, however it was not significant for the high AQ group, t(16) = .43, p = .67, d = 0.02. Furthermore, there was no main effect of group F (1, 34) = 2.6, p = .12, ηp^2= .07, indicating that absolute amplitude within the P_D time window did not differ between groups. Figure 4.12 displays the topographic distribution of amplitude in the P_D time window for contralateral and ipsilateral trials and the difference wave.

This analysis was also conducted at electrode sites used by Hickey et al., (2009); P07 and P08 (EGI: 66 & 85). There was no significant main effect of laterality at these electrode sites, F (1, 34) = 1.4, p = .24, ηp^2= .04. The interaction with AQ group was not significant F (1, 34) = 1.3, p = .26, ηp^2= .04. Furthermore, there was no main effect of group F (1, 34) = 1.9, p = .17, ηp^2= .05, indicating that absolute amplitude within the P_D time window did not differ between groups.

Figure 4.9 Grand average ERP, for all participants, showing data extracted from 4 pairs of electrodes (P3/4, P7/8, P07/08. T3/4). The P_D is evident in the diversion between the contralateral and ipsilateral signal between 230 and 280 milliseconds

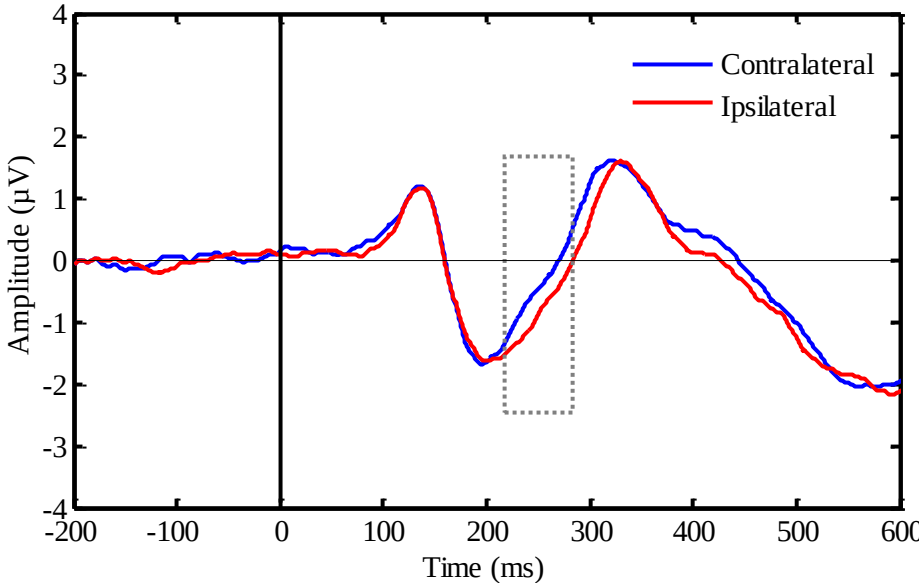


Figure 4.10 Grand average ERPs shown separately for high and low AQ scorers showing data extracted from 4 pairs of electrodes (P3/4, P7/8, P07/08. T3/4). The P_D is evident in the diversion between the contralateral and ipsilateral signal between 230 and 280 milliseconds

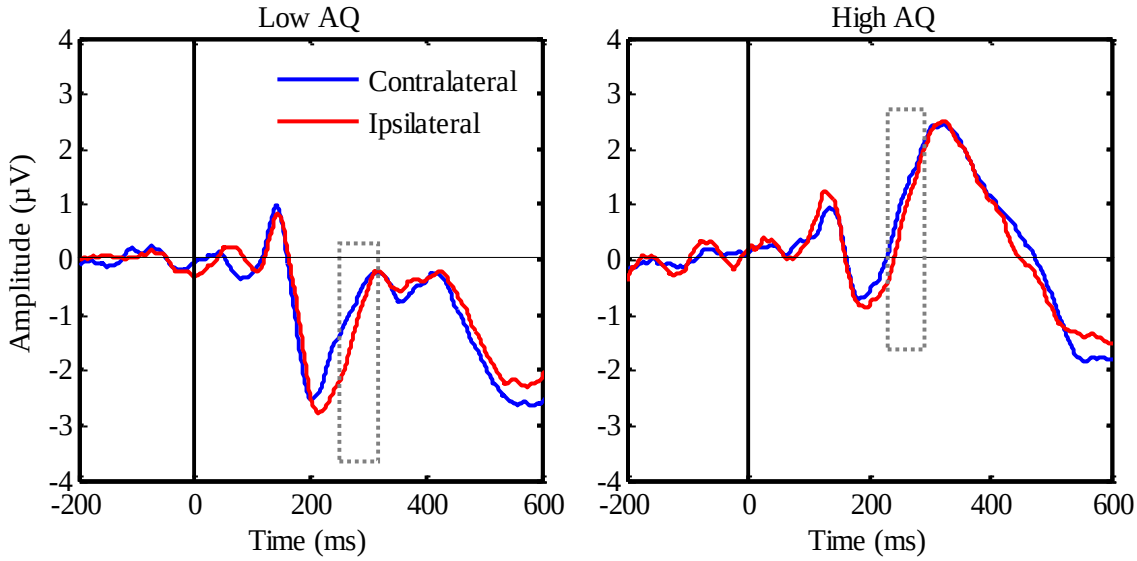


Figure 4.11 P_D difference waves (contralateral minus ipsilateral) for high and low AQ groups. The P_D is the positive going signal between 230 and 280 milliseconds.

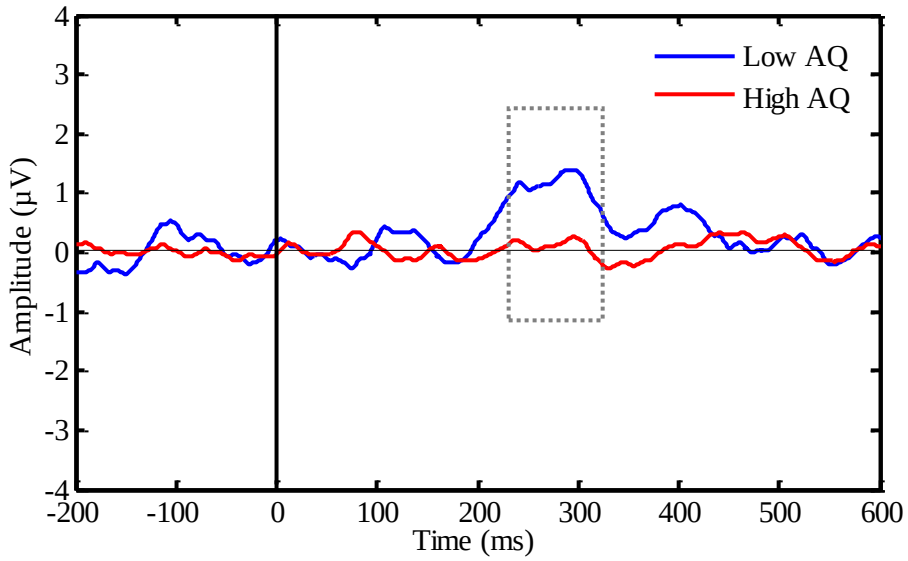
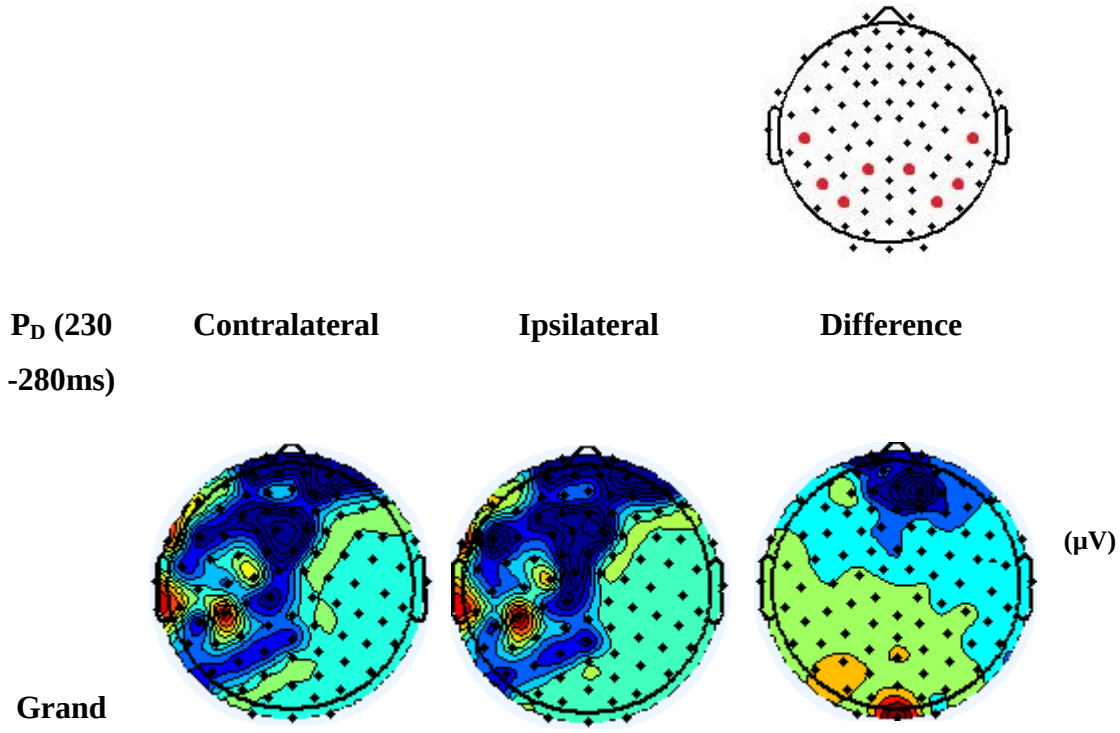
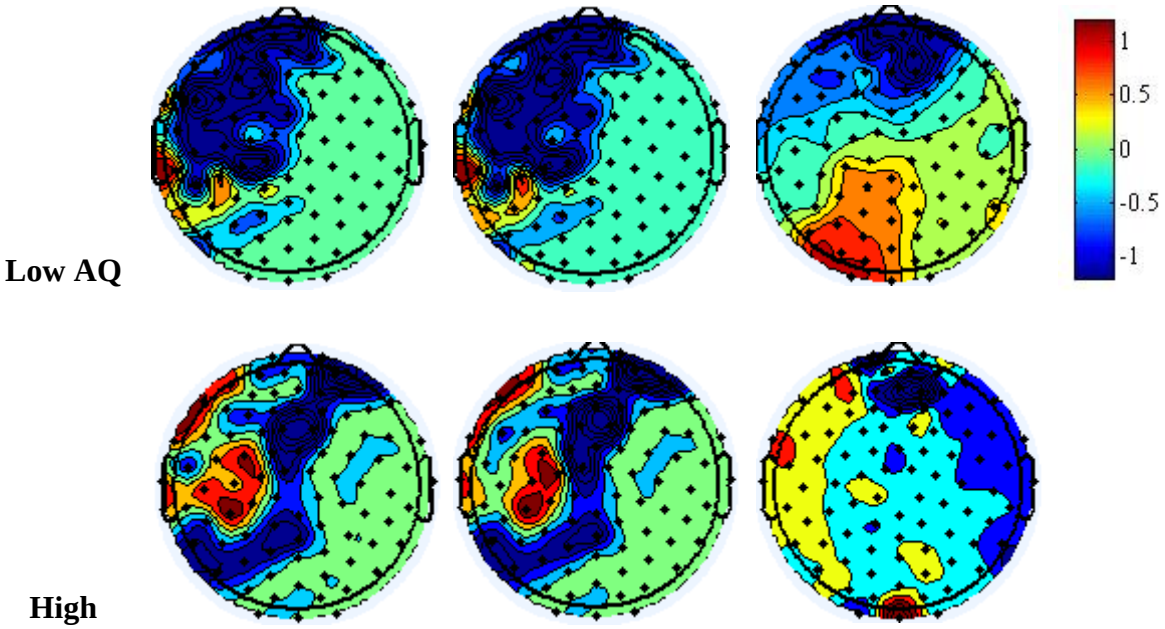


Figure 4.12 Topographic plots of the P_D showing mean amplitude across the scalp between 230 and 280 milliseconds. A scalp map displays the electrodes used to extract data.





The topographic plots display the mean amplitude across the scalp during the 230-280 millisecond P_D time window; contralateral to the target; ipsilateral to the target and the difference (contralateral minus ipsilateral). The contralateral plots are less negative than the ipsilateral plots and this is reflected in overall positivity in the difference (contralateral minus ipsilateral) plots. The P_D appears to arise from the same occipital-parietal source; however it has much more distribution across the scalp in those with low levels of autistic traits.

Target Processing and Autistic Traits

N_T amplitude was investigated by way of 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. Figure 4.13 shows the ERPs obtained from contralateral and ipsilateral sites relative to the appearance of the target. A highly significant main effect of laterality confirmed the presence of a reliable N_T, F (1, 34) = 22.1, p = <.001, ηp^2= .39. In Figure 4.14, ERP waveforms are shown separately for high and low AQ scorers. There was no significant interaction between laterality and AQ group suggesting that N_T amplitude did not differ between those with high and low levels of autistic traits, F (1, 34) = .18, p = .38, ηp^2= .01 (see Figure 4.15). Furthermore, there was no main effect of group F (1, 34) = 1.0, p = .32, ηp^2= .03, indicating that absolute amplitude within the N_T time window did not differ between groups. Figure 4.16 displays the topographic distribution of amplitude in the N_T time window for contralateral and ipsilateral trials and the difference wave.

This analysis was also conducted at electrode sites used by Hickey et al., (2009); P07 and P08 (EGI: 66 & 85). There was a significant main effect of laterality at these sites, F (1, 25) = 5.9, p = .02, ηp^2= .15 confirming the presence of an N_T. There was no significant interaction between AQ group and N_T amplitude, F (1, 25) = .47, p = .50, ηp^2= 01. Furthermore, there was no main effect of group F (1, 34) = .60, p = .45, ηp^2= .02, indicating that absolute amplitude within the N_T time window did not differ between groups.

Figure 4.13 Grand average ERP, for all participants, showing data extracted from 4 pairs of electrodes (P3/4, P7/8, P07/08. T3/4). The N_T is evident in the diversion between the contralateral and ipsilateral signal between 200 and 300 milliseconds.

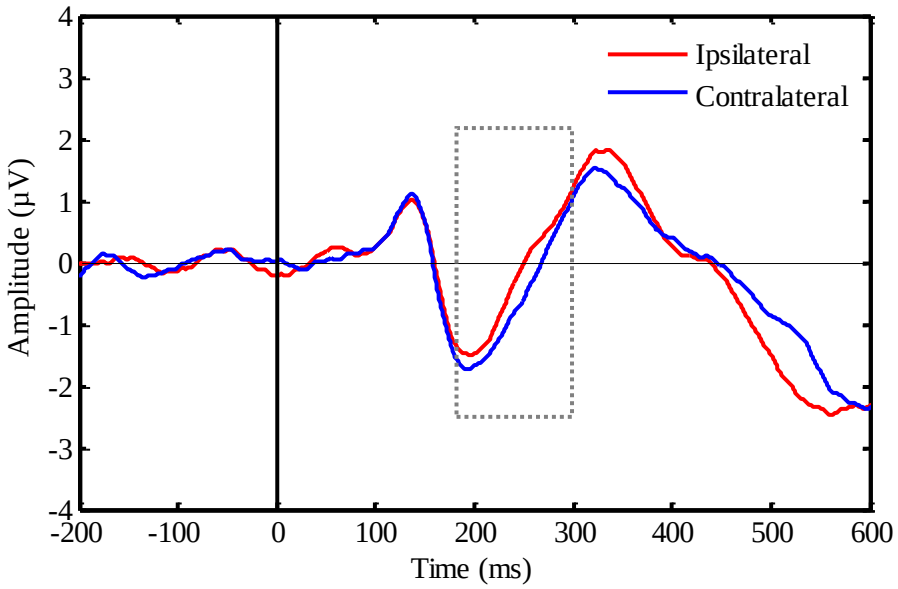


Figure 4.14 Grand average ERPs shown separately for high and low AQ scorers showing data extracted from 4 pairs of electrodes (P3/4, P7/8, P07/08. T3/4). The N_T is evident in the diversion between the contralateral and ipsilateral signal between 200 and 300 milliseconds.

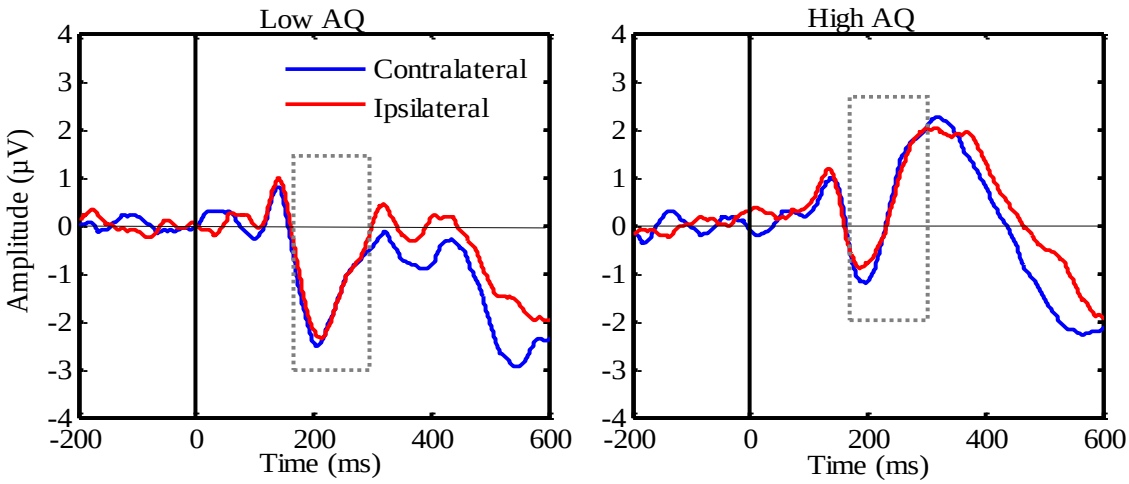


Figure 4.15 N_T difference waves (contralateral minus ipsilateral) for high and low AQ groups. The N_T is the positive going signal between 230 and 280 milliseconds.

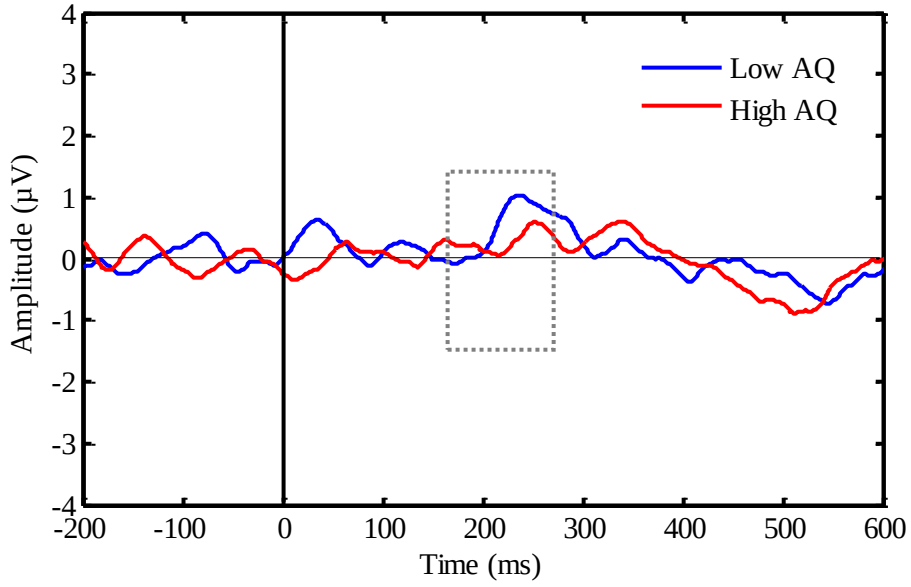
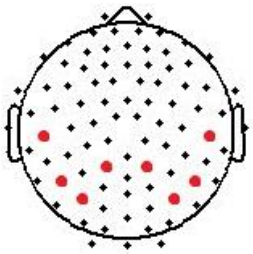


Figure 4.16 Topographic plots of the N_T showing mean amplitude across the scalp between 175 and 300 milliseconds. A scalp map displays the electrodes used to extract data.



N_T (175-325ms)	Contralateral	Ipsilateral	Difference	
Grand Average				(μV)
Low AQ				
High AQ				

The topographic plots display the mean amplitude across the scalp during the 175-300 millisecond N_T time window; contralateral to the target; ipsilateral to the target and the difference (contralateral minus ipsilateral). The contralateral plots show more negativity than the ipsilateral plots and this is reflected in negativity in the difference (contralateral minus ipsilateral) plots. The amplitude of the N_T did not differ between groups; however The N_T appears to have a temporal distribution in those with high levels of autistic traits and an occipital-parietal distribution in those with low levels of autistic traits.

ERP Amplitude and Visual Search Efficiency

In order to establish whether N2pc amplitude predicted visual search efficiency linear regressions were conducted with the (RT x set size) slope value for present or absent trials entered as the dependent variable and ERP amplitude as the independent variable. The analyses indicated that N2pc amplitude did not significantly predict visual search efficiency in absent R^2 = .03, $F(1, 34)$ = .95, p = .34, or present R^2 = .03, $F(1, 34)$ = .94, p = .34 trials. There was also no significant relationship between P_D amplitude and efficiency in absent R^2 = .00, $F(1, 34)$ = .89, p = .35 or present trials, R^2 = .04, $F(1, 34)$ = 2.5, p = .13. Finally, N_T amplitude was not significantly related with absent trial efficiency R^2 = .03, $F(1, 34)$ = .18, p = .68, or present trial efficiency R^2 = .00, $F(1, 34)$ = .27, p = .60.

ERP Latency and Autistic Traits

The method of calculating latency values is described in Chapter 2 (Page 29).

An independent-measures T-Test conducted separably for each ERP component, with a between factor of AQ group revealed no significant difference in the onset of the N2pc, t (34) = .02, p = .81, d = 0, P_D, t (34) = .10, p = .91, d = 0, or N_T, t (34) = .61, p = .60, d = 0.2.

Table 4.3 Mean and standard deviation for onset latency of the N2pc, P_D and N_T shown for both high and low AQ groups

Onset Latency (ms)	**N2pc**		**P_D**		**N_T**	
	Mean	S.D	Mean	S.D	Mean	S.D
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

Additional ERP analyses

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

P1 Amplitude and Autistic Traits

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 and Autistic Traits

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.

There was no main effect of group for N2pc, F (1, 20) = .95, p = .34, ηp^2= .03, P_D, F (1, 20) = .26, p = .62, ηp^2= .01, or N_T trials, F (1, 20) = .86, p = .36, ηp^2= .03, indicating that absolute amplitude within the SPCN time-window, which broadly corresponds to the P3 time window (Robitaille, Jolicœur, Dell'Acqua, & Sessa, 2007), did not differ between the two groups for N2pc, P_D or N_T trials.

Congruency

An additional analysis was conducted to assess whether the congruency of orientation had an effect on reaction times or the amplitude of the ERP. Congruent trials were defined as those where the two coloured T's were the same *orientation* and incongruent trials where the T's were in opposing orientations.

Accuracy

A repeated-measures ANOVA (2x2) with a between-subjects factor of AQ group revealed that participants were less accurate in congruent trials, F (1, 39) = 27.3, p = <.001, ηp^2= .41. This finding is consistent with study two. The interaction between congruency and AQ group was not significant F (1, 39) = 5.5, p = .08, η^2_P =

0. Finally, the test revealed no main effect of AQ group on accuracy F (1, 39) = .02, p = .90, η^2_P = 0.

Reaction Time

Median (correct) reaction time data for congruent and incongruent trials were entered into a repeated-measures (2x2) ANOVA with a between-subjects factor of AQ group. As expected the reaction times were significantly slower in incongruent trials compared to congruent trials F (1, 39) = 52.2, p = <.001, ηp^2= .57. However, there was no significant two-way interaction between AQ group and congruency F (1, 39) = 3.4, p = .07, ηp^2= .08. And there was no main effect of AQ group on reaction time F (1, 39) = .01, p = .93, η^2_P = 0.

N2pc Amplitude

N2pc amplitude for congruent and incongruent trials was entered into a 2x2 repeated-measures ANOVA with a between factor of AQ group. This revealed a significant difference in N2pc amplitude between congruent and incongruent trials F (1, 34) = 4.5, p = .04, η^2_P = .13, where incongruent trials elicited a larger N2pc. There was no significant interaction between congruency and AQ group F (1, 34) = .16, p = .69, ηp^2= .01. Finally, there was a significant main effect of AQ group on congruency F (1, 34) = 9.1, p = .005, ηp^2= .21, reflecting the larger N2pc amplitude in those with high levels of autistic traits.

P_D Amplitude

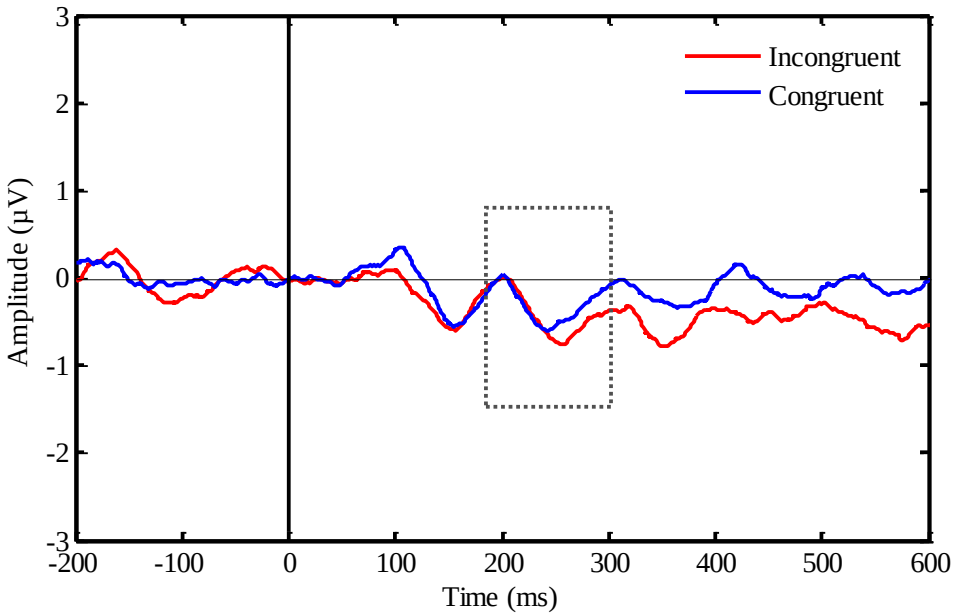
P_D amplitude for congruent and incongruent trials was entered into a 2x2 repeated-measures ANOVA with a between factor of AQ group. This revealed no significant difference in P_D amplitude between congruent and incongruent trials F (1, 34) = .80, p = .38, η^2_P = .02. There was also no significant interaction between congruency and AQ group F (1, 34) = .01, p = .94, ηp^2= 0. Finally, there was a significant main effect of AQ group on congruency F (1, 34) = 5.7, p = .02, ηp^2= .15 reflecting the P_D result presented above.

N_T Amplitude

N_T amplitude for congruent and incongruent trials was entered into a 2x2 repeated-measures ANOVA with a between factor of AQ group. As shown in Figure 5.17, this revealed a significant difference in N_T amplitude between congruent and incongruent trials F (1, 34) = 4.4, p = .04, η^2_P = .13, where incongruent trials were

associated with a larger N_T. There was no significant interaction between congruency and AQ group F (1, 34) = .20, p = .66, ηp^2= .01. Finally, there was no significant main effect of AQ group on congruency F (1, 34) = .18, p = .38, ηp^2= .01.

Figure 4.17 Displays the difference wave (contralateral minus ipsilateral) for both congruent and incongruent conditions. In the N_T time window (highlighted), the signal was more negative for trials where the orientation of the target and distracter were incongruent, beginning around 250ms.



Discussion

The third study in this thesis recruited participants with high or low levels of self-reported autistic traits and replicated study two with an increase in the number of trials. The study measured efficiency in visual search and the amplitude of the N2pc, P_D and N_T and compared the results between those with high and low levels of autistic traits.

The results from the visual search task presented here are similar to study one and two and show no difference in visual search efficiency between those with high and low levels of autistic traits. This finding has been consistent throughout this thesis and will be discussed further in Chapter 5.

This is the second study to present a larger N2pc in those with high levels of autistic traits. This finding has been present with a large effect size in both study one

and study three (ηp^2= .21). In support of the trend in study two, this study also demonstrated a significantly attenuated P_D in those with high levels of autistic traits (ηp^2= .15) and no difference between those with high and low levels of autistic traits in the amplitude of the N_T (ηp^2= .01). Further ERP analyses were conducted and confirmed that the effect was unique to the lateralized N2pc and P_D. Similarly to Chapter Four; as expected no SPCN was found in response to distracters and a significant effect of laterality was found in N_T trials in the P1 time window, possibly reflecting enhanced N1 negativity contralateral to targets (Eimer, 1994).

Congruency has had no impact on the amplitude of the N2pc or the P_D. However, two studies have now shown that the amplitude of the N_T was larger for incongruent trials. As participants typically find incongruent trials more difficult, the literature discusses associated ERP deflections in terms of conflict detection and the recruitment of resources to enhance attention when needed (Clayson and Larson, 2011; Groom & Cragg, 2015). The larger N_T could be reflecting the need for strong enhancement of a target in order to make a decision when faced with a distracter which is in an opposing orientation.

The literature suggests that those with ASC (Remington et al., 2012) and those with high levels of autistic traits (Bayliss & Kritikos, 2011) have an ehnanced perceptual capacity. Ultimately the result of this enhanced capacity appears to be the processing of normally irrelevant distracting items in a visual scene. Remington and colleagues have consistently shown that individuals with ASC do not show the usual detriment in search tasks when there is a high load on their perceptual system. The authors suggest that this is a facet of higher perceptual capacity in these individuals and one consequence appears to be that ASC individuals are able to allocate attention to task irrelevant items in a scene without a cost to performance (Remington et al., 2009). 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 distracters. They suggested that there may be reduced suppression of distracters in those with high levels of autistic traits and the attenuated P_D reported here supports this suggestion.

In conclusion, a larger N2pc in those with high levels of autistic traits has been replicated in this study. An attenuated P_D has also been reported in those with high levels of autistic traits. A large N2pc reflects enhanced orienting of focused attention when determining the precise location of a target (Eimer, 1996; Clark et al., 2015; Sawaki, Luck & Raymond, 2015). However, this does not mean more efficient processing; the large N2pc amplitude could reflect the need for more focused attention resources in those with higher levels of autistic traits because of less efficient processing of distracters, as a consequence of a higher perceptual capacity (Remington et al., 2009, 2012, Bayliss & Kritikos, 2011). A larger perceptual capacity would result in distracter processing even at high levels of perceptual load (Remington et al., 2009) and this is reflected in the smaller P_D reported here.

Chapter 5 : General Discussion

Motivation for Research

As highlighted in chapter one; there are many reports of atypical attention in ASC, with recent reports extending these findings to those in the general population who report high levels of autistic traits. No current theory is able to explain all aspects of the ASC cognitive and behavioural profile and a more preferable approach is to explain specific aspects of ASC by testing more direct hypotheses. At present the enhanced perceptual functioning model (Mottron et al., 2006) and enhanced perceptual capacity theory (Remington et al., 2009) appear to be the most accepted explanations for the altered perceptual and attentional style in ASC. This atypical perception and attention may ultimately lead to the overwhelming perceptual experience described by those with an ASC and potentially to the repetitive and rigid behaviours characteristic of the condition (Keehn, Müller & Townsend, 2013).

Studies of selective attention have revealed that those with an ASC show enhanced performance on the embedded figures task (EFT) (Jarrold et al., 2005; Shah & Frith, 1983) and in visual search (Joseph et al., 2009; Jarrold et al., 2005; Plaisted et al., 1998); this in the midst of an array of impairments in attention (Burack, 1994). In addition, recent work has extended superior EFT (Almeida et al., 2013; Grinter et al., 2009) and visual search performance to those in the general population who report high levels of autistic traits (Brock, Xu, & Brooks, 2011; Milne et al., 2013). However, the literature review revealed that work showing atypical attention in ASC and those with high levels of autistic traits is diverse and sometimes contradictory (Gregory & Plaisted-Grant, 2014; Hessels et al., 2014; Iarocci & Armstrong, 2014; Keehn et al., 2013), reflecting the heterogeneous nature of the autism spectrum.

After a review of the literature, the neural correlates of attention in ASC were identified as a key area requiring research; specifically the neural mechanisms underlying superior visual search performance. Neural correlates of attention are well researched in the typical population (Corbetta & Shulman, 2002; Hillyard & Anllo-Vento, 1998; Luck et al., 1997; Desimone &. Duncan, 1995; Moran & Desimone, 1985) offering a solid theoretical base from which to investigate the basis of cognitive and behavioural differences observed in ASC and in the broader autism

phenotype. There are very few studies investigating the neural characteristics associated with high levels of autistic traits. Previously, Milne et al., (2013) reported altered neural indices of feature based attention in those with high levels of autistic traits, which corresponded with superior performance on a conjunctive visual search task. The work in this thesis intended to investigate the neural indices of spatial attention in those with high and low levels of autistic traits by measuring the N2pc, which is a posterior ERP component reflecting covert spatial attention during the completion of visual search tasks. The N2pc is thought to reflect focused covert spatial attention during the selection of a target in space. The work here also measured the P_D and N_T, thought to reflect distracter suppression and target selection respectively. Measuring the P_D allowed for the direct study of distracter processing, to investigate the claim that those with high levels of autistic traits may not be suppressing irrelevant information as a result of an enhanced perceptual capacity (Milne et al., 2013; Remington et al., 2012). Therefore, this thesis was driven by previous findings of superior visual search in ASC and in those with high levels of autistic traits and interpretation of the data was informed by the theory of enhanced perceptual capacity, which attempts to explain the altered attention profile in ASC.

It was hypothesised that those with high levels of autistic traits would show superior performance on a conjunctive visual search task; where those with high levels of autistic traits were expected to be more rapid and efficient than those with low levels of autistic traits. In addition it was hypothesised that there would be a difference in both the amplitude of the N2pc and P_D between those with high and low levels of autistic traits; suggesting a difference in spatial attention and more specifically distracter suppression. Remington et al., (2012) suggest that enhanced perceptual capacity may allow participants to process relevant and irrelevant items in a parallel like manner. Processing relevant and irrelevant items simultaneously may be reflected by a larger N2pc because of a need for more focused attention (Sawaki, Luck & Raymond, 2015). However it is not possible to delineate the processes of target selection and distracter suppression with the N2pc and measuring the amplitude of the P_D and N_T allows insight into this. An attenuated P_D was expected in those with high levels of autistic traits, reflecting a lack of distracter suppression (Milne et al., 2013). However, no group difference was expected in the amplitude of the N_T, suggesting the similar processing of targets between groups.

Summary of Findings

The first experiment (chapter 2) in this thesis measured N2pc amplitude in individuals who had either high or low scores on the AQ. Specifically, we applied a visual search task which was a replication of Luck et al., (1997) and presented stimulus arrays of four items, from which the orientation of the pre-defined target had to be identified while the distracting stimuli, should have been ignored. In addition, the participants completed a conjunctive visual search task from which the behavioural data was analysed. The ERP results indicated, in line with the initial prediction, that the amplitude of the N2pc was larger in those with high levels of autistic traits. However, no difference in accuracy, reaction time or efficiency on the conjunctive visual search task was revealed between the groups. Finally, there was no group difference in behavioural performance on the ERP task and no group difference in the latency of the ERP; nor any difference in the amplitude of other ERP indices (P1, SPCN, P3). The follow up ERP analyses revealed that both groups were in fact showing an N2pc and the effect size was larger for those with high levels of autistic traits, therefore allowing the conclusion that those with high levels of autistic traits had a larger N2pc. This finding suggests that the mechanisms underlying covert spatial attention may differ between those with high and low levels of autistic traits.

In order to attempt to replicate and expand on the finding in study one, the second study (chapter 3) sought to additionally measure the two subcomponents of the N2pc; the P_D and N_T. The reasoning for looking at these two subcomponents lies in the work of Remington et al., (2009; 2012) who describe enhanced perceptual capacity in ASC. Remington et al., (2009) and Bayliss and Kritikos, (2010) found that those with an ASC and those with high levels of autistic traits respectively, continued to process distracting flanker letters even at high levels of perceptual load, which Remington et al., suggest reflects a larger perceptual capacity. Therefore, the same ERP task as in study one was applied with additional features from the task used by Hickey et al., (2009); this resulted in the addition of 8 potential letter locations around fixation and the removal of the two grey distracter Ts; resulting in a two letter display where the letter Ts could appear above or below fixation. In line with study one, it was predicted that those with high levels of autistic traits would show a larger N2pc amplitude. It was predicted that this would be accompanied by

an attenuated P_D amplitude in those with high levels of autistic traits, reflecting a lack of distracter suppression. If the mechanisms of target selection differ between those with high and low levels of autistic traits then we would see differences in the amplitude of the N_T; however, based on enhanced perceptual capacity and Milne et al., no differences in target processing were expected. Finally, the participants completed a conjunctive visual search task and based on the previous literature, a group difference in visual search performance could have been expected; however, based on the findings in study one; there may have been no group difference in visual search performance.

The results from the second study were in the direction expected, where those with high levels of autistic traits demonstrated a larger N2pc and a smaller P_D, however the results were not significant. In addition, there was no significant group difference in performance on the conjunctive visual search task. The ERP results from this study could have been due to a lack of trials contributing to each component (~ 280 maximum). Typically studies of this nature have between 400 and 1000 trials per condition (Hickey et al., 2009; Luck et al., 1997). In order to address this issue and to replicate the initial finding of a larger N2pc in those with high levels of autistic traits, reported in the first study (chapter 2); the third study within this thesis (chapter 4) employed the same paradigm and procedure as in study two, with the addition of significantly more trials and the same predictions made for study two.

The results from the third study replicated the initial finding of a larger N2pc in those with high levels of autistic traits and the post-hoc test revealed that those with fewer autistic traits were in fact not demonstrating an N2pc at all, a finding which is discussed in more detail in a later section. In line with the prediction made, there was a group difference in the amplitude of the P_D and post-hoc tests revealed that those with high levels of autistic traits were not demonstrating a P_D at all. In line with study two, there was no group difference in the amplitude of the N_T (ηp^2= .01), nor were there any ERP latency differences between groups or any group difference in performance on the visual search task.

Further ERP analyses conducted for all studies 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 reported here are restricted to processes that reflect the deployment of attention to goal relevant stimuli, and active suppression of distracter stimuli.

A final ERP analysis conducted in each study assessed the effect of stimulus congruency on N2pc, P_D and N_T amplitude, finding that the amplitude of the N_T was consistently larger during incongruent trials across two studies and study three revealed a large N2pc in association with incongruent trials. The N2 has been associated with the conflict detection during incongruent trials; termed the conflict N2, it peaks around 250-350ms post stimulus (Clayson and Larson, 2011). The larger N_T and N2pc in incongruent trials could be reflecting the need for strong enhancement of a target in order to make a decision when faced with a distracter which is in an opposing orientation. This will be discussed with respect to selective attention in the following section.

To summarise, the three studies conducted here found a significant difference in the amplitude of the N2pc and P_D between those with high and low levels of autistic traits; specifically a larger N2pc in those with high levels of autistic traits and a smaller P_D in those with high levels of autistic traits. There was no significant between group difference in visual search performance in any study and there was no significant between group difference in the amplitude of the N_T.

Implications for Selective Attention in ASC

Atypical attention is one of the earliest identifiable features of ASC (Ames & Fletcher-Watson, 2010) and could offer the promise of biomarkers for early diagnosis. Thus, attention in ASC has been the focus of a large body of research; however the results are diverse and often conflicting. Some findings report an impairment in selective attention (Elsabbagh et al., 2015; Christ et al., 2011; Burack, 1994) whereas others identify areas of enhanced ability (Plaisted et al., 1998; Jolliffe & Baron-Cohen, 1997; Shah & Frith, 1983). Investigating the basis of these enhanced abilities can inform us about the cognitive and neural profile of ASC,

independent of the confounding effects of a multitude of cognitive and behavioural impairments.

Studies are also beginning to build a picture of atypical selective attention in the typically developing population who report high levels of autistic traits (Milne et al., 2013; Brock et al., 2011; Bayliss & Kritikos, 2011). While Brock et al., (2011) and Bayliss and Kritikos (2011) reported altered cognition in those with high levels of autistic traits; Milne et al., (2013) reported altered neural correlates of attention in those with high levels of autistic traits. Specifically, Milne et al., reported atypical ERP amplitudes associated with feature based attention. The findings presented here add to this result by also suggesting that there is more focus of covert spatial attention in those with high levels of autistic traits. Specifically, larger N2pc amplitude suggests more effortful processing, or greater allocation of attentional resources, during target search. Though the findings here report no difference in behavioural performance, the neural differences reported may mean that those with high levels of autistic traits are arriving at the same behavioural result in a different way. This pattern has also been observed in ERP and fMRI data from participants with an ASC diagnosis; where those with an ASC showed altered ERP amplitudes and altered activation patterns even when their performance on a task of selective attention was comparable to that of control participants (Manjaly et al., 2007; Ciesielski, Courchesne, & Elmasian, 1990).

A large N2pc appears to reflect the allocation of more focused covert attention (Sawaki, Luck & Raymond, 2015). In the studies reported here, those demonstrating a large N2pc could have been allocating more attention to the task because they were finding the task more difficult; however this is not supported by the behavioural data presented here which shows comparable performance between groups. Therefore, a large N2pc in this case could mean that those participants have access to more processing resources. This supports the idea of an enhanced perceptual capacity (Remington et al., 2012), which this data suggests could extend to those with high levels of autistic traits. Remington et al., (2009) found behavioural evidence leading to this conclusion, where those with an ASC continued to show interference from flankers even at high levels of perceptual load; suggesting a greater capacity for processing visual information. The data presented here provides evidence of a neural difference which could underlie this enhanced capacity;

specifically, the large N2pc demonstrated by those with high levels of autistic traits could be reflecting a neural substrate which provides those participants with an atypical excess in processing resources.

In addition, the altered amplitude of the P_D reported here provides direct evidence of processing differences which may arise from an enhanced perceptual capacity. Milne et al., (2013) concluded that an enhanced perceptual capacity leads to the processing of normally irrelevant distracters in those with high levels of autistic traits. Here, direct electrophysiological evidence has been reported to suggest an absence of distracter suppression in those with high levels of autistic traits. This finding provides a direct report of a neural mechanism which may be a by-product of an enhanced perceptual capacity. This enhanced capacity in ASC may arise from neural over-connectivity in local areas (Bertone et al., 2005) which is the most popular aetiological theory of ASC to date. There may be neural over-connectivity in sensory and parietal cortices, leading to an excess in visual processing resources, reflected by electrophysiological correlates such as those reported here. Therefore, if the ERP findings reported here can be extended to those with an ASC, a gap in research will be filled which could link a cognitive mechanism (enhanced capacity) with the biological substrate (over-connectivity in occipital and parietal cortices).

Visual Search and Autistic Traits

The studies presented in this thesis do not support the literature showing superior visual search performance in those with high levels of autistic traits (Milne et al., 2013; Brock et al., 2011; Almeida et al., 2010). There were no differences in accuracy, reaction time or any efficiency measure, therefore this work lends support to Gregory and Plaisted-Grant (2013), who found no difference between high and low AQ scoring participants in a large sample.

The findings of no group difference in visual search cannot be explained by a problem with task design or ceiling or floor effects, increasing display size resulted in increased reaction time and the task elicited accuracy of around 90% and slope sizes of around 10ms/item for present trials and 20ms/item for absent trials. Typical (mean) search slopes for present and absent trials are 14.6 ms/item and 33 ms/item respectively (Wolfe, 1998), therefore the visual search tasks employed here were only slightly easier than average. The task used in the second study had the same

parameters as those used by Milne et al., (2013), who showed a significant correlation between visual search efficiency and AQ scores; it was hypothesised that the task used by Milne et al., may have revealed significant results because it was more difficult; however the study reported in the appendix showed that the Milne et al., task was actually easier than the task used in the thesis; reflected in the absent trial slope sizes of around 13msec/item for absent trials. Ultimately the lack of replication here suggests that the Milne et al., finding of a group difference in visual search performance may have been spurious.

Gregory and Plaisted-Grant (2013) suggest that there is some deeper aetiological factor in those who have an ASC which is linked to their visual search performance. This may mean that the autistic features being accessed by the AQ are too shallow to be linked with mechanisms that lead to a superior visual search; a superiority which may only arise in those with the deeper characteristics of ASC. Therefore, according to Gregory and Plaisted-Grant (2013), those who have a high score on the AQ and show superior visual search will be those family members in the broader autism phenotype and those with an undiagnosed ASC. The Milne et al., (2013) result could have been due to the unknowing inclusion of those participants.

Visual Search Superiority in ASC

Some have suggested that a faster search in ASC may be a result of applying more focused attention (Blaser, Eglington, Carter, & Kaldy, 2014; Kaldy et al., 2013) and the ERP data reported here supports this conclusion. Others suggest that superior visual search may be due to enhanced perceptual discrimination in ASC (O'Riordan & Plaisted, 2001) which is consistent with the concept of enhanced perceptual functioning (Mottron et al., 2006). However, the data presented here does not allow for conclusions to be made about the suitability of the enhanced discrimination theory because target-distracter similarity was not manipulated. More relevant here, the theory of enhanced perceptual capacity also has direct relevance to visual search superiority in ASC. Remington et al., (2012) suggest that an enhanced perceptual capacity may underlie superior visual search in ASC as the capability to process items in parallel leads to a faster search. Milne et al., (2013) support the idea of enhanced perceptual capacity but suggest that those with an ASC are able to process both relevant and irrelevant items in a scene, resulting in a faster search. This explanation is supported by the data reported here and may lend itself to explain why

the ASC advantage is generally only seen in target absent trials (Keehn & Joseph, 2016; Joseph et al., 2009, though see Jarrold et al., 2005 for conflicting findings).

According to the activation threshold model proposed by Chun and Wolfe (1996), participants search a target absent display until a threshold is reached and a decision is made to terminate search. Keehn and Joseph (2016) suggest that a larger perceptual capacity and the resulting processing of relevant and irrelevant items (Milne et al., 2013) results in faster coverage of all areas in a display, and this would be particularly advantageous in target absent trials, where all areas in an array must be visited to be confident of a decision. Therefore, if those with an ASC have an enhanced capacity for processing irrelevant distracters, as evidenced by the large index of focused attention and the lack of distracter suppression reported here; the search threshold proposed by Chun and Wolfe (1996) will be reached sooner and search will be faster. According to this conclusion, we might expect those with a lack of P_D to be more efficient at visual search; however the data presented here reported no relationship between P_D amplitude and visual search efficiency.

Building a Profile of Autistic Traits

Building a profile of the neural, cognitive and behavioural characteristics of those on the broader autism spectrum is a relatively new area where there is very little existing research. Research on autistic traits makes an interesting contribution to research on individual differences and examining those who report high and low levels of autistic traits contributes to a better understanding of the mechanisms associated with those traits. While the idea of a spectrum in ASC has existed for a while (Wing, 1988), it is a new development in the official diagnostic criteria (DSM-V, 2013). However, as with any approach, there are limiting factors to consider.

The studies presented here used a dichotomous sample from the AQ; splitting high and low scoring individuals into separate comparable groups using the criteria of the top and bottom 10% of scores from a large, normally distributed sample. This approach allowed the analysis of the N2pc and subcomponents to be consistent with previous work by entering laterality data into an analysis of variance (Hickey et al., 2009; Luck et al., 1997) and then entering AQ as a between participants variable. However, another approach is to correlate AQ score as a continuous variable (Dickinson, Jones & Milne, 2014; Milne et al., 2013; Brock et al., 2013); this

approach is more consistent with the idea of a spectrum in ASC. Future research should consider the suitability of either a discrete group/continuum approach when designing an AQ study.

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. This would result in findings which are actually reflecting the extreme scores of those participants who share the endo-phenotype of ASC, typically being those with an undiagnosed ASC or relatives of those with an ASC (Gregory & Plaisted-Grant, 2013). For the studies in this thesis, an attempt was made 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 ASC, making it likely that our findings do reflect differences in N2pc amplitude on the basis of AQ score alone. When using a sample from the typically developing population, caution should be observed when drawing conclusions about mechanisms underlying task performance in those diagnosed with an ASC. Ultimately, ASC is a complex and heterogeneous spectrum, reflected in extremely variable cognitive and behavioural symptoms; thus the explanations supported here cannot be extended to all those with an ASC.

N2pc Amplitude is Affected by Stimulus Characteristics

In study one (Chapter 2), 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 three (Chapter 4), the contralateral/ipsilateral difference only reached significance in the high AQ scorers. In the first study, both high and low AQ scorers showed a significant N2pc; that is there was a significant difference between the contralateral and ipsilateral signal. Therefore, the effect in this study was a larger N2pc in those with high levels of autistic traits. However, in the second study (Chapter 3) showing a group difference in N2pc amplitude, the follow up analysis revealed that the low AQ scorers were not showing an N2pc. That is, there was no significant difference between the contralateral and ipsilateral signal in the N2pc time window for those with low levels of autistic traits. Therefore, in one

study (Chapter 2) the effect arose from an abnormally large N2pc in the high AQ scorers; and in the second study (Chapter 4), the larger N2pc in the high AQ scorers arose from an abnormally small N2pc in the low 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 three, the task was modified so that N_T and P_D could be measured in addition to N2pc. For this purpose, an existing paradigm (Hickey et al., 2009) was employed; 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 three, providing support for the conclusion that N2pc amplitude is increased in individuals with high AQ scores.

The amplitude of the N_T and N2pc were additionally associated with the completion of incongruent trials, defined here as trials where the target and distracter were in opposing orientations. Amplitude of both the N_T and N2pc were larger in trials when target-distracter conflict caused response time to slow. ERP components normally associated with the completion of incongruent trials appear to process the conflict between responses and recruit resources to enhance attention (Clayson and Larson, 2011; Groom & Cragg, 2015). Groom and Cragg (2015) concluded that the N2 appears to monitor conflict and select between competing resources. The N_T is within the time range of the N2; is ventro-lateral in topography (Hickey et al., 2009), reflecting ventral stream and object identification and comes online after the mechanisms underlying the P_D have acted to spatially suppress information. Therefore, a large N_T appears to be necessary to identify and select a target in the midst of conflict arising from difficult trials and the large N2pc appears to reflect the allocation of focused attention in this situation. This supports the conclusion that a large N2pc reflects the allocation of more focused attention in those with high levels of autistic traits. In addition, this result suggests that a lack of between group difference in N_T amplitude means that those with high and low levels of autistic traits were not differing in the level of difficulty with the task.

Further Study

Further research is needed to establish whether the ERP findings reported here are replicated in those who have a clinical diagnosis of ASC. A series of studies on the electrophysiology of selective attention could fill a gap between cognitive theories of enhanced perceptual capacity in ASC and the potential biological neural over-connectivity. In addition, studies measuring visual search performance in those with high levels of autistic traits are thus far inconsistent and this thesis adds to the lack of replication. Gregory and Plaisted-Grant (2013) argue that it is strange to assume that the factors underlying superior visual search performance also underlie a participants' high AQ score. This argument is valid, particularly as the AQ is composed of five different subscales, of which attention (switching and detail) comprises only two. Therefore, a high AQ score could arise from social and communication difficulties while attention remains intact. To assess this, future research could break down the AQ by subscales and correlate behavioural performance and neural correlates with the separate subscales.

Conclusion

This thesis has presented two novel EEG findings: first, those with high levels of self-reported autistic traits have a larger N2pc; second, those with high levels of autistic traits do not show a P_D. Both findings provide neural evidence that the deployment of spatial attention differs between high and low AQ scorers. A large N2pc suggests more effortful processing; specifically greater allocation of covert attentional resources (Sawaki, Luck & Raymond, 2015). A lack of P_D suggests that those with high levels of autistic traits are not allocating resources to the suppression of distracters. This finding ties in with enhanced perceptual capacity, which may allow those with an ASC (Remington et al., 2012) and potentially those with high levels of autistic traits to process significantly more of a visual scene at one time. An enhanced perceptual capacity in those with an ASC could lead to superior visual search by enhancing the capability of parallel processing (Remington et al., 2009) or by permitting the processing of irrelevant distracters (Keehn & Joseph, 2016; Milne et al., 2013), meaning that a search threshold (Chun & Wolfe, 1996) would be reached sooner and search would be faster. The significant findings reported here were observed in two separate studies which recruited entirely different cohorts of

participants; therefore further research examining individual differences in the neural correlates of spatial attention in the broader autism phenotype is warranted.

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Appendix A

Visual Search Experiment

The motivation for the study reported here is a discrepancy in behavioural findings from a previous paper and the findings from study one and two of this thesis. Milne, Dunn, Freeth & Rosas-Martinez (2013) reported that high AQ scorers were more efficient at visual search compared to low AQ scorers, whereas both studies in this thesis have revealed no such effect. For this thesis the same task was used as in Milne et al., (2013) with one very slight alteration which meant that the overall visual angle of the display was wider. The stimuli differed in no other respect. The present study sought to investigate the differences in the two tasks using a different sample. I hypothesised that the task used in Milne et al., (2013) was harder, meaning that the study could reveal differences between those with high and low levels of autistic traits. I tested this by requiring participants to complete a task in which both types of stimuli were randomly presented so participants did not know there was any difference. I predicted that reaction times and slopes would be slower and steeper respectively for the task used in Milne et al., (2013).

Methodology

Participants

The sample consisted of first year psychology students of the University of Sheffield. 30 participants with normal or corrected-to-normal vision participated in the study (19 females, 11 males).

Stimuli and Procedure

Computer based stimuli were created using Adobe Photoshop 7.0 and presentation of all stimuli was controlled by E-Prime2 run on a 12 inch desktop PC monitor. Participants completed one visual search task which was equally composed of two main types of stimuli. Half of the stimuli were the same as in Milne, Dunn, Freeth and Rosas-Martinez (2013) and half were the same stimuli used in the first two studies of this thesis. Participants were seated 45cm from the screen and were required to state the presence or absence of a pre-specified target (green X). Targets were defined by a conjunction of both colour and form. Stimulus arrays contained 5, 15 or 25 letters (equiluminant blue Xs or green Ts); presented on a light grey background with a black fixation cross. In 50% of the trials a target (green X) was

also present. Each letter measured approximately 1° of visual angle. In the thesis task the size of the entire stimulus array did not exceed 25° of visual angle. However in the Milne et al., (2013) task the letters were much closer together and the visual angle did not exceed 15°. The luminance of each letter was within 3% of 18cd/m^2. 240 trials were presented in one block, 120 trials were presented for each visual search task with 40 of each set-size. Set size, target presence and task type was randomly occurring.

Each trial began with the presentation of a fixation cross which remained on screen for 500ms. After this, the search array appeared on-screen until the participant made their response. Twelve practice trials, with feedback on accuracy and reaction time were given prior to the experimental trials. No feedback was given during experimental trials. Responses were made by pressing the letter P with the right hand index finger to indicate target present and the letter A with the left hand index finger to indicate target absent.

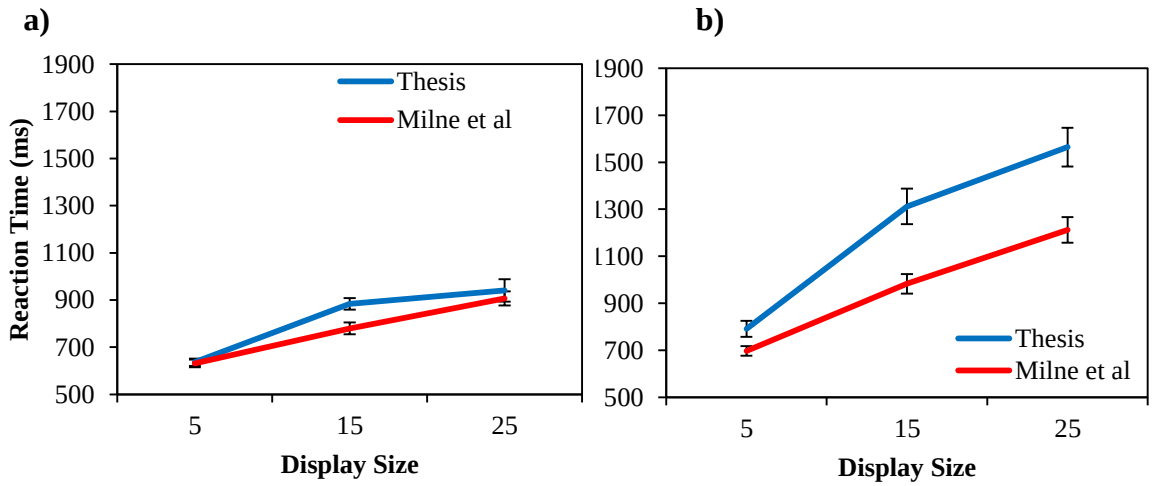
Results

Behavioural results

Reaction times three standard deviations above and below the mean for each individual were discarded; this resulted in the removal of an average 8 data points per participant (Range = 0-34). Mean accuracy in visual search (93.6%) overall was high and did not differ significantly between the Milne et al., (2013) task (mean = 93.5% , sd = 4.1) and the thesis (mean = 93.7%, sd = 4.2) task, t (1, 29) = .186, p =.85, d = 0.1.

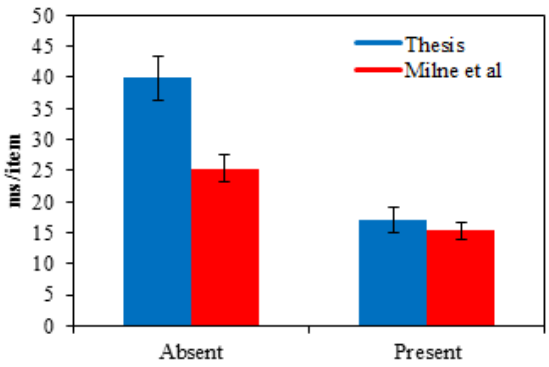
Median (correct) reaction time data for each display size and target present and absent trials were entered into a mixed-measures (3x2x2) ANOVA. As expected, the reaction times were significantly slower in absent trials compared to present trials F (1, 29) = 108.6, p = <.001, η^2_P = .80 and reaction time was significantly different across set sizes F (2, 58) = 126.2, p = <.001, η^2_P = .82. The analysis revealed a highly significant interaction between task type, target presence and set size F (2, 58) = 9.6, p = <.001, η^2_P = .26. As shown in figure 7.1, reaction time was slower in the thesis task both with increases in set size and the absence of a target when compared to the Milne et al., (2013) task, suggesting that the thesis task was more difficult.

Figure 7.1 Reaction time data for both types of visual search task in present (a) and absent (b) trials (error bars display standard error)



Slopes of RT x set size were calculated by performing a linear regression of each participant's raw (correct) visual search data. These slopes were entered into a mixed model ANOVA and as expected, slopes were significantly steeper when a target was absent than when the target was present F (1, 29) = 68.0, p = <.001, η^2_P = .70 (see figure 5.2). There was also a significant interaction between task and target presence F (1, 29) = 50.1, p = <.001, η^2_P = .64. As shown in figure 7.2, there was no difference in slope efficiency in present trials but participants were much less efficient in the thesis task in absent trials when compared to the Milne et al., (2013) task. A paired samples t-test revealed a highly significant difference in absent trial efficiency between the two tasks t (1, 29) = 6.4, p = <.001, d = 2.4 and no significant difference in search efficiency between the two tasks in target present trials t (1, 29) = 1.1, p = .29, d = 0.4.

Figure 7.2 Slope values for both types of task, error bars display standard error



Discussion

This study found a significant difference in reaction time between two variations of a visual search task. The two types of stimuli have revealed different results in studies thus far despite only differing in the overall visual angle. I predicted that participants would be less efficient/respond more slowly in the task used in Milne et al., (2013) when compared to the visual search task used in the studies for this thesis; however the result was the opposite. The study revealed that the more difficult absent trials were actually made more challenging by the wider angled thesis task.

Previously, Milne et al., (2013) found a difference in visual search efficiency between those with high and low levels of autistic traits. However the studies in the present thesis have failed to replicate this effect. I conducted this study in order to investigate whether the null findings from the thesis could be the result of a small change made to the visual search task. Based on previous literature I predicted that the task used in Milne et al., (2013) was more difficult than the thesis task meaning that there were no ceiling effects, resulting in an AQ group difference. However the present study revealed that the thesis task was actually the more difficult task. I believe this is because the thesis task has a wider visual angle and requires the participants to scan more of the array before arriving at a decision in trials where the target is absent. Absent trials require a more thorough serial scan whereas participants typically only search half of an array in present trials (Wolfe et al., 1989) therefore absent trials are more difficult overall but especially difficult when there is more area to cover.

Conversely, the difficulty of the thesis task suggests that we would be more likely to see the AQ group difference using this task. The fact that this is not the case highlights the tentative findings in this area and adds to work which suggests that the visual search advantage in high AQ scorers and even in autism is not as consistent as once thought. This will be discussed in the main discussion chapter alongside the previous literature and the behavioural findings from the studies in this thesis.

Appendix B

Autism Spectrum Quotient

Below are a list of statements. Please read each statement very carefully and rate how strongly you agree or disagree with it by circling your answer.

1. I prefer to do things with others rather than on my own.	definitely agree	slightly agree	slightly disagree	definitely disagree
2. I prefer to do things the same way over and over again.	definitely agree	slightly agree	slightly disagree	definitely disagree
3. If I try to imagine something, I find it very easy to create a picture in my mind.	definitely agree	slightly agree	slightly disagree	definitely disagree
4. I frequently get so strongly absorbed in one thing that I lose sight of other things.	definitely agree	slightly agree	slightly disagree	definitely disagree
5. I often notice small sounds when others do not.	definitely agree	slightly agree	slightly disagree	definitely disagree
6. I usually notice car number plates or similar strings of information.	definitely agree	slightly agree	slightly disagree	definitely disagree
7. Other people frequently tell me that what I've said is impolite, even though I think it is polite.	definitely agree	slightly agree	slightly disagree	definitely disagree
8. When I'm reading a story, I can easily imagine what the characters might look like.	definitely agree	slightly agree	slightly disagree	definitely disagree
9. I am fascinated by dates.	definitely agree	slightly agree	slightly disagree	definitely disagree

10. In a social group, I can easily keep track of several different people's conversations.	definitely agree slightly agree slightly disagree definitely disagree
11. I find social situations easy.	definitely agree slightly agree slightly disagree definitely disagree
12. I tend to notice details that others do not.	definitely agree slightly agree slightly disagree definitely disagree
13. I would rather go to a library than a party.	definitely agree slightly agree slightly disagree definitely disagree
14. I find making up stories easy.	definitely agree slightly agree slightly disagree definitely disagree
15. I find myself drawn more strongly to people than to things.	definitely agree slightly agree slightly disagree definitely disagree
16. I tend to have very strong interests which I get upset about if I can't pursue.	definitely agree slightly agree slightly disagree definitely disagree
17. I enjoy social chit-chat.	definitely agree slightly agree slightly disagree definitely disagree
18. When I talk, it isn't always easy for others to get a word in edgeways.	definitely agree slightly agree slightly disagree definitely disagree
19. I am fascinated by numbers.	definitely agree slightly agree slightly disagree definitely disagree

20. When I'm reading a story, I find it difficult to work out the characters' intentions.	definitely agree slightly agree slightly disagree definitely disagree
21. I don't particularly enjoy reading fiction.	definitely agree slightly agree slightly disagree definitely disagree
22. I find it hard to make new friends.	definitely agree slightly agree slightly disagree definitely disagree
23. I notice patterns in things all the time.	definitely agree slightly agree slightly disagree definitely disagree
24. I would rather go to the theatre than a museum.	definitely agree slightly agree slightly disagree definitely disagree
25. It does not upset me if my daily routine is disturbed.	definitely agree slightly agree slightly disagree definitely disagree
26. I frequently find that I don't know how to keep a conversation going.	definitely agree slightly agree slightly disagree definitely disagree
27. I find it easy to "read between the lines" when someone is talking to me.	definitely agree slightly agree slightly disagree definitely disagree
28. I usually concentrate more on the whole picture, rather than the small details.	definitely agree slightly agree slightly disagree definitely disagree
29. I am not very good at remembering phone numbers.	definitely agree slightly agree slightly disagree definitely disagree

30. I don't usually notice small changes in a situation, or a person's appearance.	definitely agree	slightly agree	slightly disagree	definitely disagree
31. I know how to tell if someone listening to me is getting bored.	definitely agree	slightly agree	slightly disagree	definitely disagree
32. I find it easy to do more than one thing at once.	definitely agree	slightly agree	slightly disagree	definitely disagree
33. When I talk on the phone, I'm not sure when it's my turn to speak.	definitely agree	slightly agree	slightly disagree	definitely disagree
34. I enjoy doing things spontaneously.	definitely agree	slightly agree	slightly disagree	definitely disagree
35. I am often the last to understand the point of a joke.	definitely agree	slightly agree	slightly disagree	definitely disagree
36. I find it easy to work out what someone is thinking or feeling just by looking at their face.	definitely agree	slightly agree	slightly disagree	definitely disagree
37. If there is an interruption, I can switch back to what I was doing very quickly.	definitely agree	slightly agree	slightly disagree	definitely disagree
38. I am good at social chit-chat.	definitely agree	slightly agree	slightly disagree	definitely disagree
39. People often tell me that I keep going on and on about the same thing.	definitely agree	slightly agree	slightly disagree	definitely disagree
40. When I was young, I used to enjoy playing games involving pretending with other children.	definitely agree	slightly agree	slightly disagree	definitely disagree

41. I like to collect information about categories of things (e.g. types of car, types of bird, types of train, types of plant, etc.).	definitely agree	slightly agree	slightly disagree	definitely disagree
42. I find it difficult to imagine what it would be like to be someone else.	definitely agree	slightly agree	slightly disagree	definitely disagree
43. I like to plan any activities I participate in carefully.	definitely agree	slightly agree	slightly disagree	definitely disagree
44. I enjoy social occasions.	definitely agree	slightly agree	slightly disagree	definitely disagree
45. I find it difficult to work out people's intentions.	definitely agree	slightly agree	slightly disagree	definitely disagree
46. New situations make me anxious.	definitely agree	slightly agree	slightly disagree	definitely disagree
47. I enjoy meeting new people.	definitely agree	slightly agree	slightly disagree	definitely disagree
48. I am a good diplomat.	definitely agree	slightly agree	slightly disagree	definitely disagree
49. I am not very good at remembering people's date of birth.	definitely agree	slightly agree	slightly disagree	definitely disagree
50. I find it very easy to play games with children that involve pretending.	definitely agree	slightly agree	slightly disagree	definitely disagree