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Mapping Attention Across Space: Evidence for Sharper Attentional Enhancement in Autism

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ABSTRACT

Atypical perception is a defining feature of Autism Spectrum Conditions (ASC). A striking aspect of autistic perception, found in both anecdotal reports and behavioural experiments, is superior perception of local elements of visual scenes – even though basic acuity and contrast detection are unremarkable. One of the most ubiquitous mechanisms of improving perceptual performance in the face of noise is lateral inhibition, and hypotheses have placed this inhibition at the heart of superior autistic perception. Increased inhibition in retinotopic cortex would likely predict a contracted distribution of spatial attention. Such contraction may underlie the efficient local perception observed in ASC. We used an exogenous attentional cueing paradigm in which we varied the spatial and temporal offsets between the cue and target. Facilitation of performance fell off more steeply with increasing distance in our group of individuals with high-functioning autism. A repeated measures ANOVA revealed a significant interaction between group and distance from cue, while showing no significant interaction between group and time. We conclude that sharper attentional enhancement is a feature of autistic perception, and propose that this may be one of the underlying mechanisms that produce more complex symptoms in autistic perception.

ABBREVIATIONS

ASC	Autism Spectrum Conditions
ANOVA	Analysis of Variance
EPF	Enhanced Perceptual Functioning
DSM	Diagnostics and Statistical Manual
ISI	Inter-Stimulus Interval
IQ	Intelligence Quotient
WASI	Wechsler Abbreviated Scale of Intelligence
AQ	Autism Quotient
ADOS	Autism Diagnostic Observation Schedule
WCC	Weak Central Coherence
UCH	Under-Connectivity Hypothesis
fMRI	Functional Magnetic Resonance Imaging
E/I	Excitation / Inhibition
GABA	Gamma-Aminobutyric Acid
LI	Lateral Inhibition

Unless otherwise stated, all distances referred to are measured in degrees of visual angle.

Equally, unless otherwise stated, all tests were non-parametric.

"My bed was surrounded and totally encased by tiny spots which I called stars, like some kind of mystical glass coffin. I have since learned that they are actually air particles yet my vision was so hypersensitive that they often became a hypnotic foreground with the rest of 'the world' fading away."

Donna Williams (1992), *Nobody Nowhere: The remarkable autobiography of an autistic girl*

1. INTRODUCTION

1.1 Atypical Perception in Autism

Autism spectrum conditions (ASC) are a group of neurodevelopmental conditions traditionally considered social or communication disorders. However, since their first discovery, atypical responses to sensory stimulation in the auditory, somatosensory, olfactory and tactile domain have been important features in autobiographical descriptions (Grandin, 1992, 1997; Williams, 1994) and clinical observations of the conditions (Dawson et al., 2000; Kanner, 1943; Asperger, 1944). Most recently, "hyper-or hypo-reactivity to sensory input or unusual interest in sensory aspects of environment" have been proposed for incorporation into the Diagnostic and Statistical Manual of Mental Disorders 5 as a diagnostic criterion for ASC (DSM-V, American Psychiatric Association, 2011). At the same time, perception has moved more and more into the focus of research – with a particular focus on vision (Dakin and Frith, 2005; Simmons et al., 2009). One of the most reported phenomena in the literature of visual perception in ASC is a bias towards perception of individual features of a scene, accompanied by reduced perception of its global features (Bogdashina, 2003).

1.2 Theoretical Approaches to Detailed Perception in Autism

Initially, increased detail perception was linked to reduced integration of components of a stimulus. This would leave autistic patients 'stuck' at low level perception. An attractive idea, 'Weak Central Coherence' theory (WCC, Frith & Shah, 1983; Happé & Frith, 2006) provided a cognitive mechanism that, if impaired, would lead to problems in both social perception and language interpretation. However, subsequent studies led to findings irreconcilable with this theory of high-level impairment: In many experiments, ASC

participants were perfectly capable of perceiving global patterns of integrated components if advantageous to the task (Caron et al., 2006; Wang et al., 2007).

Thus, a more differentiated description of autistic vision has been considered necessary, and the focus shifted from apparent impairments to peaks of visuo-spatial abilities in autism. Superior performance of ASC individuals on tasks such as orientation discrimination (Bertone et al., 2005), configural or pattern discrimination (Plaisted et al., 2003), and classic experiments such as the embedded figures task (Jolliffe and Baron-Cohen, 1997; Frith and Shah, 1983) or the conjunctive search task (Plaisted et al., 1998) indicated that superior processing of individual scenes might be able to explain a local bias.

This led to the formulation of the Enhanced Perceptual Functioning (EPF) theory (Mottron and Burack, 2001; Mottron et al., 2006). Dispensing with the ambition to provide one mechanism for social, communicative and perceptual atypicalities at once, it only aims to explain autistic perception and tries to integrate neurobiological findings. It suggests that a general skew of the processing hierarchy towards early stages can explain the performance peaks on discrimination tasks as well as the bias towards local processing.

1.3 The Neurobiology of Enhanced Early Visual Processing

The neural circuitry underlying visual perception has been well characterised through electrophysiological studies in cats and primates and through psychophysical experiments and neuroimaging studies in humans. This means that it is possible to link EPF to studies of the neurobiology of autism. One such finding is that autistic participants show increased occipital activation and reduced frontal activation in various tasks (Samson et al., 2011). This parallels the prediction of EPF that perceptual processing is shifted towards early stages, which occur in the most occipital areas.

A shift in the balance of activity from later, "higher" areas to posterior, "earlier" areas could potentially arise from two types of changes in connectivity: Increased local connectivity between neurons in the early visual areas, and reduced connections to later, frontal areas of the brain. Two areas of research provide evidence for both: functional imaging studies show reduced synchrony in ASC subjects (Belmonte and Yurgelun-Todd, 2003; Lai et al., 2010); and cellular studies show increased GABAergic synapse formation in mouse models of autism (Tabuchi et al., 2007) and reduced neuropil space in post-mortem studies of autistic individuals (Casanova et al., 2006). This led to the formulation of an under-/over-connectivity theory of autism (Belmonte et al., 2004), which places higher local and reduced long-range connectivity at the heart of ASC.

Atypical lateral connectivity has predictable effects on sensation. Lateral inhibition (LI) between columns is a ubiquitous mechanism of sharpening the specificity of a column. Similar to LI in the retina, it sharpens the tuning curve by raising the signal-to-noise ratio. The heightened discriminatory abilities seen in ASC, for example, can be explained by an increase in LI between orientation-specific columns (Tolhurst and Thompson, 1974). In a visual system made up of serial instances of retinotopic representations of the visual world (Saygin and Sereno, 2008), LI in the cortex also defines the spatial resolution of cortical representations, and increased lateral connections can thus be linked to detail-focused vision.

While this hypothesis ties in extremely well with an EPF account of autistic perception, it should be noted that they are not uncontroversial. Multiple studies with mouse models of autism have found decreased GABAergic synapse formation (Gogolla et al., 2009), and atypical mini-columnar structures were not found in the occipital cortex of humans with autism, where they could have an influence on early perceptual processes.

1.4 Spatial Lateral Connectivity, Behaviour and Attention

However contentious the exact nature of neurobiological mechanisms in autism may be, a recent behavioural study has shown how they can affect vision in individuals. Kéïta *et al.* investigated the effect of collinear flankers on the detection thresholds of a Gabor Patch (GP). This facilitation effect is proposed to be reliant on long-range, excitatory connections between retinotopic representations of flanker and target (Kéïta et al., 2011a). However, the excitatory connections between collinear gratings are balanced with inhibitory connections with little orientation selectivity and increased spatial specificity, and changes in either would affect the facilitation effect. In the ASC group, the effect of collinear facilitation was significantly enhanced for flankers that are close to the target, providing strong evidence for an enhanced lateral connectivity, and showing that they have definite influence on behaviour.

We hypothesised that atypically strong lateral interactions, as proposed in the EPF account of autistic perception and indicated by Kéïta *et al.,* would fundamentally alter the distibution of spatial attention in a predictable way: there would be a sharper gradient of attentional enhancement in individuals with ASC. Attention is known to potentiate activity of neurons in early stages of the visual system (Ito and Gilbert, 1999). This enhancement is spatially selective and falls with increasing distance from the focus of attention. This can be seen in electrophysiological recordings in monkeys (Motter, 1993) and in behavioural studies with humans (Kravitz and Behrmann, 2008; Gobell et al., 2004). Imaging reveals that this neuronal activity enhancement is retinotopically distributed (Brefczynski-Lewis et al., 2009). Enhanced lateral interactions in such a retinotopically organised cortex would thus be expected to sharpen the spatial extent of attention. Mapping this gradient in detail may provide further support for atypical early visual processing and for the neural mechanisms behind it; and it may elucidate a fundamentally atypical factor in autistic vision that may ultimately give an explanation for some of the perceptual symptomologies in autism.

In fact, attention has been investigated in autism before. Plaisted (2000) summarised attentional findings and concluded that research converged on an impairment in the ability to shift attention, later supported by experiments in which autistic subjects showed impaired ability to broaden their attentional focus from a small area of space to a larger area (Courchesne et al., 1994; Mann and Walker, 2003). However, these experiments studied endogenous attention, using stimuli which required wilful shifts of attention. This means that in addition to sensory atypicalities, the task was confounded by potential executive dysfunction in autism. While endogenous attention is important in vision, this means that it was impossible to make inferences about the perceptual side of attention.

Our paradigm thus used an exogenous attentional cue in order to measure its effect on performance on targets that could be presented at three different possible distances. A cue that raises saliency in a part of the visual field is known to enhance perception, having the largest effect close to the cue and reduced effect as offset between the target and cue is increased.

Attention has also been shown to have atypical temporal properties in ASC. In a previous exogenous cueing task, participants with ASC showed reduced attentional enhancement when there were 100ms between cue and target, but typical enhancement when there were 800ms in between (Townsend et al., 1996). We hypothesised that any paradigm that does not include time as a variable factor will be liable to confoundment by atypical timing, and therefore included a temporal dimension in order to investigate delayed attention further.

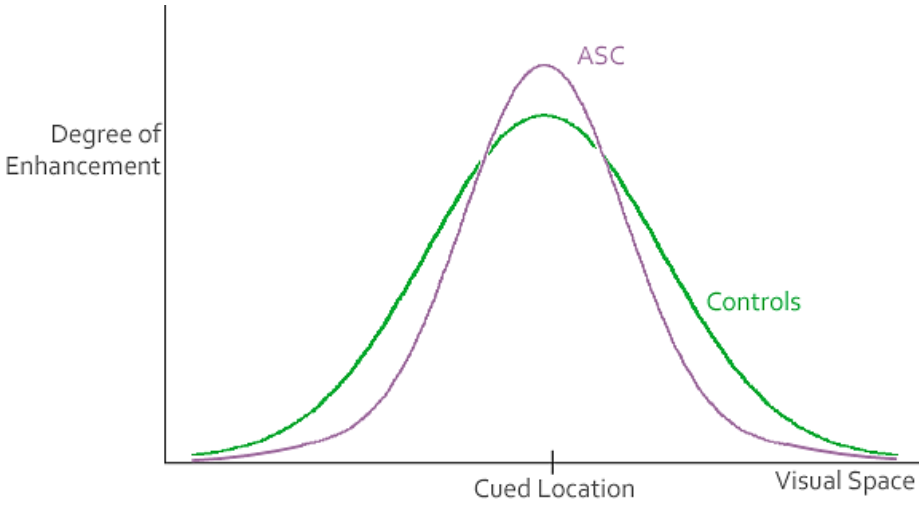

Figure 1: Schematic of the hypothesised distribution of attentional enhancement around a cued location in autistic and non-autistic subjects.

2. METHODS

2.1 Subjects

We recruited 43 adult participants (22 with high-functioning autism) to participate in the study. All patients were diagnosed by a clinician specialised in the assessment and diagnosis of individuals with ASC, according to the criteria for an autism spectrum disorder (American Psychiatric Association, 1994). Participants had normal or corrected-to-normal vision. The two groups were matched for age and non-verbal IQ, as assessed by the Performance scale of the Wechsler Abbreviated Scale of Intelligence (WASI). Additionally, all participants were asked to complete the Autism Spectrum Quotient (AQ) (Baron-Cohen et al., 2001), designed to measure traits associated with ASC among the general population. The Autism Diagnostic Observation Schedule (ADOS, Lord et al., 2000) was administered to autistic participants, designed to assess communication and social symptoms in autistic participants.

Participants were recruited from the University of Cambridge's Autism Research Centre volunteer database and received money as compensation for their time. Written consent was obtained from all participants in accordance with a protocol approved by the University of Cambridge Psychology Research Ethics Committee.

	ASC Participants	Control Participants	Independent t-test
IQ	116.1 (st.dev.=13.0)	117.7 (st.dev.=9.1)	t=0.449 (p=0.656)
Age	32.3 (st.dev.=8.4)	30.85 (st.dev.=7.7)	t=-0.568 (p=0.574)

Table 1: Mean non-verbal IQ and age of the two groups. t-tests show that the two groups are matched on both measures. For scatter plots and full descriptive statistics, see Figure 7 (Appendix).

2.2 Apparatus

The task was displayed in a dark room using a Tobii t120 screen (Tobii Technology) that also recorded eye movements. Scripts for the task were written in MatLab 2011Ra Psychtoolbox. The subjects rested their head on a chinrest, positioned 57 cm from the screen. Responses were indicated by key press.

2.3 Experimental Procedure & Stimuli

The task is a basic visual acuity task using exogenous attentional cues (Carrasco et al., 2000). The display shown to the participants was a dark screen with a fixation cross at the centre. Each individual trial consisted of a cue presentation, an inter-stimulus interval (ISI), and a target presentation. The cue was presented for 67ms, the ISI could either be 67, 135 or 210ms, and the target was presented for 67ms. A new trial was presented 500 ms after the previous response was given, and there was auditory feedback for wrong responses.

The cue was a white dot that appeared on the horizontal, either to the left or to the right of the fixation cross, and it always validly predicted the hemifield the target would appear in. The target was a Landolt C (Bach, 1996) and could appear +/- 15, 30 or 45° from the horizontal, on an arc that had a radius of 9° from the fixation cross (Figure 2). The target was 0.5° wide. The task was to identify whether the direction of opening of the target was up or down. Alongside the target, a full circle (distractor) was presented exactly opposite the target (Figure 2C).

With 3 distances and 3 ISIs, there were 9 possible conditions. Each contained 128 trials. These 1152 trials were split into 12 sets of 96 trials, in between which subjects took breaks.

Accuracy of response and reaction time were recorded by the script as measurements of the subjects' performance.

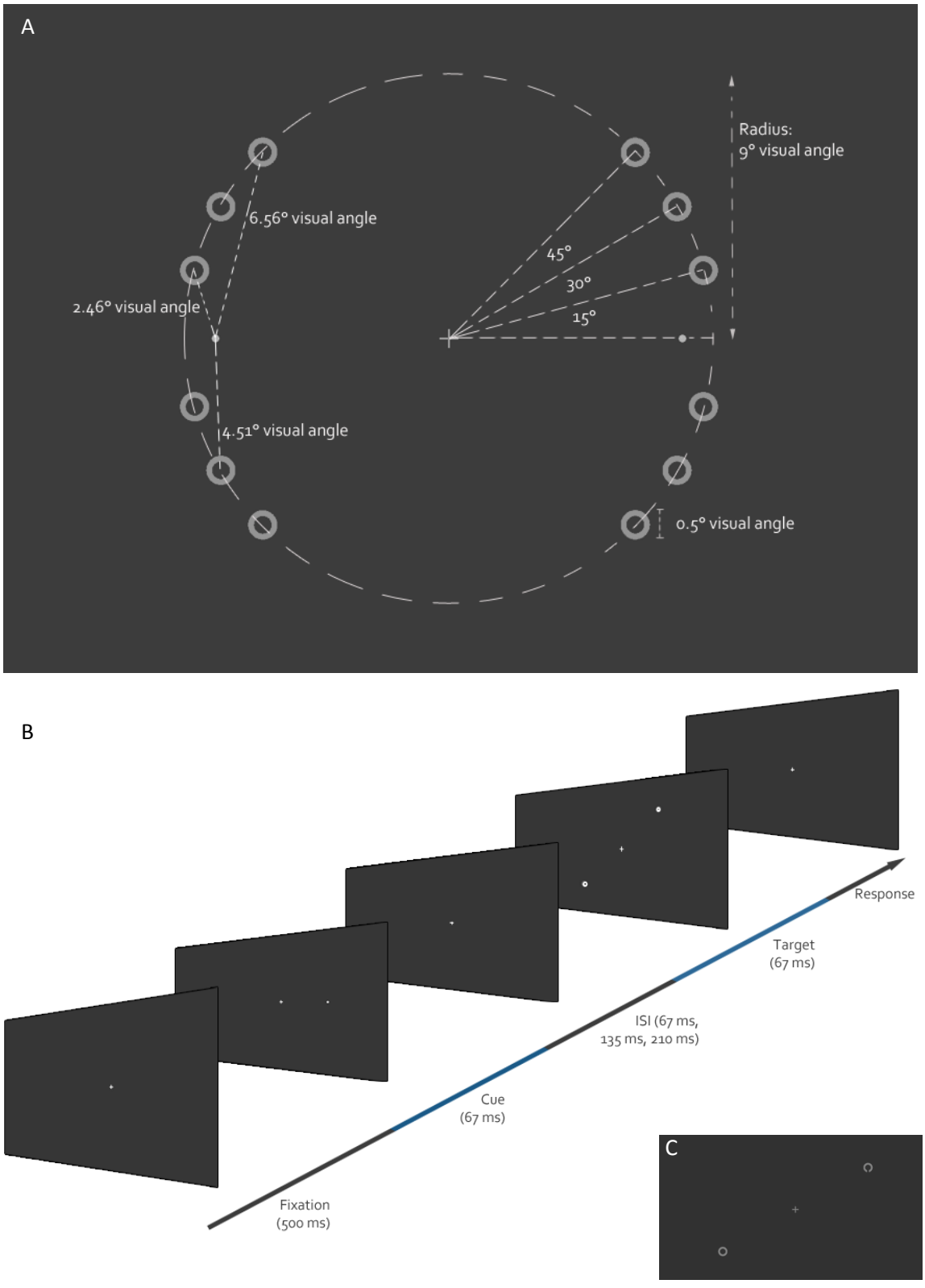

Figure 2: A: The possible positions of targets, along with all parameters. A distractor was always shown exactly 180° opposite the target. The distractor was shown 180° opposite. **B:** The time course of a single trial. The contrast was raised for illustrational purposes. **C:** One target / distractor display.

2.4 Threshold Determination

Subjects were allowed to practice the task, first for 10 trials in a slow condition in which the target remained on the screen until participants responded while they were allowed to move their eyes across the screen. Once it was clear they understood the task, they practiced an additional 96 trials under experimental conditions. Afterwards, the luminance of the target at which subjects achieved 75% correct on the most distant and shortest ISI condition was determined. This was done in order to avoid ceiling or floor effects and to present the task to each subject at subjectively the same difficulty.

The procedure used was a staircase procedure in which the luminance of the target was raised by 7.5% when the subjects gave a wrong response, and lowered when the subjects gave a correct response (by 2.5%) (after Yu & Levi, 2000). Background luminance was kept constant (RGB value [60, 60, 60]). Due to the 75/25 weighting of the adjustment, the average of reversion points statistically yields the point at which 75% accuracy is achieved.

A check was done after the first set of 96 experimental trials, and if performance was above 85% or below 65% on the condition that we thresholded at (furthest distance, shortest ISI), the experiment was stopped and the thresholding was repeated.

2.5 Analysis

We excluded participants if their threshold value was more than two standard deviations above or below the mean , on the assumption that outliers in this measure had inadequate vision correction they were not aware of. This led to the exclusion of one participant in the control group and one in the ASC group. We further excluded two participants in the ASC group: one because of an inability to complete the WASI

assessment, and one because her overall performance on the thresholded condition was below 65%.

Also excluded were all responses with reaction time was lower than 100 ms, assuming that those responses are random guesses which are caused by the mere appearance of the cue.

We analysed accuracy, reaction time (RT) and "efficiency scores" using repeated measures ANOVA (Within-subject factors: ISI, distance from cue; Between-subject factors: Group). Efficiency scores incorporate accuracy as well as reaction time into a single measure of performance, calculated as reaction time divided by accuracy. This accounted for any individual differences in 'speed-accuracy trade-offs' (see i.e. Nixon et al., 1998).

For the correlational analysis and effect size estimation, we collapsed performance across ISIs after normalising within the ISI conditions. This normalisation was done by taking the mean value of both groups combined at every ISI and subtracting it from each individual's value. The resulting values were divided by the standard deviation of both groups together. This led to all values expressed in terms of a standard deviation of 1 from a mean of 0, allowing averaging across ISI (for illustration, see Equation 1 in the appendix).

We used the difference of these averaged values on the closest and furthest spatial location, as a measure of attentional enhancement (Rogosa, 1983). This "difference score" score was correlated with our assessment of autistic traits by the AQ and ADOS, and used to identify the effect size of any difference between the groups.

3. RESULTS

3.1 There Is No Difference In Baseline Performance

There was no significant difference between the RGB values at threshold of either group. There was no correlation between the 75% correct threshold and the IQ, age, AQ score, or ADOS score of individuals, indicating that baseline performance on the task is independent of any other measure.

There was also no difference in the gaze stability between the two groups (Average position in the horizontal and vertical, respectively: Control [17.36° +/-1.24°, 10.80° +/- 0.46°]; ASC [17.78° +/1.96°, 10.70° +/- 0.68°].)

3.2 Reaction Time is Higher in the ASC Group

There was no overall difference in accuracy between the two groups ($F(1,36)=1.108$, $p=0.299$). However, on average the ASC participants responded slower than controls ($F(1,36)=4.460$, $p=0.042$). Reaction time (RT) and accuracy both improved close to the cue, as reflected by a significant main effect of distance (Figure 4; Reaction time: $F(2,72)=33.206$, $p<0.001$; Accuracy: $F(2,72)=44.825$, $p<0.001$). In order to take the qualitatively different effects on both measures into account, we used efficiency scores (RT divided by accuracy) as the main measure of performance. This also accounted for individual differences in a speed-accuracy trade-off, where some people tend to take longer to respond with more certainty than others.

The data for accuracy and reaction time is shown in Figure 4; the full ANOVA analyses can be seen in Table 4 and Table 5.

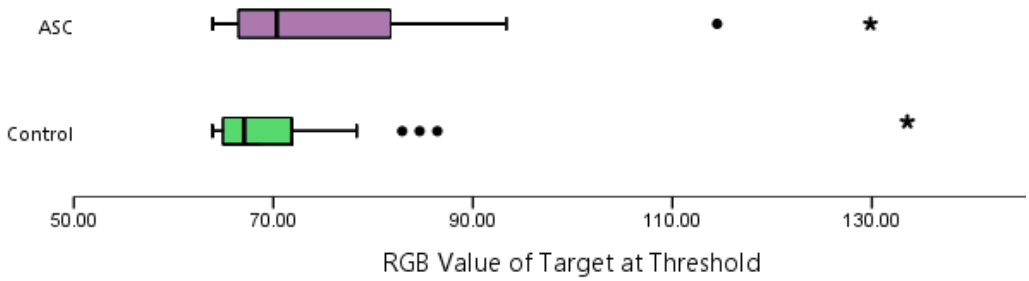

Figure 3: A boxplot showing the distribution of RGB values of the target at 75% Threshold. The two extreme outliers are shown as stars.

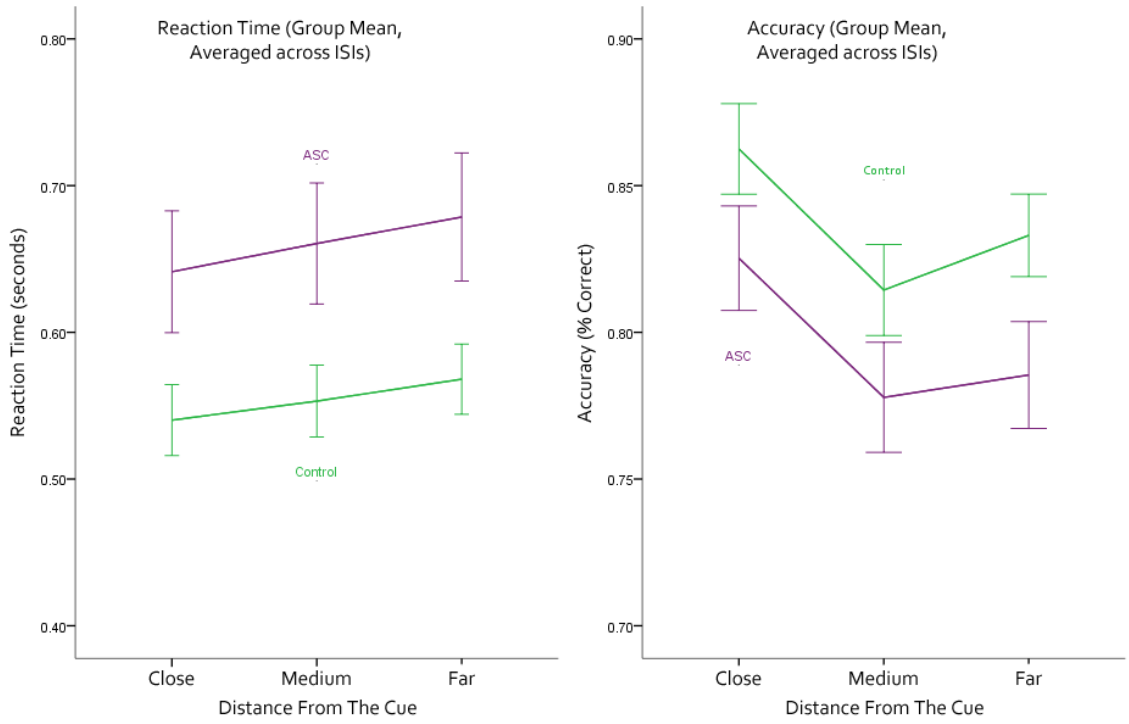

Figure 4: Mean reaction time and mean accuracy plotted against target offset, averaged across ISI. The main effect of group on RT is visible, as are the interaction effect of distance and ISI on RT and the main effects of distance on RT and accuracy. Error bars represent +/- 1 SEM

3.3 Attentional Enhancement Is Sharper in the ASC Group

Analysis of efficiency scores revealed that participants with ASC showed significantly more improvement close to the cue than control participants. Figure 5 shows efficiency scores, normalised for each individual for illustrative purposes. A sharper gradient of performance is visible, and revealed by a significant interaction of group and distance ($F(2,72)=4.305$, $p=0.019$).

To investigate this effect of distance in the two groups, we compared the spatial gradient using difference scores (the difference between the close and distant condition) as measures of the linear component of the slope. The slope was significantly different between the groups: while there was no difference in the fast condition, there was a significant difference of the peak values in the medium and long condition ($p=0.021$ and $p=0.032$, respectively).

The delay between the cue and the target presentation also had a clear effect on performance. This is seen in the increased gradients of attentional enhancement at the medium and long ISIs in Figure 5, and revealed by a main effect of ISI in the ANOVA analysis of efficiency scores ($F(2,72)=5.071$, $p=0.010$). However, this effect was the same for both groups, as indicated by a lack of interaction between ISI and group ($F(2,72=0.523$, $p=0.584$).

To estimate the effect size of the difference between the groups, we divided the average linear slope of the autistic group by that of the control group. ASC participants had, on average, 1.898 times the slope of control participants.

An ANCOVA, performed by considering the same factors as above while co-varying for IQ and age, in order to exclude all possible influences these measures could have on performance, produced no quantitative differences in our effects. For the full ANOVA summaries, see Table 4 (Appendix).

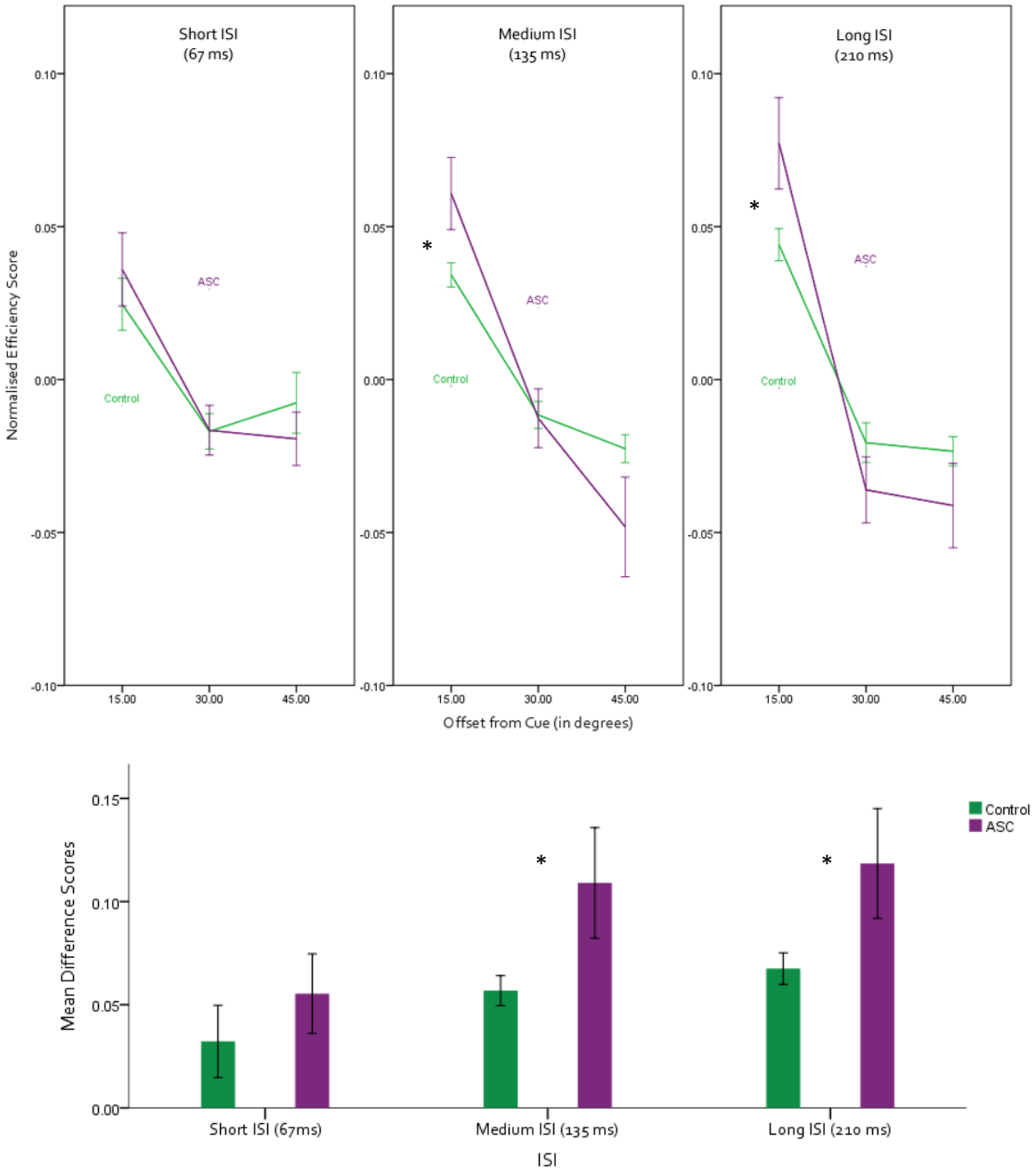

Figure 5: A: Normalised performance of the two groups, shown in the three different ISI conditions. Shown is the sharper attentional enhancement across space as well as the growth of the attentional enhancement over time. The full lines represent the ASC group, the dotted lines the control group. The main effect of group was removed by subtracting the mean score of individuals at each ISI. **B:** Bar charts of the mean difference scores of the two groups at each ISI. The stars indicate significant differences between the difference scores. Error bars represent +/- 1 SEM

3.4 Autistic Symptomology Correlates with Attentional Enhancement

Not only was an increased attentional enhancement a feature of the ASC group, but the degree of enhancement was significantly correlated with autistic symptomology in the ASC group as well as the control group. For the correlational analysis, we were able to average difference scores across ISIs due to the fact that the effect of ISI was equal in the two groups. We corrected for the ISI effect by normalising within each ISI condition before averaging (see Section 2.5 (Analysis) and Equation 1 (Appendix)).

We found a significant correlation between the AQ scores and the difference scores, as well as a significant correlation between the ADOS scores and the difference scores. On further investigation, we found that the correlation between AQ scores and difference scores only holds in the control group, while there is no correlation in the ASC group. Scatter plots of the distribution of difference scores against AQ and ADOS scores can be seen in Figure 7.

The difference scores did not correlate with age or IQ.

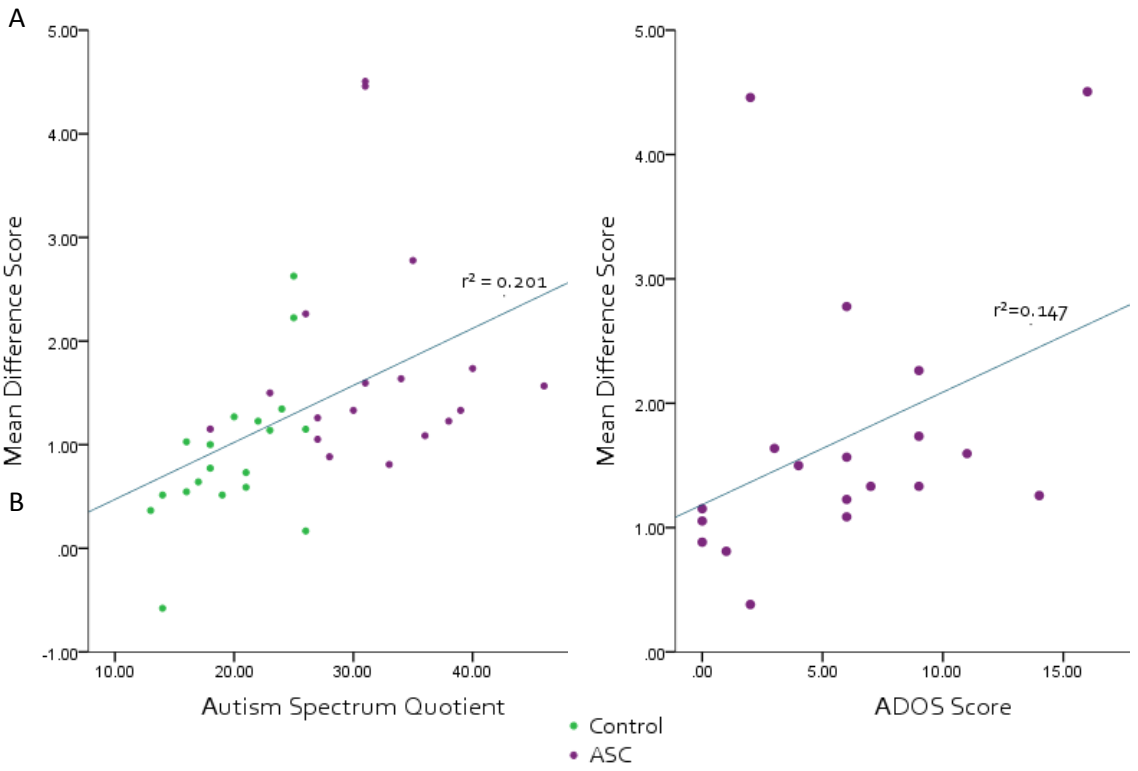

Figure 6: Scatter plots of the mean difference score (taken between the position closest and the position most distant to the cue), plotted against AQ scores (A) and ADOS scores (B). Lines of best fit are shown, along with adjusted r^2 values of a linear regression analysis.

Difference Scores & AQ Scores	Difference Scores & ADOS Scores
Spearman's ρ = 0.626 p<0.001; N = 39	Spearman's ρ = 0.554 p = 0.014; N = 19

Table 2: Correlation coefficients between the difference scores and the AQ and ADOS scores.

4. DISCUSSION

4.1 Attentional Enhancement and Autistic Perception

The results confirm the hypothesis that there is a sharper, contracted attentional enhancement in ASC. The interaction between group and distance, along with the t-tests of the peak difference, show that there is a steeper slope of attentional enhancement across space. The correlations between difference scores and autistic traits and symptoms suggests that this is a definitive characteristic of the perceptual profile of autism.

A delayed rise of enhancement was not observed in autism, indicating that an atypical temporal profile is not a fundamental part of autistic attention. However, the significantly higher reaction times in the autistic group do indicate that autistic subjects require more time for equally accurate responses. This may lie within the steps that are required by this task post-perception, such as the decision process or the motor process required to actually respond. It could reflect different strategies adopted by subjects in the two groups.

Ultimately, these results provide an insight into a fundamental mechanism of autistic perception. A sharper attentional curve leads to a higher signal to noise ratio in the autistic visual system, leading to improved performance on a wide variety of low-level perceptual tasks. With this in mind, it is possible to hypothesise about sharpened 'curves' in other systems, since retinotopy is not the only cellular architecture in the visual system. At the level of V1, there are orientation pin-wheels (Ohki et al., 2006) in which neurons possess tuning curves of orientation selectivity and are laterally inhibited by neurons which respond to different orientations (Blakemore and Tobin, 1972). Equally, LI is employed in the auditory cortex (Pantev et al., 2004). Enhanced lateral connectivity would predict increased stimulus discrimination, as found in sub-populations of ASC using frequency discrimination (Jones et al., 2009), and in visual search tasks where discriminability is the limiting factor (O'Riordan and Plaisted, 2001).

4.2 Neurobiological Mechanisms

It is impossible to infer from this behavioural data the exact neural underpinnings that cause it. What makes it particularly difficult to form a conclusive interpretation of this data is the fact that the task positions itself between saliency effects and exogenous attentional influences, originating from V1 and the parietal cortex, respectively. However, retinotopic mapping is ubiquitous in the visual system, from the occipital to the parietal cortex (Saygin and Sereno, 2008), so any atypical lateral interactions would affect both processes in a similar way. The results in this experiment support a tighter columnar organisation of retinotopic space and stronger lateral connectivity.

While there is consensus that lateral or horizontal connectivity is indeed atypical in ASC, there is much debate about how it is atypical. One line of evidence has long supported a shift in the balance between excitation and inhibition (E/I) towards excitation (Rubenstein and Merzenich, 2003). Experiments indicate that GABAergic inhibition is impaired in ASC: mouse models of autism show defect GABA cells in critical periods of plasticity (Gogolla et al., 2009), and impaired GABA signalling in later life (Pizzarelli and Cherubini, 2011). This reduced inhibition is also supported by the high prevalence of epilepsy in the ASC population (Canitano, 2007), a disorder associated with excitability of the cortex. However, the E/I theory mainly focuses on non-perceptual features and on hypersensitivity in autism (mainly found within the auditory and somatosensory domain).

Conversely, multiple lines of evidence also point towards the exact opposite: that lateral inhibition in the visual system is increased, and that this may lead to enhanced perception. For example, replicating a genetic mutation that is linked to autism actually increases GABAergic synapse formation (Tabuchi et al., 2007). Furthermore, urine samples from autistic individuals show elevated GABA metabolism products (Dhossche et al., 2002).

But what is striking about this theory of increased inhibitory synapse formation is its congruency with behavioural. It predicts the larger effect of spatially adjacent flankers in

ASC individuals, and it also predicts increased discriminatory abilities (Bertone et al., 2005; Jones et al., 2009; Kéïta et al., 2011b). It also predicts exactly what was shown in this experiment – a sharper attentional curve across retinotopic space.

4.3 Conclusion and Further Directions

Further research in this area is necessary. One obvious and important experiment to carry out would be an analysis of receptive field sizes within primary visual cortex using, for example, fMRI (Smith et al., 2001) – smaller receptive fields in V1 may be key to atypical lateral interactions.

Additionally, attentional involvement could be removed by using facilitation of cues that the subjects are unaware of. This has been done by Zhang et al. (2012), in an experiment in which they presented cues at low threshold levels and for very short amounts of time, but which still produced cue effects. This removed the possibility of voluntary, executive shifts of attention and produced a measurable effect of a saliency map in V1 that was visible in fMRI data. Mapping the effect of distance to the cue for a task using these below-awareness stimuli would thus elucidate the spread of a purely V1-based saliency map.

While this experiment is unable to form conclusions about the neurobiology about autistic perception, it supports a possible over-connectivity of inhibitory interneurons, at least in the visual system, and provides a possible mechanism underlying the EPF theory. A narrower attentional field is a fundamental property of autistic vision, and in early childhood this will have a large impact on the way the child understands the world. It is important to understand the implications of this finding, for our understanding of the neurobiology of autism and of autistic individuals themselves.

ACKNOWLEDGMENTS

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APPENDIX

Figure 7: Scatter plots of the distributions of age and IQ within the control and the ASC group.

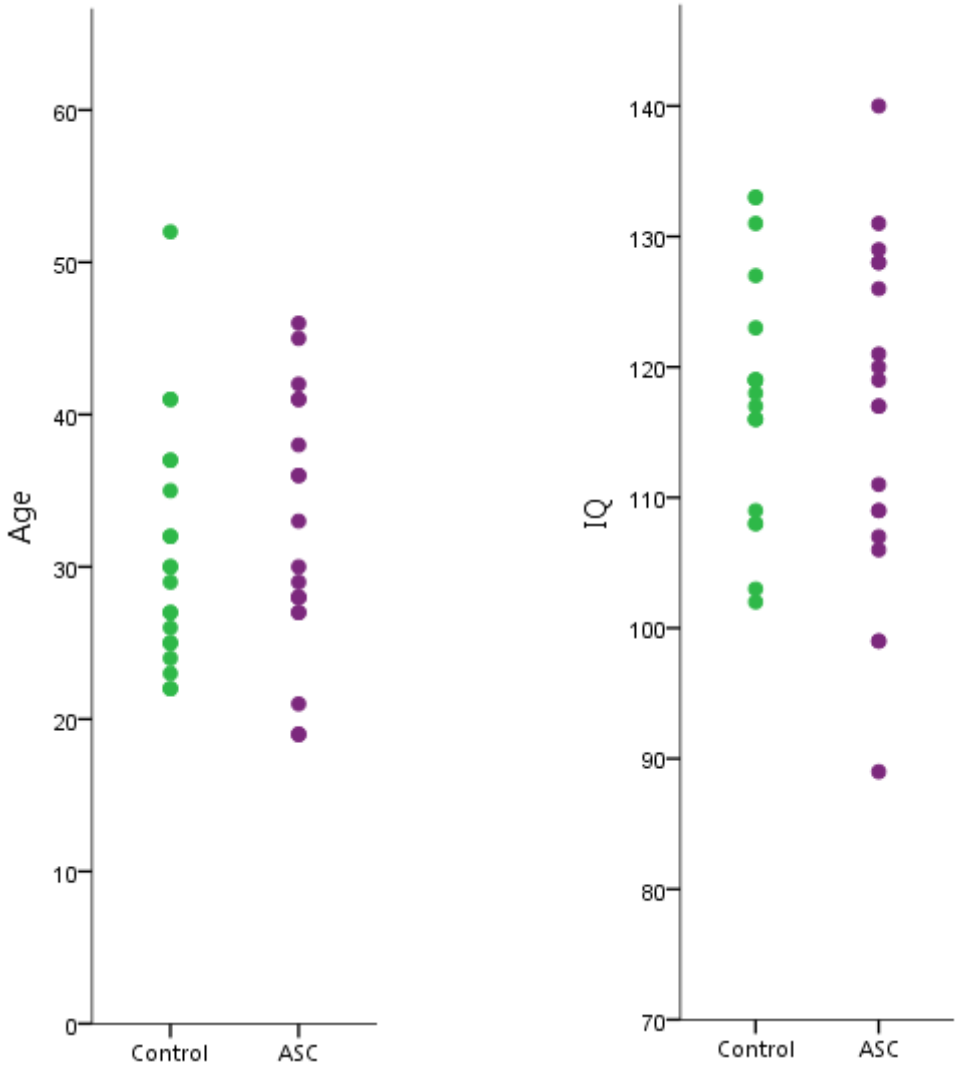

Table 3: Descriptive statistics on the distribution of IQ and age.

		N	Minimum	Maximum	Mean	Std. Deviation
ASC	Age	20	22	52	30.85	7.748
	IQ	19	102.00	133.00	117.6842	9.13511
	Valid N (listwise)	19[1]				
Control	Age	19	19	46	32.32	8.380
	IQ	19	89.00	140.00	116.0526	12.95494
	Valid N (listwise)	19				

[1]**One of the IQ scores in the control group went missing.**

Table 4: Full ANOVA analysis table of Reaction Time. Values mentioned are highlighted.

Tests of Within-Subjects Effects

Measure: ReactionTime

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
ISI	Sphericity Assumed	.017	2	.009	7.687	.001
	Greenhouse-Geisser	.017	1.456	.012	7.687	.003
	Huynh-Feldt	.017	1.543	.011	7.687	.003
	Lower-bound	.017	1.000	.017	7.687	.009
ISI * diagnosis	Sphericity Assumed	.000	2	.000	.132	.877
	Greenhouse-Geisser	.000	1.456	.000	.132	.810
	Huynh-Feldt	.000	1.543	.000	.132	.824
	Lower-bound	.000	1.000	.000	.132	.719
Error(ISI)	Sphericity Assumed	.080	72	.001		
	Greenhouse-Geisser	.080	52.398	.002		
	Huynh-Feldt	.080	55.556	.001		
	Lower-bound	.080	36.000	.002		
Distance	Sphericity Assumed	.071	2	.035	33.206	.000
	Greenhouse-Geisser	.071	1.675	.042	33.206	.000
	Huynh-Feldt	.071	1.797	.039	33.206	.000
	Lower-bound	.071	1.000	.071	33.206	.000
Distance * diagnosis	Sphericity Assumed	.004	2	.002	1.928	.153
	Greenhouse-Geisser	.004	1.675	.002	1.928	.161
	Huynh-Feldt	.004	1.797	.002	1.928	.158
	Lower-bound	.004	1.000	.004	1.928	.173
Error(Distance)	Sphericity Assumed	.077	72	.001		
	Greenhouse-Geisser	.077	60.318	.001		
	Huynh-Feldt	.077	64.679	.001		
	Lower-bound	.077	36.000	.002		
ISI * Distance	Sphericity Assumed	.015	4	.004	4.971	.001
	Greenhouse-Geisser	.015	2.099	.007	4.971	.008
	Huynh-Feldt	.015	2.293	.007	4.971	.007
	Lower-bound	.015	1.000	.015	4.971	.032
ISI * Distance * diagnosis	Sphericity Assumed	.005	4	.001	1.574	.185
	Greenhouse-Geisser	.005	2.099	.002	1.574	.213
	Huynh-Feldt	.005	2.293	.002	1.574	.211
	Lower-bound	.005	1.000	.005	1.574	.218
Error(ISI*Distance)	Sphericity Assumed	.110	144	.001		
	Greenhouse-Geisser	.110	75.554	.001		
	Huynh-Feldt	.110	82.565	.001		
	Lower-bound	.110	36.000	.003		

Tests of Between-Subjects Effects

Measure: ReactionTime
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	128.725	1	128.725	506.745	.000
diagnosis	1.133	1	1.133	4.460	.042
Error	9.145	36	.254		

Table 5: Full ANOVA Analysis of Accuracy. Values mentioned are highlighted.

Tests of Within-Subjects Effects

Measure: Accuracy

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
ISI	Sphericity Assumed	.004	2	.002	1.335	.270
	Greenhouse-Geisser	.004	1.907	.002	1.335	.269
	Huynh-Feldt	.004	2.000	.002	1.335	.270
	Lower-bound	.004	1.000	.004	1.335	.255
ISI * diagnosis	Sphericity Assumed	.002	2	.001	.631	.535
	Greenhouse-Geisser	.002	1.907	.001	.631	.528
	Huynh-Feldt	.002	2.000	.001	.631	.535
	Lower-bound	.002	1.000	.002	.631	.432
Error(ISI)	Sphericity Assumed	.104	72	.001		
	Greenhouse-Geisser	.104	68.665	.002		
	Huynh-Feldt	.104	72.000	.001		
	Lower-bound	.104	36.000	.003		
Distance	Sphericity Assumed	.141	2	.070	44.825	.000
	Greenhouse-Geisser	.141	1.973	.071	44.825	.000
	Huynh-Feldt	.141	2.000	.070	44.825	.000
	Lower-bound	.141	1.000	.141	44.825	.000
Distance * diagnosis	Sphericity Assumed	.003	2	.002	1.069	.349
	Greenhouse-Geisser	.003	1.973	.002	1.069	.348
	Huynh-Feldt	.003	2.000	.002	1.069	.349
	Lower-bound	.003	1.000	.003	1.069	.308
Error(Distance)	Sphericity Assumed	.113	72	.002		
	Greenhouse-Geisser	.113	71.028	.002		
	Huynh-Feldt	.113	72.000	.002		
	Lower-bound	.113	36.000	.003		
ISI * Distance	Sphericity Assumed	.003	4	.001	.998	.411
	Greenhouse-Geisser	.003	3.563	.001	.998	.406
	Huynh-Feldt	.003	4.000	.001	.998	.411
	Lower-bound	.003	1.000	.003	.998	.325
ISI * Distance * diagnosis	Sphericity Assumed	.003	4	.001	.877	.479
	Greenhouse-Geisser	.003	3.563	.001	.877	.470
	Huynh-Feldt	.003	4.000	.001	.877	.479
	Lower-bound	.003	1.000	.003	.877	.355
Error(ISI*Distance)	Sphericity Assumed	.123	144	.001		
	Greenhouse-Geisser	.123	128.254	.001		
	Huynh-Feldt	.123	144.000	.001		
	Lower-bound	.123	36.000	.003		

Tests of Between-Subjects Effects

Measure: Accuracy

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	234.737	1	234.737	5673.458	.000
diagnosis	.046	1	.046	1.108	.299
Error	1.489	36	.041		

Table 6: Full ANOVA Analysis of Efficiency Scores. Values mentioned are highlighted.

Tests of Within-Subjects Effects

Measure: EfficiencyScore

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
ISI	Sphericity Assumed	.036	2	.018	5.071	.009
	Greenhouse-Geisser	.036	1.881	.019	5.071	.010
	Huynh-Feldt	.036	2.000	.018	5.071	.009
	Lower-bound	.036	1.000	.036	5.071	.031
ISI * diagnosis	Sphericity Assumed	.004	2	.002	.523	.595
	Greenhouse-Geisser	.004	1.881	.002	.523	.584
	Huynh-Feldt	.004	2.000	.002	.523	.595
	Lower-bound	.004	1.000	.004	.523	.474
Error(ISI)	Sphericity Assumed	.253	72	.004		
	Greenhouse-Geisser	.253	67.704	.004		
	Huynh-Feldt	.253	72.000	.004		
	Lower-bound	.253	36.000	.007		
Distance	Sphericity Assumed	.372	2	.186	56.673	.000
	Greenhouse-Geisser	.372	1.891	.197	56.673	.000
	Huynh-Feldt	.372	2.000	.186	56.673	.000
	Lower-bound	.372	1.000	.372	56.673	.000
Distance * diagnosis	Sphericity Assumed	.028	2	.014	4.305	.017
	Greenhouse-Geisser	.028	1.891	.015	4.305	.019
	Huynh-Feldt	.028	2.000	.014	4.305	.017
	Lower-bound	.028	1.000	.028	4.305	.045
Error(Distance)	Sphericity Assumed	.236	72	.003		
	Greenhouse-Geisser	.236	68.070	.003		
	Huynh-Feldt	.236	72.000	.003		
	Lower-bound	.236	36.000	.007		
ISI * Distance	Sphericity Assumed	.036	4	.009	3.619	.008
	Greenhouse-Geisser	.036	2.504	.014	3.619	.022
	Huynh-Feldt	.036	2.781	.013	3.619	.018
	Lower-bound	.036	1.000	.036	3.619	.065
ISI * Distance * diagnosis	Sphericity Assumed	.005	4	.001	.481	.750
	Greenhouse-Geisser	.005	2.504	.002	.481	.662
	Huynh-Feldt	.005	2.781	.002	.481	.682
	Lower-bound	.005	1.000	.005	.481	.492
Error(ISI*Distance)	Sphericity Assumed	.358	144	.002		
	Greenhouse-Geisser	.358	90.145	.004		
	Huynh-Feldt	.358	100.116	.004		
	Lower-bound	.358	36.000	.010		

Tests of Between-Subjects Effects

Measure: EfficiencyScore

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	192.599	1	192.599	429.977	.000
diagnosis	2.521	1	2.521	5.627	.023
Error	16.125	36	.448		

Equation 1: Calculation of difference scores and effect size

For each ISI, scores were normalised in terms of the total variance and the total mean (of both groups together) within that ISI.

$$x'_{ISI} = \frac{x - Mean_{Total}}{St.Dev._{Total}}$$

These normalised scores were then averaged across ISIs for each individual.

$$x'_{collapsed} = \frac{x'_1 + x'_2 + x'_3}{3}$$

The difference scores between the closest and furthest target position was then calculated using these adjusted averaged values.

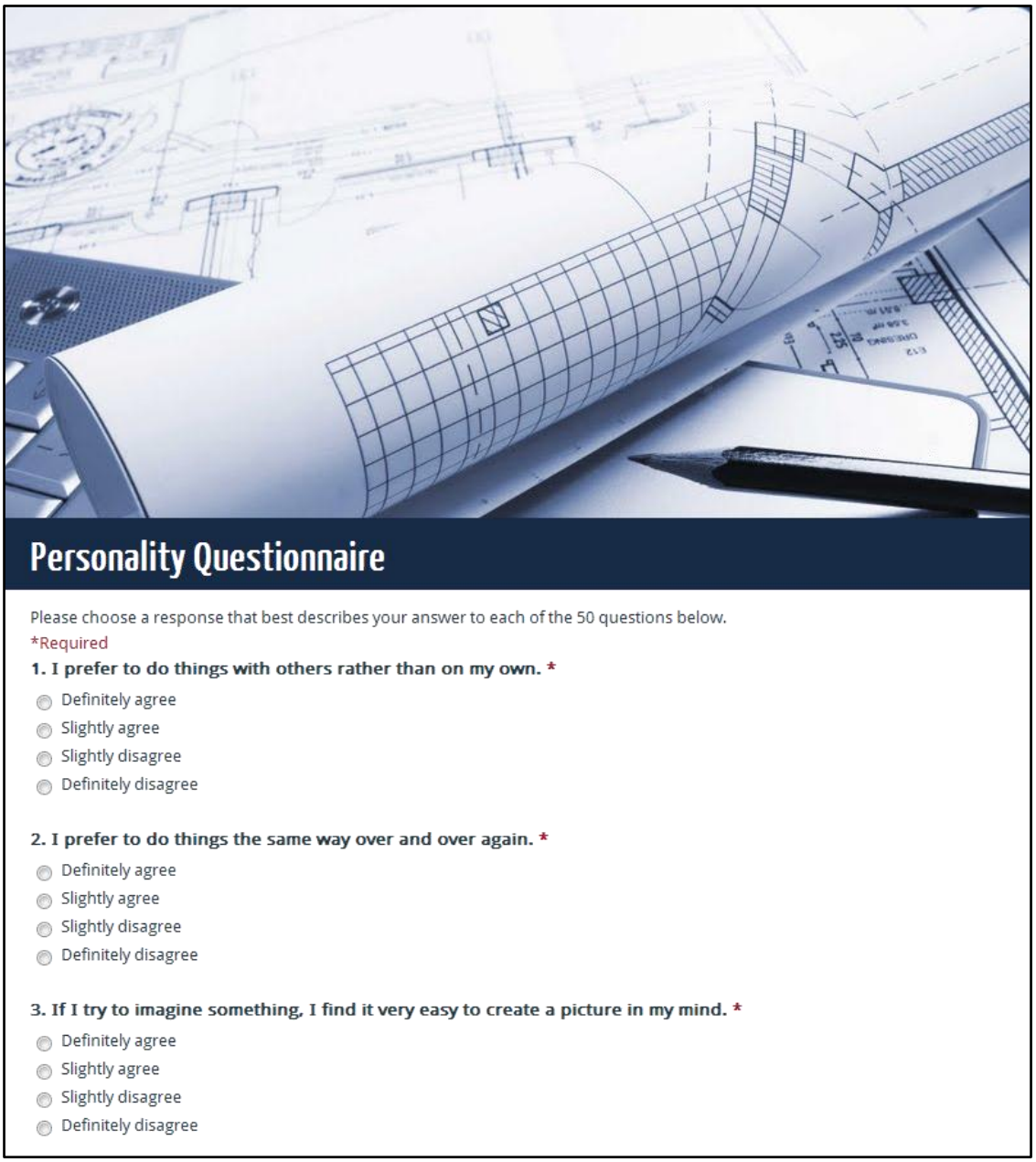

Figure 8: A screenshot of the way the Autism Spectrum Quotient was presented to subjects. All other questions (50 in total) were presented lower on the same website and in the same format. It was entitled 'Personality Questionnaire' to avoid people from being influenced by the more loaded title 'Autism Spectrum Quotient'.