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Looking, Seeing and Believing in Autism: Eye Movements reveal how subtle cognitive processing differences impact in the social domain.

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Looking, Seeing and Believing in Autism: Eye Movements reveal how subtle

cognitive processing differences impact in the social domain.

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Lay Abstract

Adults with High Functioning Autism (ASD) viewed scenes with people in them, whilst having their eye movements recorded. The task was to indicate, using a button press, whether the pictures were normal, or in some way weird or odd. Oddities in the pictures were categorized as violations of either perceptual or social norms. Compared to a Typically Developed (TD) control group, the ASD participants were equally able to categorise the scenes as odd or normal, but they took longer to respond. The eye movement patterns showed that the ASD group made more fixations and revisits to the target areas in the odd scenes compared to the TD group. Additionally, when the ASD group first fixated the target areas in the scenes, they failed to initially detect the social oddities. These two findings have clear implications for processing difficulties in ASD for the social domain, where it is important to detect social cues on-line, and where there is little opportunity to go back and recheck possible cues in fast dynamic interactions.

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Scientific Abstract

Autistic Spectrum Disorder (ASD) and Typically Developed (TD) adult participants had to decide whether scenes were 'odd', 'unusual' or 'weird'. All scenes contained people, with 'oddness' operationally defined as either perceptual or social. There were no group differences in accuracy, but the ASD group were slower overall to respond manually. Eye movements revealed that the ASD group made more fixations overall and more re-fixations into the target regions of the pictures, for both conditions. Importantly, as indexed by the first fixation duration the ASD group failed to 'pick up' immediately on what was 'odd' for the social violations. The propensity to 'go back' and re-fixate targets, coupled with a failure to initially detect social violations, has obvious significance for ASD in fast dynamic social communication.

Key phrases: Autism Spectrum Disorder, Eye movements, On-line cognitive processing, Social and Perceptual Oddities.

Looking, Seeing and Believing in Autism: Eye Movements reveal how subtle cognitive

processing differences impact in the social domain.

Autism spectrum disorders (ASD) are lifelong neuro-developmental conditions characterized by repetitive behaviours and impairments in interaction and communication (American Psychiatric Association, 2013). Incidence rates are rising across the globe with the prevalence rate in the UK approximately 10 per 1000 (1%) individuals (Brugha et al., 2011) and the UK National Audit office recently called for more research into adults with ASD (Clark et al., 2009).

High functioning adults with ASD are similar to typically developed (TD) adults in terms of performance on pencil and paper and IQ tests, however in the social domain evidence suggests an inability to process social information in a typical fashion. Eye movement studies report unusual gaze behaviour for faces appearing on their own (Dalton et al., 2005), in social scenes (Riby & Hancock, 2009) or in dynamic movie clips (Klin & Jones, 2006; Speer et al., 2007). Research consistently reports a lack of spontaneous gaze fixation towards the eyes (Jones et al., 2008; Klin et al., 2002a; Pelphrey et al., 2002). However, where one study reports impairments, say for face processing (Klin et al., 2002b), another study does not (Fletcher-Watson et al., 2009). Moreover, lack of attentional modulation for social stimuli (Bird et al., 2006) may be overridden, as when cued, attention may be allocated to faces in a more 'typical' manner (Bar-Haim et al., 2006).

A recent scene perception study (Louwerse et al., 2014) reported that abnormal autonomic responses in ASD are unlikely to underpin social processing impairments. It is interesting then to ask whether impairments in the cognitive domain in ASD (Happé & Frith, 2006; Minshew et al., 1997; Russell, 1997) could account for impairments in the social domain?

Current cognitive theories of ASD include, among others, Weak Central Coherence (WCC) theory (Frith & Happé, 1994; Happé & Frith, 2006) which proposes that a reduced sensitivity to global context in favour of focussing on details, results in integration difficulties in ASD. Executive function theory (Russell, 1997), proposes that ASD are impaired at switching their focus of attention, and may engage is perseverative behaviour. Alternatively, the Complex Information Processing theory (Minshew & Goldstein, 1998) proposes that individuals with ASD have impairments in processing complex information with intact processing for tasks that require simple (rule based) processing. Finally, the Extreme Male Brain (EMB) theory (Baron-Cohen, 2002) posits that individuals with ASD have above average levels of systemizing, that contribute to the non-social characteristics of the disorder, coupled with below average levels of empathizing, which results in atypical social functioning. These contemporary theories of ASD can, for different reasons, offer some account of ineffective social functioning in ASD. However, to date very few investigations have examined processing differences as these occur on-line in ASD.

Our studies investigating cognitive processing in adults with ASD (Au-Yeung et al., 2011; Au-Yeung et al., 2013; Benson et al., 2012; Benson et al., 2009; Benson & Fletcher-Watson, 2011) have found subtle on-line processing differences, as revealed by eye movements, for a range of tasks that are more in line with Minshew and Goldsteins (1998) theory, than with any other. For example, there are more similarities than differences in eye movements between TD and ASD groups for simple rule based tasks in the attentional (Kuhn et al., 2010) and the social domains (Benson & Fletcher-Watson, 2011). Whereas for more complex abstract reasoning tasks where there is ambiguity with relation to target items (Au-Yeung et al., 2013), or where value judgements rely on top down knowledge (Benson et al., 2012), there are early

processing differences indicating that initial orienting to, and immediate detection of weird target items in scenes is absent in ASD. Moreover, the time to respond and to locate the weird target items was modulated by whether or not the pictures had people in them (Benson et al., 2012). These differences have potential for impact on everyday activities, since the time course for detection of socially relevant information is crucial for successful everyday interactions.

The aim of the present study was to examine whether increased times to find and initially detect an unusual target in a scene would be modulated by whether the violation that rendered the target unusual or odd could be categorised as social or perceptual. We employed a similar paradigm to that used in a previously reported study (Rayner et al., 2009) where single scenes, all with people in them, were presented in isolation and the task was to indicate whether each picture was normal or in some way weird unusual or odd.

Insert Figure 1. about here

Social oddities in the pictures were operationally defined as violations of social norms e.g. someone in the picture throwing a baby in the air. Access to top down knowledge is required in that condition to inform a subjective value judgement as to whether a social violation is present in the picture. No value judgement as to whether a violation infringes some implicit or explicit social rule is needed for the perceptual oddities in this study, which are operationally defined as physical violations e.g. someone in the picture has a limb positioned back to front. See supplementary information for Materials. Figure 1 shows an example of the stimuli.

Method

Participants

ASD participants (n = 24 age 18 – 52 years, 20 males), with a formal diagnosis of either

Autistic Disorder (n = 3) or Asperger's Syndrome were recruited from local charitable

organisations. TD participants (n = 24, age 20– 52 years, 20 males) were volunteers from the

local community. All participants were paid and had normal or corrected to normal vision. Each

ASD participant completed module 4 of the Autism Diagnostic Observation Scale 2 (Lord et al.,

2012) and five (3 males and 2 females with a diagnosis of Asperger's Syndrome) failed to meet

the Autism Spectrum criteria. To ensure maximum homogeneity in our study those five

participants were excluded from the analyses, resulting in a final sample of 19 ASD participants.

Both groups completed the Autism-spectrum Quotient (AQ; Baron-Cohen et al., 2001) and the

ASD participants reported a higher number of autistic traits t (41) = 8.04, p < .001 (TD M =

15.42, SD = 7.55; ASD M = 35.32, SD = 8.45). The two groups did not differ in age t (41) =

0.31, p = .759 (TD M = 30.29, SD = 10.20; ASD M = 31.26, SD = 10.29), performance IQ t (41)

= 0.21, p = .832 (TD M = 111.79, SD = 12.01; ASD M = 110.95, SD = 13.84), verbal IQ t (41) =

1.21, p = .234 (TD M = 116.96, SD = 10.65, ASD M = 112.26, SD = 14.84), or full scale IQ t

(46) = 0.87, p = .392 (TD M = 116.04, SD = 9.98, ASD M = 112.95, SD = 13.48), as measured

by two performance (Block Design and Matrix Reasoning) and verbal components (Vocabulary

and Similarity) of the Weschler Abbrevated Scale of Intelligence (The Psychological

Corporation, 1999).

Eye movement recording

Eye movements were sampled at 1000Hz using an Eyelink tracker with spatial accuracy

of less than 1/4th degree (S.R. Research Ltd, Canada). The start and end of saccades were

detected automatically using a default velocity criterion of 30degrees per second using the

Eyelink software. See Stampe (1993) for an in depth technical description of how the software detects saccades and fixations. A chin rest and forehead support, were used to stabilize head position. Viewing was binocular but data were analysed for the right eye only. Individual participants were calibrated using a nine point matrix that covered the dimensions of the screen (1024 x 768 pixels), with each point fixated sequentially, followed by a validation procedure to ensure that fixation was within 0.5 degrees of each calibration point. Calibration was checked using a validation procedure prior to each trial, whereby participants fixated five dots, presented at five different locations that covered the dimensions of the screen and recalibration was performed if the eyes were off centre for any of these dots.

Materials

In total, 96 full-colour photographs were used as stimuli, all of which contained people. In both the perceptual and social oddity conditions there were 48 pictures (24 weird and 24 normal). Perceptual oddities in the pictures violated a physical norm e.g. someone in the picture has a limb positioned back to front, or a vehicle was in an unexpected position e.g midway through the upper wall of a building. Social oddities in the pictures violated a social norm e.g. someone in the picture throwing a baby in the air, or someone with a cabbage on a lead. A small number of the pictures were from a previous study (Benson et al., 2012) and the remainder were collected from the internet and included either a perceptual or social oddity. Adobe Photoshop was used to prepare a normal version of each scene in which the oddity was replaced with either the background elements or with another suitable object. The scenes typically had a focal object or a central group of objects. Figure 1 shows an example of a normal and a socially odd scene, and below those examples, a normal and a perceptually odd scene. The target regions for these

scenes are outlined in black – but these black outlines were not visible during the presentation of the scenes in the experiment.

A norming study was conducted to verify the validity of the images used to examine the processing of social and perceptual violations. Twenty undergraduates from Queen's university participated (*M* age: 19.8years, *SD*: 1.71, 10 Females) with five participants in each of the four conditions (counterbalanced conditions: weird/normal and right/left button response). Stimuli were displayed on a 21inch CRT monitor with a refresh rate of 100Hz and the experiment was run using E-Prime software. Participants were presented with a fixation cross for 500ms followed by the presentation of the image for 20 seconds or until a keyboard "Y' (yes) or "N" (N) was made. Participants had to indicate as quickly as possible whether the presented image was "odd", "weird" or "unusual" in some way. The proportion of identified images indicated that on average, the social normal (*M* = 0.86, *SD* = 0.15) and social weird (*M* = 0.84, *SD* = 0.17), perceptual normal (*M* = 0.82, *SD* = 0.17) and perceptual weird (*M* = 0.77, *SD* = 0.19) images were identified correctly.

Design

For the behavioural measures of Accuracy and RT a mixed design with Picture Type (weird versus normal) and Oddity Type (social versus perceptual) as within participants variables, and Group (ASD versus TD) as a between participants variable was employed for the experiment. On condition that accuracy was equivalent for both normal and weird pictures, for the eye movement measures the main focus of interest was to compare social versus perceptual oddities in both groups. Therefore a mixed design with Oddity Type (social versus perceptual) as

a within participants variable, and Group (ASD versus TD) as a between participants variable was employed in the eye movement analysis.

Procedure

All participants were shown a hard copy of an example picture from each condition prior to completing the task, to ensure comprehension of the task and the ability to respond appropriately. The specific instruction was 'for each of the following pictures, please indicate whether you think the picture is odd, unusual or strange in some way'.

For the task, 48 pictures were presented randomly to either the left or the right of the centre of a 19inch colour monitor, at a distance of 65cm for 20s or until a button press response was made. Prior to the onset of a picture, participants fixated a cross that was presented on the opposite side of the screen to where the picture was set to appear, to ensure all participants started at the same point in each trial. Once participants fixated this cross, the experimenter initiated each trial. Picture type (normal vs. weird) and, the position of the picture (left or right on the display) were counterbalanced across items. The buttons used to respond either yes or no (left or right trigger button) was counterbalanced across participants.

Data preparation and analyses

For each 'odd' picture we created an interest region around the target item and the corresponding region of the same size in the counterpart 'normal' picture. Regions of interest were created using the approximate average regions from those identified and manually selected by participants who took part in the norming experiment.

Eyelink software was used to detect saccades and fixations using a default velocity criterion and in-house software was used to calculate the distribution of fixations falling into the target region. Five items were removed from analysis because for these scenes, participant accuracy scores were significantly below chance[1]. In addition, each participant was asked whether they had seen any of the scenes previously, and if so these scenes were also removed. This resulted in a loss of 2.3% of trials. Fixations below 90ms and above 1200ms were classed as outliers and removed; resulting in a loss of 5.13% of the fixation data.

Results

For the principal analyses we compared manual reaction times and accuracy (see Table 1), as well as a number of eye movement measures, such as, the time taken to begin fixating in the target region (ELT), the duration of the first fixation when the eyes landed in the target region (FFD) and the mean time (MFD) spent fixating in the target area (see Table. 2). Global eye movement measures for the target region, such as mean fixation duration and mean number of fixations over all trials were also analysed, Finally, baseline measures (not just target related), were calculated across the duration of the trials, to check for overall sampling differences between the ASD and TD participants (see Table 2). See supplementary information for methods and materials.

Behavioural Data

Accuracy. There was no effect of oddity type (perceptual vs. social) $F (1, 41) = 1.44$, $p = .237$, $\eta_p^2 = .03$, picture type (normal or weird) $F (1, 41) = 0.94$ $p = .339$, $\eta_p^2 = .02$, or group, $F (1, 41) = .06$, $p = .808$, $\eta_p^2 < .01$ on accuracy rates, and no interactions (Fs < 2.39, p's $> .130$). At

least in terms of accuracy, performance was the same for both groups. For means and standard deviations for behavioural data see Table 1.

Response Time (RT). A main effect of oddity type $F(1, 41) = 8.16$, $p = .007$, $\eta_p^2 = .17$, showed participants took longer to respond when presented with a perceptual oddity in comparison to a social oddity. Longer response times for perceptual oddities could reflect that these 'impossible', physical violations were so unusual that they resulted in more time spent looking at them prior to responding. See below for confirmation of that in the eye movement data. There was also a main effect of picture type $F(1, 41) = 24.03$, $p < .001$, $\eta_p^2 = .37$, with participants taking longer to respond when the picture was normal in comparison to when it was weird, in line with longer reaction times for target absent trials in standard visual search tasks (Wolfe, 1998). A significant oddity type x picture type interaction $F(1, 41) = 4.22$, $p = .046$, $\eta_p^2 = .09$, demonstrated that the difference between RTs for perceptual and social pictures was reliable for odd (TD; $t(23)$ 2.62, $p = .015$, ASD; $t(18) = 2.98$, $p = .008$) but not for normal pictures (TD; $t(23)$ 0.94, $p = .355$, ASD: $t(18) = 0.08$, $p = .935$). A main effect of group $F(1, 41) = 4.07$, $p = .050$, $\eta_p^2 = .09$, showed the ASD participants had longer reaction times, in line with a previous study (Benson et al., 2012). There were no significant group interactions (Fs < 1) demonstrating both groups to be slower for normal versus odd pictures, and for perceptual vs social oddities. See Table 1 for the means. The eye movement data below reveals subtle processing differences that contribute to this overall slowed manual responding in the ASD group.

Eye Movement Data

Having shown that all participants could distinguish between 'odd' and 'normal' pictures, normal picture trials were excluded from the eye movement analyses resulting in a 2 (group: ASD versus TD) X 2 (oddity type: social versus perceptual) design to investigate on-line processing differences between the two groups for the two types of oddities.

Baseline eye movement measures, calculated across the full length of trials indicated no group difference in mean fixation duration $F (1, 41) = 1.14$, $p = .293$, $\eta_p^2 = .03$, but the ASD group made more fixations overall $F (1, 41) = 9.44$, $p = .004$, $\eta_p^2 = .19$, corresponding to the increased RT's reported above. Table 2 presents a summary of all the eye movement measures.

Elapsed time to the target region (ELT). A marginal effect of oddity type $F (1, 41) = 3.99$, $p = .053$, $\eta_p^2 = .09$, on the time taken from the onset of each trial display to the start of the first fixation on the target region, revealed both groups took less time to fixate the target region when the oddity was perceptual in comparison to social in nature. There was no effect of group $F (1, 41) = 0.59$, $p = .446$, $\eta_p^2 = .01$, and no interaction $F (1, 41) = 0.72$, $p = .401$, $\eta_p^2 = .02$**.**

First Fixation Duration (FFD) on target region. There was no effect of oddity type $F (1, 41) = 1.84$, $p = .182$, $\eta_p^2 = .04$ or group $F (1, 41) = 0.15$, $p = .699$, $\eta_p^2 < .01$ but a significant interaction $F (1, 41) = 6.72$, $p = .013$, $\eta_p^2 = .14$ (See Figure 2) revealed that FFDs were equivalent for perceptual and social oddities for TD participants $t (23) = 0.86$, $p = .399$, $d = .16$, but for ASD participants FFDs for social oddities were significantly shorter, in comparison to perceptual oddities, $t (18) = 2.99$, $p = .008$, $d = .65$, see Figure 2. Given that the FFD is a measure of early processing (Liversedge & Findlay, 2000; Rayner, 1998; Rayner, 2009). This finding indicates

that the ASD group did not detect the social oddities as quickly as the perceptual oddities on initial fixation, whereas TD participants detected both types of oddity equally fast.

Insert Figure 2. about here

First gaze duration (FGD) in the target region. The FGD is the elapsed time from when the target region is first fixated until the eye moves on to a new location. FGD includes multiple fixations in the target region reflects an overt strategy to re-examine an area. A main effect of oddity type, $F (1, 41) = 12.10$, $p = .001$, $\eta_p^2 = .23$ demonstrated that both groups spent more time inspecting perceptual oddities, again highlighting the salience of the perceptual oddities in comparison to social oddities in this study. However, there was no group effect $F (1, 41) = 2.43$, $p = .127$, $\eta_p^2 = .06$, or interaction $F (1, 41) = .08$, $p = .785$, $\eta_p^2 < .01$.

Mean Fixation Count in the target region. If the ASD are slower to respond manually, but do not take longer to begin inspecting the target region, then extra time to respond might reflect more fixations in the target region. A main effect of oddity type $F (1, 41) = 64.27$, $p < .001$, $\eta_p^2 = .61$, demonstrated more fixations in the target region when the oddity was perceptual, rather than social. A main effect of group $F (1, 41) = 6.99$, $p = .012$, $\eta_p^2 = .15$ showed that the ASD group made more fixations than the TD group in the target regions, for both types of oddities. However no interaction was observed $F (1, 41) = 0.77$, $p = .386$, $\eta_p^2 = .02$ indicating that the ASD group made more fixations in the target regions for both types of oddities.

Mean Fixation Duration in the target region. Longer mean fixation durations indicate that more processing has been done during the task. A main effect of oddity type $F(1, 41) = 8.22$, $p = .007$, $\eta_p^2 = .17$ showed significantly longer fixations for social, compared to perceptual oddity target regions. This suggests that processing social oddities was more effortful, and since there was no main effect of group $F(1, 41) = 0.34$, $p = .562$, $\eta_p^2 < .01$, and no interaction $F(1, 41) = 1.12$, $p = .297$, $\eta_p^2 = .03$, both groups on average fixated the social oddity target region for longer than the perceptual target region. Thus, while the perceptual oddities attracted more fixations overall, individual fixations were longer for the social target region.

This interesting juxtaposition, although unrelated to the main aim of this study, suggests that difficulty associated with processing each oddity type manifests in different eye movement patterns: one reflecting an overt strategy (fixation count) to re-inspect the target area, and one reflecting more in depth on-line cognitive processing (fixation duration) on the target areas.

Mean Number of Entries to the target region. Since there were no group differences in FGD, and no increased MFD, both reported above, the delayed RT in ASD might reflect repeated visits to inspect the target region?

A main effect of oddity type was found $F(1, 41) = 9.83$, $p = .003$, $\eta_p^2 = .19$, with the target region entered more often for perceptual oddities in comparison to social oddities. In addition, a main effect of group was found $F(1, 41) = 5.72$, $p = .021$, $\eta_p^2 = .12$, with ASD participants entering the target regions significantly more than the TD group, before making a response. There was no interaction $F(1, 41) = 0.13$, $p = .717$, $\eta_p^2 < .01$.

Mean Total Time in the target region. A higher mean total time means that more attention to, and processing of, information in that region was carried out overall. This measure should complement the measures reported above – namely, that if there are more fixations overall in ASD then the Total Time spent fixating in the target region should be longer in ASD.

A main effect of oddity type $F (1, 41) = 34.89$, $p < .001$, $\eta_p^2 = .46$, showed perceptual oddities received more overall processing time, in line with the previous measures for the perceptual oddities. In addition, a main effect of group $F (1, 41) = 6.41$, $p = .015$, $\eta_p^2 = .14$ revealed that the ASD participants spent a longer period of time inspecting the target regions for both perceptual and social oddities. There was no interaction $F (1, 41) = 0.51$, $p = .481$, $\eta_p^2 = .01$.

As above, this finding reflects a greater number of entries to the target region overall by the ASD group prior to making their decision as to whether the picture under inspection was weird, odd or unusual, irrespective of the nature of the violation (perceptual or social).

Discussion

A principal aim of the study was to investigate whether increased times in ASD to find and initially detect an unusual target in a scene containing people would be modulated by whether the violation could be categorised as social or perceptual.

Accuracy rates were equivalent and high for both groups, but the ASD group took longer to respond manually. It was hypothesised that the eye movement data would reveal the cause of this delayed response in ASD, since eye movements reflect how information is processed on-line (Liversedge & Findlay, 2000; Rayner, 1998; 2009). The data showed that our ASD group did not take longer to find the target regions, but that they scanned the scenes more prior to responding manually, as shown by an increased number of fixations throughout each scene presentation.

Furthermore, these increased fixations were not random, but were made to the target regions of both social and perceptually odd pictures. Thus, increased fixations reflect a propensity to re-inspect the target regions prior to making a response in ASD, regardless as to the type of oddity in the scenes. It should be noted here that the oddity detection task in the current study provides the ASD participants with structure that is not typically available in real-life. As such, the task is not implicit and the knowledge that oddities might be present could also be a factor that drives the repeated scanning in ASD.

The eye movement patterns also showed that our ASD group failed to immediately detect social oddities, thus looking at but not seeing them. An obvious question from this finding is whether the failure to quickly spot subtle social oddities in ASD reflects an inability to react or respond appropriately to social cues in everyday communication? This one impairment in itself could potentially account for the significant problems experienced in dynamic social interactions in this high functioning population. For example, a failure to immediately spot social cues would result in a failure to react or respond to such cues thus resulting in an inability to both keep track of what is going on in social interactions, and a failure to engage appropriately or effectively with other people.

If social oddities are more complex to detect in ASD, then the Complex Information Processing theory (Minshew & Goldstein, 1998) might explain the failure to detect the social oddity on first fixation. This lack of immediate detection could reflect the less obvious and more 'inferential' nature of the social oddities, which required more complex reasoning, at least in the ASD group, for detection. It is important to note that social rules are often implicit, sometimes ambiguous, and cannot always be understood by following a script or flow chart as in the case for logical rule based tasks. At a neurobiological level, it has been postulated that that

impairments in cognitive processing in ASD reflect slow information transmission rates for high

level cognitive tasks, resulting from underconnectivity between frontal-posterior cortical regions

(Just et al., 2013; Just et al., 2012; Minshew & Williams, 2007). Since underconnectivity reduces

the rate of inter-region information transfer, it could be that in social communication tasks that

rely on the fast detection of implicit, often ambiguous cues, a failure to be able to transmit

information across different cortical areas quickly, might mean that these cues are missed,

rendering inappropriate responses in ASD.

The findings of repeated scanning of the target areas, coupled with an inability to

immediately recognise social violations upon initial fixation, reflect how eye movements can

reveal subtle processing differences in ASD. In everyday social communication in the real world

there is no opportunity to 'go back' to check if one has missed an important cue. Social

processing in such circumstances must be carried out on-line, and our eye movement data clearly

show that ASD are unable to do this quickly. The strategy of re-checking their interpretation, and

thus not believing what they have seen, before responding, may be related to cortical

underconnectivity in ASD. In everyday terms, these findings have obvious consequences for fast

dynamic social interactions, and offer an account as to why high functioning adults with ASD

experience difficulty in the social domain.

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Footnotes

1. Accuracy errors for the excluded scenes were either a result of a failure to detect a subtle

oddity, or were a result of participants thinking the control version of the scenes were odd.

Removing these items from analysis did not change the pattern of effects, but reduced variation

in reaction time and eye movement data.

Tables

Table 1.

Accuracy and reaction time means (standard deviations).

	Perceptual				Social			
	Normal		Weird		Normal		Weird	
	TD	ASD	TD	ASD	TD	ASD	TD	ASD
Accuracy	0.81 (0.20)	0.86 (0.10)	0.84 (0.20)	0.77 (0.17)	0.80 (0.17)	0.83 (0.12)	0.80 (0.21)	0.76 (0.24)
Reaction Time (ms)	5289 (2372)	6024 (2560)	3697 (1703)	5184 (2228)	5117 (2443)	6053 (2884)	3056 (1270)	4633 (2131)

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Table 2.

Eye movement measure means in ms (standard deviations).

		Perceptual Oddity		Social Oddity	
		TD	ASD	TD	ASD
Mean Fixation Duration (overall)		250 (31)	257 (29)	241 (26)	252 (33)
Mean Fixation Count (overall)		11 (4)	15 (6)	9 (4)	13 (7)
Elapsed time to target region	ELT	551 (235)	557 (144)	600 (235)	679 (284)
Fixation count before target region	FCT	2.32 (0.72)	2.49 (0.67)	2.62 (0.76)	2.68 (0.73)
First fixation duration in target region	FFD	224 (52)	237 (42)	232 (45)	210 (41)
First gaze duration in target region	FGD	808 (250)	924 (437)	630 (163)	715 (208)
Mean fixation duration in target region	MFD	262 (43)	274 (34)	281 (38)	282 (45)
Mean fixation count in target region	MFC	5.78 (2.28)	7.72 (2.84)	3.97 (1.81)	5.47 (2.14)
Mean number of entries into target region	MNE	1.93 (0.64)	2.32 (0.73)	1.62 (0.52)	2.07 (0.66)
Mean total time in target region	TT	1522 (729)	2065 (809)	1040 (527)	1450 (664)

Figures captions

Figure 1. Example of social normal (A), social weird (B), perceptual normal (C) and perceptual weird (D) stimuli. The black square represents the target region. Note the black square is not visible during the experiment.

Figure 2. Interaction for first fixation duration (ms) between group and oddity type. Error bars denote $\pm/-$ 1 SE.

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Looking, Seeing and Believing in Autism: Eye Movements reveal how subtle

cognitive processing differences impact in the social domain.

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Lay Abstract

Adults with High Functioning Autism (ASD) viewed scenes with people in them, whilst having their eye movements recorded. The task was to indicate, using a button press, whether the pictures were normal, or in some way weird or odd. Oddities in the pictures were categorized as violations of either perceptual or social norms. Compared to a Typically Developed (TD) control group, the ASD participants were equally able to categorise the scenes as odd or normal, but they took longer to respond. The eye movement patterns showed that the ASD group made more fixations and revisits to the target areas in the odd scenes compared to the TD group. Additionally, when the ASD group first fixated the target areas in the scenes, they failed to initially detect the social oddities. These two findings have clear implications for processing difficulties in ASD for the social domain, where it is important to detect social cues on-line, and where there is little opportunity to go back and recheck possible cues in fast dynamic interactions.

LOOKING, SEEING AND BELIEVING IN AUTISM   3

Scientific Abstract

Autistic Spectrum Disorder (ASD) and Typically Developed (TD) adult participants had to decide whether scenes were 'odd', 'unusual' or 'weird'. All scenes contained people, with 'oddness' operationally defined as either perceptual or social. There were no group differences in accuracy, but the ASD group were slower overall to respond manually. Eye movements revealed that the ASD group made more fixations overall and more re-fixations into the target regions of the pictures, for both conditions. Importantly, as indexed by the first fixation duration the ASD group failed to 'pick up' immediately on what was 'odd' for the social violations. The propensity to 'go back' and re-fixate targets, coupled with a failure to initially detect social violations, has obvious significance for ASD in fast dynamic social communication.

Key phrases: Autism Spectrum Disorder, Eye movements, On-line cognitive processing, Social and Perceptual Oddities.

Looking, Seeing and Believing in Autism: Eye Movements reveal how subtle cognitive processing differences impact in the social domain.

Autism spectrum disorders (ASD) are lifelong neuro-developmental conditions characterized by repetitive behaviours and impairments in interaction and communication (American Psychiatric Association, 2013). Incidence rates are rising across the globe with the prevalence rate in the UK approximately 10 per 1000 (1%) individuals (Brugha et al., 2011) and the UK National Audit office recently called for more research into adults with ASD (Clarke et al., 2009).

High functioning adults with ASD are similar to typically developed (TD) adults in terms of performance on pencil and paper and IQ tests, however in the social domain evidence suggests an inability to process social information in a typical fashion. Eye movement studies report unusual gaze behaviour for faces appearing on their own (Dalton et al., 2005), in social scenes (Riby & Hancock, 2009) or in dynamic movie clips (Klin & Jones, 2006; Speer et al., 2007). Research consistently reports a lack of spontaneous gaze fixation towards the eyes (Jones et al., 2008; Klin et al., 2002a; Pelphrey et al., 2002). However, where one study reports impairments, say for face processing (Klin et al., 2002b), another study does not (Fletcher-Watson et al., 2009). Moreover, lack of attentional modulation for social stimuli (Bird et al., 2006) may be overridden, as when cued, attention may be allocated to faces in a more 'typical' manner (Bar-Haim et al., 2006).

A recent scene perception study (Louwerse et al., 2014) reported that abnormal autonomic responses in ASD are unlikely to underpin social processing impairments. It is interesting then to ask whether impairments in the cognitive domain in ASD (Happé & Frith, 2006; Minshew et al., 1997; Russell, 1997) could account for impairments in the social domain?

Current cognitive theories of ASD include, among others, Weak Central Coherence (WCC) theory (Frith & Happé, 1994; Happé & Frith, 2006) which proposes that a reduced sensitivity to global context in favour of focussing on details, results in integration difficulties in ASD. Executive function theory (Russell, 1997), proposes that ASD are impaired at switching their focus of attention, and may engage is perseverative behaviour. Alternatively, the Complex Information Processing theory (Minshew & Goldstein, 1998) proposes that individuals with ASD have impairments in processing complex information with intact processing for tasks that require simple (rule based) processing. Finally, the Extreme Male Brain (EMB) theory (Baron-Cohen, 2002) posits that individuals with ASD have above average levels of systemizing, that contribute to the non-social characteristics of the disorder, coupled with below average levels of empathizing, which results in atypical social functioning. These contemporary theories of ASD can, for different reasons, offer some account of for ineffective social functioning in ASD. However, but sparse research to date has very few investigations have examineded time course processing differences as these occur on-line in ASD., and how these might impact in the social domain.

Our studies investigating cognitive processing in adults with ASD (Au-Yeung et al., 2011; Au-Yeung et al., 2013; Benson et al., 2012; Benson et al., 2009; Benson & Fletcher-Watson, 2011) have found subtle on-line processing differences, as revealed by eye movements, for a range of tasks that are more in line with Minshew and Goldsteins (1998) theory, than with any other. For example, there are more similarities than differences in eye movements between TD and ASD groups for simple rule based tasks in the attentional (Kuhn et al., 2010) and the social domains (Benson & Fletcher-Watson, 2011). Whereas for more complex abstract reasoning tasks where there is ambiguity with relation to target items (Au-Yeung et al., 2013), or

where value judgements rely on top down knowledge (Benson et al., 2012), there are early processing differences indicating that initial orienting to, and immediate detection of weird target items in scenes is absent in ASD. Moreover, the time to respond and to locate the weird target items was modulated by whether or not the pictures had people in them (Benson et al., 2012). These differences have potential for~~to~~ impact on~~in~~ everyday activities, since the time course for detection of socially relevant information is crucial for successful everyday interactions.

The aim of the present study was to examine whether increased times to find and initially detect an unusual target in a scene would be modulated by whether the violation that rendered the target unusual or odd could be categorised as social or perceptual. We employed a similar paradigm to that used in a previously reported study (Rayner et al., 2009) where single scenes, all with people in them, were presented in isolation and the task was to indicate whether each picture was normal or in some way weird unusual or odd.

Insert Figure 1. about here

Social oddities in the pictures were operationally defined as violations of social norms e.g. someone in the picture throwing a baby in the air. Access to top down knowledge is required in that condition to inform a subjective value judgement as to whether a social violation is present in the picture. No value judgement as to whether a violation infringes some implicit or explicit social rule is needed for the perceptual oddities in this study, which are operationally defined as physical violations e.g. someone in the picture has a limb positioned back to front. See supplementary information for Materials ~~and Methods~~. Figure 1 shows an example of the stimuli.

Method

Participants

ASD participants (n = 24 age 18 – 52 years, 20 males), with a formal diagnosis of either Autistic Disorder (n = 3) or Asperger's Syndrome were recruited from local charitable organisations. TD participants (n = 24, age 20– 52 years, 20 males) were volunteers from the local community. All participants were paid and had normal or corrected to normal vision. Each ASD participant completed module 4 of the Autism Diagnostic Observation Scale 2 (Lord et al., 2012) and five (3 males and 2 females with a diagnosis of Asperger's Syndrome) failed to meet the Autism Spectrum criteria. To ensure maximum homogeneity in our study those five participants were excluded from the analyses, resulting in a final sample of 19 ASD participants. Both groups completed the Autism-spectrum Quotient (AQ; Baron-Cohen et al., 2001) and the ASD participants reported a higher number of autistic traits t (41) = 8.04, p < .001 (TD M = 15.42, SD = 7.55; ASD M = 35.32, SD = 8.45). The two groups did not differ in age t (41) = 0.31, p = .759 (TD M = 30.29, SD = 10.20; ASD M = 31.26, SD = 10.29), performance IQ t (41) = 0.21, p = .832 (TD M = 111.79, SD = 12.01; ASD M = 110.95, SD = 13.84), verbal IQ t (41) = 1.21, p = .234 (TD M = 116.96, SD = 10.65, ASD M = 112.26, SD = 14.84), or full scale IQ t (46) = 0.87, p = .392 (TD M = 116.04, SD = 9.98, ASD M = 112.95, SD = 13.48), as measured by two performance (Block Design and Matrix Reasoning) and verbal components (Vocabulary and Similarity) of the Weschler Abbrevated Scale of Intelligence (The Psychological Corporation, 1999).

Eye movement recording

Eye movements were sampled at 1000Hz using an Eyelink tracker with spatial accuracy of less than 1/4th degree (S.R. Research Ltd, Canada). The start and end of saccades were

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detected automatically using a default velocity criterion of 30degrees per second using the Eyelink software. See Stampe (1993) for an in depth technical description of how the software detects saccades and fixations. A chin rest and forehead support, were used to stabilize head position. Viewing was binocular but data were analysed for the right eye only. Individual participants were calibrated using a nine point matrix that covered the dimensions of the screen (1024 x 768 pixels), with each point fixated sequentially, followed by a validation procedure to ensure that fixation was within 0.5 degrees of each calibration point. Calibration was checked using a validation procedure prior to each trial, whereby participants fixated five dots, presented at five different locations that covered the dimensions of the screen and recalibration was performed if the eyes were off centre for any of these dots.

Materials

In total, 96 full-colour photographs were used as stimuli, all of which contained people. In both the perceptual and social oddity conditions there were 48 pictures (24 weird and 24 normal). Perceptual oddities in the pictures violated a physical norm e.g. someone in the picture has a limb positioned back to front, or a vehicle was in an unexpected position e.g midway through the upper wall of a building. Social oddities in the pictures violated a social norm e.g. someone in the picture throwing a baby in the air, or someone with a cabbage on a lead. A small number of the pictures were from a previous study (Benson et al., 2012) and the remainder were collected from the internet and included either a perceptual or social oddity. Adobe Photoshop was used to prepare a normal version of each scene in which the oddity was replaced with either the background elements or with another suitable object. The scenes typically had a focal object or a central group of objects. Figure 1 shows an example of a normal and a socially odd scene,

and below those examples, a normal and a perceptually odd scene. The target regions for these scenes are outlined in black – but these black outlines were not visible during the presentation of the scenes in the experiment.

A norming study was conducted to verify the validity of the images used to examine the processing of social and perceptual violations. Twenty undergraduates from Queen's university participated (*M* age: 19.8years, *SD*: 1.71, 10 Females) with five participants in each of the four conditions (counterbalanced conditions: weird/normal and right/left button response). Stimuli were displayed on a 21inch CRT monitor with a refresh rate of 100Hz and the experiment was run using E-Prime software. Participants were presented with a fixation cross for 500ms followed by the presentation of the image for 20 seconds or until a keyboard "Y' (yes) or "N" (N) was made. Participants had to indicate as quickly as possible whether the presented image was "odd", "weird" or "unusual" in some way. ~~Results~~ The proportion of identified images indicated that on average, the social normal (*M* = 0.86, *SD* = 0.15) and social weird (*M* = 0.84, *SD* = 0.17), perceptual normal (*M* = 0.82, *SD* = 0.17) and perceptual weird (*M* = 0.77, *SD* = 0.19) images were identified correctly.

Design

For the behavioural measures of Accuracy and RT a mixed design with Picture Type (weird versus normal) and Oddity Type (social versus perceptual) as within participants variables, and Group (ASD versus TD) as a between participants variable was employed for the experiment. On condition that accuracy was equivalent for both normal and weird pictures, for the eye movement measures the main focus of interest was to compare social versus perceptual oddities in both groups. Therefore a mixed design with Oddity Type (social versus perceptual) as

a within participants variable, and Group (ASD versus TD) as a between participants variable

was employed in the eye movement analysis.

Procedure

All participants were shown a hard copy of an example picture from each condition prior

to completing the task, to ensure comprehension of the task and the ability to respond

appropriately. The specific instruction was 'for each of the following pictures, please indicate

whether you think the picture is odd, unusual or strange in some way'.

For the task, 48 pictures were presented randomly to either the left or the right of the

centre of a 19inch colour monitor, at a distance of 65cm for 20s or until a button press response

was made. Prior to the onset of a picture, participants fixated a cross that was presented on the

opposite side of the screen to where the picture was set to appear, to ensure all participants

started at the same point in each trial. Once participants fixated this cross, the experimenter

initiated each trial. Picture type (normal vs. weird) and, the position of the picture (left or right

on the display) were counterbalanced across items. The buttons used to respond either yes or no

(left or right trigger button) was counterbalanced across participants.

Data preparation and analyses

For each 'odd' picture we created an interest region around the target item and the

corresponding region of the same size in the counterpart 'normal' picture. Regions of interest

were created using the approximate average regions from those identified and manually selected

by participants who took part in the norming experiment.

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Eyelink software was used to detect saccades and fixations using a default velocity criterion and in-house software was used to calculate the distribution of fixations falling into the target region. Five items were removed from analysis because for these scenes, participant accuracy scores were significantly below chance[1]. In addition, each participant was asked whether they had seen any of the scenes previously, and if so these scenes were also removed. This resulted in a loss of 2.3% of trials. Fixations below 90ms and above 1200ms were classed as outliers and removed; resulting in a loss of 5.13% of the fixation data.

Results

For the principal analyses we compared manual reaction times and accuracy (see Table 1), as well as a number of eye movement measures, such as, the time taken to begin fixating in the target region (ELT), the duration of the first fixation when the eyes landed in the target region (FFD) and the mean time (MFD) spent fixating in the target area (see Table. 2). Global eye movement measures for the target region, such as mean fixation duration and mean number of fixations over all trials were also analysed, Finally, baseline measures (not just target related), were calculated across the duration of the trials, to check for overall sampling differences between the ASD and TD participants (see Table 2). See supplementary information for methods and materials.

Behavioural Data

Accuracy. There was no effect of oddity type (perceptual vs. social) $F (1, 41) = 1.44$, $p = .237$, $\eta_p^2 = .03$, picture type (normal or weird) $F (1, 41) = 0.94$ $p = .339$, $\eta_p^2 = .02$, or group, $F (1, 41) = .06$, $p = .808$, $\eta_p^2 < .01$ on accuracy rates, and no interactions (Fs < 2.39, $p's > .130$). At

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least in terms of accuracy, performance was the same for both groups. For means and standard

deviations for behavioural data see Table 1.

Response Time (RT). A main effect of oddity type F (1, 41) = 8.16, p = .007, η_p^2 = .17,

showed participants took longer to respond when presented with a perceptual oddity in

comparison to a social oddity. Longer response times for perceptual oddities could reflect that

these 'impossible', physical violations were so unusual that they resulted in more time spent

looking at them prior to responding. See below for confirmation of that in the eye movement

data. There was also a main effect of picture type F (1, 41) = 24.03, p < .001, η_p^2 = .37, with

participants taking longer to respond when the picture was normal in comparison to when it was

weird, in line with longer reaction times for target absent trials in standard visual search tasks

(Wolfe, 1998). A significant oddity type x picture type interaction F (1, 41) = 4.22, p = .046, η_p^2

= .09, demonstrated that the difference between RTs for perceptual and social pictures was

reliable for odd (TD; t (23) 2.62, p = .015, ASD; t (18) = 2.98, p = .008) but not for normal

pictures (TD; t (23) 0.94, p = .355, ASD: t (18) = 0.08, p = .935). A main effect of group F (1,

41) = 4.07, p = .050, η_p^2 = .09, showed the ASD participants had longer reaction times, in line

with a previous study (Benson et al., 2012 25). There were no significant group interactions (Fs

< 1) demonstrating both groups to be slower for normal versus odd pictures, and for perceptual

vs social oddities. See Table 1 for the means. The eye movement data below reveals subtle

processing differences that contribute to this overall slowed manual responding in the ASD

group.

Eye Movement Data

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Having shown that all participants could distinguish between 'odd' and 'normal' pictures, normal picture trials were excluded from the eye movement analyses resulting in a 2 (group: ASD versus TD) X 2 (oddity type: social versus perceptual) design to investigate on-line processing differences between the two groups for the two types of oddities.

Baseline eye movement measures, calculated across the full length of trials indicated no group difference in mean fixation duration $F(1, 41) = 1.14$, $p = .293$, $\eta_p^2 = .03$, but the ASD group made more fixations overall $F(1, 41) = 9.44$, $p = .004$, $\eta_p^2 = .19$, corresponding to the increased RT's reported above. Table 2 presents a summary of all the eye movement measures.

Elapsed time to the target region (ELT). A marginal effect of oddity type $F(1, 41) = 3.99$, $p = .053$, $\eta_p^2 = .09$, on the time taken from the onset of each trial display to the start of the first fixation on the target region, revealed both groups took less time to fixate the target region when the oddity was perceptual in comparison to social in nature. ~~The impossible nature of the perceptual violation may have increased the salience of the target region but T~~there was no effect of group $F(1, 41) = 0.59$, $p = .446$, $\eta_p^2 = .01$, and no interaction $F(1, 41) = 0.72$, $p = .401$, $\eta_p^2 = .02$.

First Fixation Duration (FFD) on target region. There was no effect of oddity type $F(1, 41) = 1.84$, $p = .182$, $\eta_p^2 = .04$ or group $F(1, 41) = 0.15$, $p = .699$, $\eta_p^2 < .01$ but a significant interaction $F(1, 41) = 6.72$, $p = .013$, $\eta_p^2 = .14$ (See Figure 2) revealed that FFDs were equivalent for perceptual and social oddities for TD participants $t(23) = 0.86$, $p = .399$, $d = .16$, but for ASD participants FFDs for social oddities were significantly shorter, in comparison to perceptual oddities, $t(18) = 2.99$, $p = .008$, $d = .65$, see Figure 2. Given that the FFD is a measure of early

processing ((Liversedge & Findlay, 2000; Rayner, 1998; Rayner, 2009). 31-33), this finding indicates that the ASD group did not detect the social oddities as quickly as the perceptual oddities on initial fixation, whereas TD participants detected both types of oddity equally fast.

Insert Figure 2. about here

First gaze duration (FGD) in the target region. The FGD is the elapsed time from when the target region is first fixated until the eye moves on to a new location. FGD includes multiple fixations in the target region reflects an overt strategy to re-examine an area. A main effect of oddity type, $F(1, 41) = 12.10$, $p = .001$, $\eta_p^2 = .23$ demonstrated that both groups spent more time inspecting perceptual oddities, again highlighting the salience of the perceptual oddities in comparison to social oddities in this study. However, there was no group effect $F(1, 41) = 2.43$, $p = .127$, $\eta_p^2 = .06$, or interaction $F(1, 41) = .08$, $p = .785$, $\eta_p^2 < .01$.

Mean Fixation Count in the target region. If the ASD are slower to respond manually, but do not take longer to begin inspecting the target region, then extra time to respond might reflect more fixations in the target region. A main effect of oddity type $F(1, 41) = 64.27$, $p < .001$, $\eta_p^2 = .61$, demonstrated more fixations in the target region when the oddity was perceptual, rather than social. A main effect of group $F(1, 41) = 6.99$, $p = .012$, $\eta_p^2 = .15$ showed that the ASD participants group made more fixations than the TD group in the target regions, for both types of oddities overall. However no interaction was observed $F(1, 41) = 0.77$, $p = .386$, $\eta_p^2 = .02$ indicating that the ASD group made more fixations in the target regions for both types of oddities.

Mean Fixation Duration in the target region. Longer mean fixation durations indicate that more processing has been done during the task. A main effect of oddity type $F(1, 41) = 8.22$, $p = .007$, $\eta_p^2 = .17$ showed significantly longer fixations for social, compared to perceptual oddity target regions. This suggests that processing social oddities was more effortful, and since there was no main effect of group $F(1, 41) = 0.34$, $p = .562$, $\eta_p^2 < .01$, and no interaction $F(1, 41) = 1.12$, $p = .297$, $\eta_p^2 = .03$, both groups on average fixated the social oddity target region for longer than the perceptual target region. Thus, while the perceptual oddities attracted more fixations overall, individual fixations were longer for the social target region.

This interesting juxtaposition, although unrelated to the main aim of this study, suggests that difficulty associated with processing each oddity type manifests in different eye movement patterns: one reflecting an overt strategy (fixation count) to re-inspect the target area, and one reflecting more in depth on-line cognitive processing (fixation duration) on the target areas.

Mean Number of Entries to the target region. Since there were no group differences in FGD, and no increased MFD, both reported above, the delayed RT in ASD might reflect repeated visits to inspect the target region?

A main effect of oddity type was found $F(1, 41) = 9.83$, $p = .003$, $\eta_p^2 = .19$, with the target region entered more often for perceptual oddities in comparison to social oddities. In addition, a main effect of group was found $F(1, 41) = 5.72$, $p = .021$, $\eta_p^2 = .12$, with ASD participants entering the target regions significantly more than the TD group, before making a response. There was no interaction $F(1, 41) = 0.13$, $p = .717$, $\eta_p^2 < .01$.

Mean Total Time in the target region. A higher mean total time means that more attention to, and processing of, information in that region was carried out overall. This measure should complement the measures reported above – namely, that if there are more fixations overall in ASD then the Total Time spent fixating in the target region should be longer in ASD.

A main effect of oddity type $F(1, 41) = 34.89$, $p < .001$, $\eta_p^2 = .46$, showed perceptual oddities received more overall processing time, in line with the previous measures for the perceptual oddities. In addition, a main effect of group $F(1, 41) = 6.41$, $p = .015$, $\eta_p^2 = .14$ revealed that the ASD participants spent a longer period of time inspecting the target regions for both perceptual and social oddities. There was no interaction $F(1, 41) = 0.51$, $p = .481$, $\eta_p^2 = .01$.

As above, this finding reflects a greater number of entries to the target region overall by the ASD group prior to making their decision as to whether the picture under inspection was weird, odd or unusual, irrespective of the nature of the violation (perceptual or social).

Discussion

A principal aim of the study was to investigate whether increased times in ASD to find and initially detect an unusual target in a scene containing people would be modulated by whether the violation could be categorised as social or perceptual.

Accuracy rates were equivalent and high for both groups, but the ASD group took longer to respond manually. It was hypothesised that the eye movement data would reveal the cause of this delayed response in ASD, since eye movements reflect how information is processed on-line (Liversedge & Findlay, 2000; Rayner, 1998; 2009). The data showed that our ASD group did not take longer to find the target regions, but that they scanned the scenes more prior to responding manually, as shown by an increased number of fixations throughout each scene presentation.

Furthermore, these increased fixations were not random, but were made to the target regions of both social and perceptually odd pictures. Thus, increased fixations reflect a propensity to re-inspect the target regions prior to making a response in ASD, regardless as to the type of oddity in the scenes. It should be noted here that the oddity detection task in the current study provides the ASD participants with structure that is not typically available in real-life. As such, the task is not implicit and the knowledge that oddities might be present could also be a factor that drives the repeated scanning in ASD.

The eye movement patterns also showed that our ASD group failed to immediately detect social oddities, thus looking at but not seeing them. An obvious question from this finding is whether the failure to quickly spot subtle social oddities in ASD reflects an inability to react or respond appropriately to social cues in everyday communication? This one impairment in itself could potentially account for the significant problems experienced in dynamic social interactions in this high functioning population. For example, a failure to immediately spot social cues would result in a failure to react or respond to such cues thus resulting in an inability to both keep track of what is going on in social interactions, and a failure to engage appropriately or effectively with other people.

In relation to current theories that underpin ASD our findings do not fit with WCC theory (Frith & Happé, 1994; Happé & Frith. 2006), since clearly context can be taken into account in ASD during task completion. Moreover, the slowness to respond in ASD is not reflected in longer times to find the target, and the increased fixations in ASD were seen for both perceptual and social oddities in the scenes. It may be that repeated visits to the target area indicate integration problems in ASD, but even if that were the case, such problems are not restricted to social processing per se. Neither do the support the executive function theory (Russell, 1997), as

LOOKING, SEEING AND BELIEVING IN AUTISM   18

ASD participants showed no indication of increased mean fixation durations, thus no evidence of perseveration or any inability to switch focus throughout the task. Our findings could however be interpreted to support the EMB (Baron-Cohen, 2002), with the detection of social oddities that required empathy being delayed in ASD, however note that higher re-inspection of perceptual oddities that could be detected on the basis of systematic rules, was also found for ASD participants.

If social oddities are more complex to detect in ASD, then the Complex Information Processing theory (Minshew & Goldstein, 1998) might explain the failure to detect the social oddity on first fixation. This lack of immediate detection could reflect the less obvious and more 'inferential' nature of the social oddities, which required more complex reasoning, at least in the ASD group, for detection. It is important to note that social rules are often implicit, sometimes ambiguous, and cannot always be understood by following a script or flow chart as in the case for logical rule based tasks. At a neurobiological level, it has been postulated that that impairments in cognitive processing in ASD reflect slow information transmission rates for high level cognitive tasks, resulting from underconnectivity between frontal-posterior cortical regions (Just et al., 2013; Just et al., 2012; Minshew & Williams, 2007). Since underconnectivity reduces the rate of inter-region information transfer, it could be that in social communication tasks that rely on the fast detection of implicit, often ambiguous cues, a failure to be able to transmit information across different cortical areas quickly, might mean that these cues are missed, rendering inappropriate responses in ASD.

The findings of repeated scanning of the target areas, coupled with an inability to immediately recognise social violations upon initial fixation, reflect how eye movements can reveal subtle processing differences in ASD. In everyday social communication in the real world

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there is no opportunity to 'go back' to check if one has missed an important cue. Social

processing in such circumstances must be carried out on-line, and our eye movement data clearly

show that ASD are unable to do this quickly. The strategy of re-checking their interpretation, and

thus not believing what they have seen, before responding, may be related to cortical

underconnectivity in ASD. In everyday terms, these findings have obvious consequences for fast

dynamic social interactions, and offer an account as to why high functioning adults with ASD

experience difficulty in the social domain.

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LOOKING, SEEING AND BELIEVING IN AUTISM   26

Footnotes

1. Accuracy errors for the excluded scenes were either a result of a failure to detect a subtle

oddity, or were a result of participants thinking the control version of the scenes were odd.

Removing these items from analysis did not change the pattern of effects, but reduced variation

in reaction time and eye movement data.

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Tables

Table 1.

Accuracy and reaction time means (standard deviations).

	Perceptual				Social			
	Normal		Weird		Normal		Weird	
	TD	ASD	TD	ASD	TD	ASD	TD	ASD
Accuracy	0.81 (0.20)	0.86 (0.10)	0.84 (0.20)	0.77 (0.17)	0.80 (0.17)	0.83 (0.12)	0.80 (0.21)	0.76 (0.24)
Reaction Time (ms)	5289 (2372)	6024 (2560)	3697 (1703)	5184 (2228)	5117 (2443)	6053 (2884)	3056 (1270)	4633 (2131)

Table 2.

Eye movement measure means in ms (standard deviations).

		Perceptual Oddity		Social Oddity	
		TD	ASD	TD	ASD
Mean Fixation Duration (overall)		250 (31)	257 (29)	241 (26)	252 (33)
Mean Fixation Count (overall)		11 (4)	15 (6)	9 (4)	13 (7)
Elapsed time to target region	ELT	551 (235)	557 (144)	600 (235)	679 (284)
Fixation count before target region	FCT	2.32 (0.72)	2.49 (0.67)	2.62 (0.76)	2.68 (0.73)
First fixation duration in target region	FFD	224 (52)	237 (42)	232 (45)	210 (41)
First gaze duration in target region	FGD	808 (250)	924 (437)	630 (163)	715 (208)
Mean fixation duration in target region	MFD	262 (43)	274 (34)	281 (38)	282 (45)
Mean fixation count in target region	MFC	5.78 (2.28)	7.72 (2.84)	3.97 (1.81)	5.47 (2.14)
Mean number of entries into target region	MNE	1.93 (0.64)	2.32 (0.73)	1.62 (0.52)	2.07 (0.66)
Mean total time in target region	TT	1522 (729)	2065 (809)	1040 (527)	1450 (664)

Figures captions

Figure 1. Example of social normal (A), social weird (B), perceptual normal (C) and perceptual weird (D) stimuli. The black square represents the target region. Note the black square is not visible during the experiment.

Figure 2. Interaction for first fixation duration (ms) between group and oddity type. Error bars denote +/- 1 SE.

Figure 1. Example of social normal (A), social weird (B), perceptual normal (C) and perceptual weird (D) stimuli. The black square represents the target region. Note the black square is not visible during the experiment.
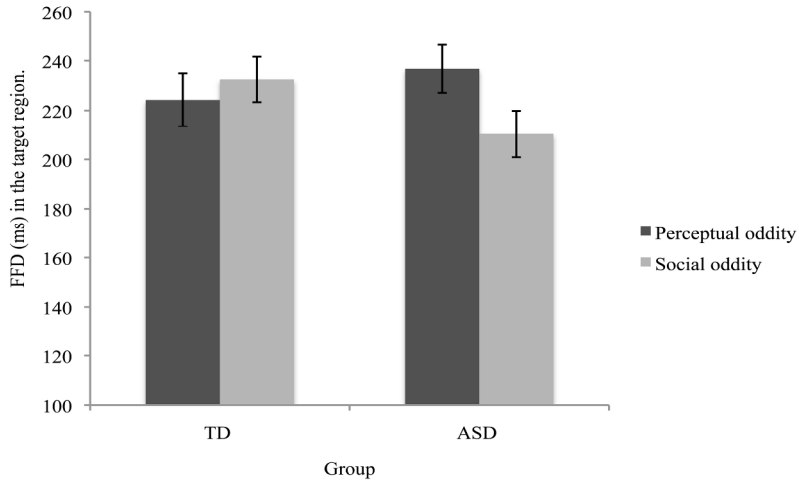149x129mm (300 x 300 DPI)

Figure 2. Interaction for first fixation duration (ms) between group and oddity type. Error bars denote +/- 1 SE.
228x158mm (300 x 300 DPI)

Looking, Seeing and Believing in Autism: Eye Movements reveal how subtle

cognitive processing differences impact in the social domain.

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LOOKING, SEEING AND BELIEVING IN AUTISM 2

Lay Abstract

Adults with High Functioning Autism (ASD) viewed scenes with people in them, whilst having their eye movements recorded. The task was to indicate, using a button press, whether the pictures were normal, or in some way weird or odd. Oddities in the pictures were categorized as violations of either perceptual or social norms. Compared to a Typically Developed (TD) control group, the ASD participants were equally able to categorise the scenes as odd or normal, but they took longer to respond. The eye movement patterns showed that the ASD group made more fixations and revisits to the target areas in the odd scenes compared to the TD group. Additionally, when the ASD group first fixated the target areas in the scenes, they failed to initially detect the social oddities. These two findings have clear implications for processing difficulties in ASD for the social domain, where it is important to detect social cues on-line, and where there is little opportunity to go back and recheck possible cues in fast dynamic interactions.

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LOOKING, SEEING AND BELIEVING IN AUTISM   3

Scientific Abstract

Autistic Spectrum Disorder (ASD) and Typically Developed (TD) adult participants had to decide whether scenes were 'odd', 'unusual' or 'weird'. All scenes contained people, with 'oddness' operationally defined as either perceptual or social. There were no group differences in accuracy, but the ASD group were slower overall to respond manually. Eye movements revealed that the ASD group made more fixations overall and more re-fixations into the target regions of the pictures, for both conditions. Importantly, as indexed by the first fixation duration the ASD group failed to 'pick up' immediately on what was 'odd' for the social violations. The propensity to 'go back' and re-fixate targets, coupled with a failure to initially detect social violations, has obvious significance for ASD in fast dynamic social communication.

Key phrases: Autism Spectrum Disorder, Eye movements, On-line cognitive processing, Social and Perceptual Oddities.

Looking, Seeing and Believing in Autism: Eye Movements reveal how subtle cognitive processing differences impact in the social domain.

Autism spectrum disorders (ASD) are lifelong neuro-developmental conditions characterized by repetitive behaviours and impairments in interaction and communication (American Psychiatric Association, 2013). Incidence rates are rising across the globe with the prevalence rate in the UK approximately 10 per 1000 (1%) individuals (Brugha et al., 2011) and the UK National Audit office recently called for more research into adults with ASD (Clarke et al., 2009).

High functioning adults with ASD are similar to typically developed (TD) adults in terms of performance on pencil and paper and IQ tests, however in the social domain evidence suggests an inability to process social information in a typical fashion. Eye movement studies report unusual gaze behaviour for faces appearing on their own (Dalton et al., 2005), in social scenes (Riby & Hancock, 2009) or in dynamic movie clips (Klin & Jones, 2006; Speer et al., 2007). Research consistently reports a lack of spontaneous gaze fixation towards the eyes (Jones et al., 2008; Klin et al., 2002a; Pelphrey et al., 2002). However, where one study reports impairments, say for face processing (Klin et al., 2002b), another study does not (Fletcher-Watson et al., 2009). Moreover, lack of attentional modulation for social stimuli (Bird et al., 2006) may be overridden, as when cued, attention may be allocated to faces in a more 'typical' manner (Bar-Haim et al., 2006).

A recent scene perception study (Louwerse et al., 2014) reported that abnormal autonomic responses in ASD are unlikely to underpin social processing impairments. It is interesting then to ask whether impairments in the cognitive domain in ASD (Happé & Frith, 2006; Minshew et al., 1997; Russell, 1997) could account for impairments in the social domain?

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LOOKING, SEEING AND BELIEVING IN AUTISM   5

Current cognitive theories of ASD include, among others, Weak Central Coherence (WCC) theory (Frith & Happé, 1994; Happé & Frith, 2006) which proposes that a reduced sensitivity to global context in favour of focussing on details, results in integration difficulties in ASD. Executive function theory (Russell, 1997), proposes that ASD are impaired at switching their focus of attention, and may engage ins perseverative behaviour. Alternatively, the Complex Information Processing theory (Minshew & Goldstein, 1998) proposes that individuals with ASD have impairments in processing complex information with intact processing for tasks that require simple (rule based) processing. Finally, the Extreme Male Brain (EMB) theory (Baron-Cohen, 2002) posits that individuals with ASD have above average levels of systemizing, that contribute to the non-social characteristics of the disorder, coupled with below average levels of empathizing, which results in atypical social functioning. These contemporary theories of ASD can, for different reasons, offer some account offer ineffective social functioning in ASD. However., but sparse research to date has very few investigations have examined onlineed time course processing differences as these occur on-line in ASD., and how these might impact in the social domain.

Our studies investigating cognitive processing in adults with ASD (Au-Yeung et al., 2011; Au-Yeung et al., 2013; Benson et al., 2012; Benson et al., 2009; Benson & Fletcher-Watson, 2011) have found subtle on-line processing differences, as revealed by eye movements, for a range of tasks that are more in line with Minshew and Goldstein's (1998) theory, than with any other. For example, there are more similarities than differences in eye movements between TD and ASD groups for simple rule based tasks in the attentional (Kuhn et al., 2010) and the social domains (Benson & Fletcher-Watson, 2011). Whereas for more complex abstract reasoning tasks where there is ambiguity with relation to target items (Au-Yeung et al., 2013), or

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where value judgements rely on top down knowledge (Benson et al., 2012), there are early processing differences indicating that initial orienting to, and immediate detection of weird target items in scenes is absent in ASD. Moreover, the time to respond and to locate the weird target items was modulated by whether or not the pictures had people in them (Benson et al., 2012). These differences have potential for~~to~~ impact on~~in~~ everyday activities, since the time course for detection of socially relevant information is crucial for successful everyday interactions.

The aim of the present study was to examine whether increased times to find and initially detect an unusual target in a scene would be modulated by whether the violation that rendered the target unusual or odd could be categorised as social or perceptual. We employed a similar paradigm to that used in a previously reported study (Rayner et al., 2009) where single scenes, all with people in them, were presented in isolation and the task was to indicate whether each picture was normal or in some way weird unusual or odd.

Insert Figure 1. about here

Social oddities in the pictures were operationally defined as violations of social norms e.g. someone in the picture throwing a baby in the air. Access to top down knowledge is required in that condition to inform a subjective value judgement as to whether a social violation is present in the picture. No value judgement as to whether a violation infringes some implicit or explicit social rule is needed for the perceptual oddities in this study, which are operationally defined as physical violations e.g. someone in the picture has a limb positioned back to front. See supplementary information for Materials~~and Methods~~. Figure 1 shows an example of the stimuli.

Method

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Participants

ASD participants (n = 24 age 18 – 52 years, 20 males), with a formal diagnosis of either Autistic Disorder (n = 3) or Asperger's Syndrome were recruited from local charitable organisations. TD participants (n = 24, age 20– 52 years, 20 males) were volunteers from the local community. All participants were paid and had normal or corrected to normal vision. Each ASD participant completed module 4 of the Autism Diagnostic Observation Scale 2 (Lord et al., 2012) and five (3 males and 2 females with a diagnosis of Asperger's Syndrome) failed to meet the Autism Spectrum criteria. To ensure maximum homogeneity in our study those five participants were excluded from the analyses, resulting in a final sample of 19 ASD participants. Both groups completed the Autism-spectrum Quotient (AQ; Baron-Cohen et al., 2001) and the ASD participants reported a higher number of autistic traits $t(41) = 8.04$, $p < .001$ (TD $M = 15.42$, $SD = 7.55$; ASD $M = 35.32$, $SD = 8.45$). The two groups did not differ in age $t(41) = 0.31$, $p = .759$ (TD $M = 30.29$, $SD = 10.20$; ASD $M = 31.26$, $SD = 10.29$), performance IQ $t(41) = 0.21$, $p = .832$ (TD $M = 111.79$, $SD = 12.01$; ASD $M = 110.95$, $SD = 13.84$), verbal IQ $t(41) = 1.21$, $p = .234$ (TD $M = 116.96$, $SD = 10.65$, ASD $M = 112.26$, $SD = 14.84$), or full scale IQ $t(46) = 0.87$, $p = .392$ (TD $M = 116.04$, $SD = 9.98$, ASD $M = 112.95$, $SD = 13.48$), as measured by two performance (Block Design and Matrix Reasoning) and verbal components (Vocabulary and Similarities) of the Weschler Abbrevated Scale of Intelligence (The Psychological Corporation, 1999).

Eye movement recording

Eye movements were sampled at 1000Hz using an Eyelink tracker with spatial accuracy of less than 1/4th degree (S.R. Research Ltd, Canada). The start and end of saccades were

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detected automatically using a default velocity criterion of 30degrees per second using the Eyelink software. See Stampe (1993) for an in depth technical description of how the software detects saccades and fixations. A chin rest and forehead support, were used to stabilize head position. Viewing was binocular but data were analysed for the right eye only. Individual participants were calibrated using a nine point matrix that covered the dimensions of the screen (1024 x 768 pixels), with each point fixated sequentially, followed by a validation procedure to ensure that fixation was within 0.5 degrees of each calibration point. Calibration was checked using a validation procedure prior to each trial, whereby participants fixated five dots, presented at five different locations that covered the dimensions of the screen and recalibration was performed if the eyes were off centre for any of these dots.

Materials

In total, 96 full-colour photographs were used as stimuli, all of which contained people. In both the perceptual and social oddity conditions there were 48 pictures (24 weird and 24 normal). Perceptual oddities in the pictures violated a physical norm e.g. someone in the picture has a limb positioned back to front, or a vehicle was in an unexpected position e.g midway through the upper wall of a building. Social oddities in the pictures violated a social norm e.g. someone in the picture throwing a baby in the air, or someone with a cabbage on a lead. A small number of the pictures were from a previous study (Benson et al., 2012) and the remainder were collected from the internet and included either a perceptual or social oddity. Adobe Photoshop was used to prepare a normal version of each scene in which the oddity was replaced with either the background elements or with another suitable object. The scenes typically had a focal object or a central group of objects. Figure 1 shows an example of a normal and a socially odd scene,

and below those examples, a normal and a perceptually odd scene. The target regions for these scenes are outlined in black – but these black outlines were not visible during the presentation of the scenes in the experiment.

A norming study was conducted to verify the validity of the images used to examine the processing of social and perceptual violations. Twenty undergraduates from Queen's university participated (M age: 19.8years, SD: 1.71, 10 Females) with five participants in each of the four conditions (counterbalanced conditions: weird/normal and right/left button response). Stimuli were displayed on a 21inch CRT monitor with a refresh rate of 100Hz and the experiment was run using E-Prime software. Participants were presented with a fixation cross for 500ms followed by the presentation of the image for 20 seconds or until a keyboard "Y' (yes) or "N" (N) was made. Participants had to indicate as quickly as possible whether the presented image was "odd", "weird" or "unusual" in some way. ~~Results~~ The proportion of identified images indicated that on average, the social normal ($M = 0.86$, $SD = 0.15$) and social weird ($M = 0.84$, $SD = 0.17$), perceptual normal ($M = 0.82$, $SD = 0.17$) and perceptual weird ($M = 0.77$, $SD = 0.19$) images were identified correctly.

Design

For the behavioural measures of Accuracy and RT a mixed design with Picture Type (weird versus normal) and Oddity Type (social versus perceptual) as within participants variables, and Group (ASD versus TD) as a between participants variable was employed for the experiment. On condition that accuracy was equivalent for both normal and weird pictures, for the eye movement measures the main focus of interest was to compare social versus perceptual oddities in both groups. Therefore a mixed design with Oddity Type (social versus perceptual) as

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a within participants variable, and Group (ASD versus TD) as a between participants variable was employed in the eye movement analysis.

Procedure

All participants were shown a hard copy of an example picture from each condition prior to completing the task, to ensure comprehension of the task and the ability to respond appropriately. The specific instruction was 'for each of the following pictures, please indicate whether you think the picture is odd, unusual or strange in some way'.

For the task, 48 pictures were presented randomly to either the left or the right of the centre of a 19inch colour monitor, at a distance of 65cm for 20s or until a button press response was made. Prior to the onset of a picture, participants fixated a cross that was presented on the opposite side of the screen to where the picture was set to appear, to ensure all participants started at the same point in each trial. Once participants fixated this cross, the experimenter initiated each trial. Picture type (normal vs. weird) and, the position of the picture (left or right on the display) were counterbalanced across items. The buttons used to respond either yes or no (left or right trigger button) was counterbalanced across participants.

Data preparation and analyses

For each 'odd' picture we created an interest region around the target item and the corresponding region of the same size in the counterpart 'normal' picture. Regions of interest were created using the approximate average regions from those identified and manually selected by participants who took part in the norming experiment.

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Eyelink software was used to detect saccades and fixations using a default velocity criterion and in-house software was used to calculate the distribution of fixations falling into the target region. Five items were removed from analysis because for these scenes, participant accuracy scores were significantly below chance[1]. In addition, each participant was asked whether they had seen any of the scenes previously, and if so these scenes were also removed. This resulted in a loss of 2.3% of trials. Fixations below 90ms and above 1200ms were classed as outliers and removed; resulting in a loss of 5.13% of the fixation data.

Results

For the principal analyses we compared manual reaction times and accuracy (see Table 1), as well as a number of eye movement measures, such as, the time taken to begin fixating in the target region (ELT), the duration of the first fixation when the eyes landed in the target region (FFD) and the mean time (MFD) spent fixating in the target area (see Table. 2). Global eye movement measures for the target region, such as mean fixation duration and mean number of fixations over all trials were also analysed, Finally, baseline measures (not just target related), were calculated across the duration of the trials, to check for overall sampling differences between the ASD and TD participants (see Table 2). See supplementary information for methods and materials.

Behavioural Data

Accuracy. There was no effect of oddity type (perceptual vs. social) $F (1, 41) = 1.44$, $p = .237$, $\eta_p^2 = .03$, picture type (normal or weird) $F (1, 41) = 0.94$ $p = .339$, $\eta_p^2 = .02$, or group, $F (1, 41) = .06$, $p = .808$, $\eta_p^2 < .01$ on accuracy rates, and no interactions ($Fs < 2.39$, $p's > .130$). At

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least in terms of accuracy, performance was the same for both groups. For means and standard deviations for behavioural data see Table 1.

Response Time (RT). A main effect of oddity type $F(1, 41) = 8.16$, $p = .007$, $\eta_p^2 = .17$, showed participants took longer to respond when presented with a perceptual oddity in comparison to a social oddity. Longer response times for perceptual oddities could reflect that these 'impossible', physical violations were so unusual that they resulted in more time spent looking at them prior to responding. See below for confirmation of that in the eye movement data. There was also a main effect of picture type $F(1, 41) = 24.03$, $p < .001$, $\eta_p^2 = .37$, with participants taking longer to respond when the picture was normal in comparison to when it was weird, in line with longer reaction times for target absent trials in standard visual search tasks (Wolfe, 1998) A significant oddity type x picture type interaction $F(1, 41) = 4.22$, $p = .046$, $\eta_p^2 = .09$, demonstrated that the difference between RTs for perceptual and social pictures was reliable for odd (TD; $t(23)$ 2.62, $p = .015$, ASD: $t(18) = 2.98$, $p = .008$) but not for normal pictures (TD; $t(23)$ 0.94, $p = .355$, ASD: $t(18) = 0.08$, $p = .935$). A main effect of group $F(1, 41) = 4.07$, $p = .050$, $\eta_p^2 = .09$, showed the ASD participants had longer reaction times, in line with a previous study (Benson et al., 2012 25). There were no significant group interactions ($Fs < 1$) demonstrating both groups to be slower for normal versus odd pictures, and for perceptual vs social oddities. See Table 1 for the means. The eye movement data below reveals subtle processing differences that contribute to this overall slowed manual responding in the ASD group.

Eye Movement Data

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Having shown that all participants could distinguish between 'odd' and 'normal' pictures, normal picture trials were excluded from the eye movement analyses resulting in a 2 (group: ASD versus TD) X 2 (oddity type: social versus perceptual) design to investigate on-line processing differences between the two groups for the two types of oddities.

Baseline eye movement measures, calculated across the full length of trials indicated no group difference in mean fixation duration $F (1, 41) = 1.14$, $p = .293$, $\eta_p^2 = .03$, but the ASD group made more fixations overall $F (1, 41) = 9.44$, $p = .004$, $\eta_p^2 = .19$, corresponding to the increased RT's reported above. Table 2 presents a summary of all the eye movement measures.

Elapsed time to the target region (ELT). A marginal effect of oddity type $F (1, 41) = 3.99$, $p = .053$, $\eta_p^2 = .09$, on the time taken from the onset of each trial display to the start of the first fixation on the target region, revealed both groups took less time to fixate the target region when the oddity was perceptual in comparison to social in nature. ~~The impossible nature of the perceptual violation may have increased the salience of the target region but T~~there was no effect of group $F (1, 41) = 0.59$, $p = .446$, $\eta_p^2 = .01$, and no interaction $F (1, 41) = 0.72$, $p = .401$, $\eta_p^2 = .02$.

First Fixation Duration (FFD) on target region. There was no effect of oddity type $F (1, 41) = 1.84$, $p = .182$, $\eta_p^2 = .04$ or group $F (1, 41) = 0.15$, $p = .699$, $\eta_p^2 < .01$ but a significant interaction $F (1, 41) = 6.72$, $p = .013$, $\eta_p^2 = .14$ (See Figure 2) revealed that FFDs were equivalent for perceptual and social oddities for TD participants $t (23) = 0.86$, $p = .399$, $d = .16$, but for ASD participants FFDs for social oddities were significantly shorter, in comparison to perceptual oddities, $t (18) = 2.99$, $p = .008$, $d = .65$, see Figure 2. Given that the FFD is a measure of early

processing. (Liversedge & Findlay, 2000; Rayner, 1998; Rayner, 2009) 31-33; this finding indicates that the ASD group did not detect the social oddities as quickly as the perceptual oddities on initial fixation, whereas TD participants detected both types of oddity equally fast.

Insert Figure 2. about here

First gaze duration (FGD) in the target region. The FGD is the elapsed time from when the target region is first fixated until the eye moves on to a new location. FGD includes multiple fixations in the target region reflects an overt strategy to re-examine an area. A main effect of oddity type, $F(1, 41) = 12.10$, $p = .001$, $\eta_p^2 = .23$ demonstrated that both groups spent more time inspecting perceptual oddities, again highlighting the salience of the perceptual oddities in comparison to social oddities in this study. However, there was no group effect $F(1, 41) = 2.43$, $p = .127$, $\eta_p^2 = .06$, or interaction $F(1, 41) = .08$, $p = .785$, $\eta_p^2 < .01$.

Mean Fixation Count in the target region. If the ASD are slower to respond manually, but do not take longer to begin inspecting the target region, then extra time to respond might reflect more fixations in the target region. A main effect of oddity type $F(1, 41) = 64.27$, $p < .001$, $\eta_p^2 = .61$, demonstrated more fixations in the target region when the oddity was perceptual, rather than social. A main effect of group $F(1, 41) = 6.99$, $p = .012$, $\eta_p^2 = .15$ showed that the ASD participants group made more fixations than the TD group in the target regions, for both types of oddities overall. However no interaction was observed $F(1, 41) = 0.77$, $p = .386$, $\eta_p^2 = .02$ indicating that the ASD group made more fixations in the target regions for both types of oddities.

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21 **Mean Fixation Duration in the target region.** Longer mean fixation durations indicate that
22 more processing has been done during the task. A main effect of oddity type $F(1, 41) = 8.22$, $p =$
23 .007, $\eta_p^2 = .17$ showed significantly longer fixations for social, compared to perceptual oddity
24 target regions. This suggests that processing social oddities was more effortful, and since there
25 was no main effect of group $F(1, 41) = 0.34$, $p = .562$, $\eta_p^2 < .01$, and no interaction $F(1, 41) =$
26 1.12, $p = .297$, $\eta_p^2 = .03$, both groups on average fixated the social oddity target region for longer
27 than the perceptual target region. Thus, while the perceptual oddities attracted more fixations
28 overall, individual fixations were longer for the social target region.
29   This interesting juxtaposition, although unrelated to the main aim of this study, suggests
30 that difficulty associated with processing each oddity type manifests in different eye movement
31 patterns: one reflecting an overt strategy (fixation count) to re-inspect the target area, and one
32 reflecting more in depth on-line cognitive processing (fixation duration) on the target areas.
33
34 **Mean Number of Entries to the target region.** Since there were no group differences in FGD,
35 and no increased MFD, both reported above, the delayed RT in ASD might reflect repeated visits
36 to inspect the target region?
37   A main effect of oddity type was found $F(1, 41) = 9.83$, $p = .003$, $\eta_p^2 = .19$, with the
38 target region entered more often for perceptual oddities in comparison to social oddities. In
39 addition, a main effect of group was found $F(1, 41) = 5.72$, $p = .021$, $\eta_p^2 = .12$, with ASD
40 participants entering the target regions significantly more than the TD group, before making a
41 response. There was no interaction $F(1, 41) = 0.13$, $p = .717$, $\eta_p^2 < .01$.
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Mean Total Time in the target region. A higher mean total time means that more attention to, and processing of, information in that region was carried out overall. This measure should complement the measures reported above – namely, that if there are more fixations overall in ASD then the Total Time spent fixating in the target region should be longer in ASD.

A main effect of oddity type $F (1, 41) = 34.89$, $p < .001$, $\eta_p^2 = .46$, showed perceptual oddities received more overall processing time, in line with the previous measures for the perceptual oddities. In addition, a main effect of group $F (1, 41) = 6.41$, $p = .015$, $\eta_p^2 = .14$ revealed that the ASD participants spent a longer period of time inspecting the target regions for both perceptual and social oddities. There was no interaction $F (1, 41) = 0.51$, $p = .481$, $\eta_p^2 = .01$.

As above, this finding reflects a greater number of entries to the target region overall by the ASD group prior to making their decision as to whether the picture under inspection was weird, odd or unusual, irrespective of the nature of the violation (perceptual or social).

Discussion

A principal aim of the study was to investigate whether increased times in ASD to find and initially detect an unusual target in a scene containing people would be modulated by whether the violation could be categorised as social or perceptual.

Accuracy rates were equivalent and high for both groups, but the ASD group took longer to respond manually. It was hypothesised that the eye movement data would reveal the cause of this delayed response in ASD, since eye movements reflect how information is processed on-line (Liversedge & Findlay, 2000; Rayner, 1998; 2009). The data showed that our ASD group did not take longer to find the target regions, but that they scanned the scenes more prior to responding manually, as shown by an increased number of fixations throughout each scene presentation.

Furthermore, these increased fixations were not random, but were made to the target regions of both social and perceptually odd pictures. Thus, increased fixations reflect a propensity to re-inspect the target regions prior to making a response in ASD, regardless as to the type of oddity in the scenes. It should be noted here that the oddity detection task in the current study provides the ASD participants with structure that is not typically available in real-life. As such, the task is not implicit and the knowledge that oddities might be present could also be a factor that drives the repeated scanning in ASD.

The eye movement patterns also showed that our ASD group failed to immediately detect social oddities, thus looking at but not seeing them. An obvious question from this finding is whether the failure to quickly spot subtle social oddities in ASD reflects an inability to react or respond appropriately to social cues in everyday communication? This one impairment in itself could potentially account for the significant problems experienced in dynamic social interactions in this high functioning population. For example, a failure to immediately spot social cues would result in a failure to react or respond to such cues thus resulting in an inability to both keep track of what is going on in social interactions, and a failure to engage appropriately or effectively with other people.

In relation to current theories that underpin ASD our findings do not fit with WCC theory (Frith & Happé, 1994; Happé & Frith, 2006), since clearly context can be taken into account in ASD during task completion. Moreover, the slowness to respond in ASD is not reflected in longer times to find the target, and the increased fixations in ASD were seen for both perceptual and social oddities in the scenes. It may be that repeated visits to the target area indicate integration problems in ASD, but even if that were the case, such problems are not restricted to social processing per se. Neither do the support the executive function theory (Russell, 1997), as

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ASD participants showed no indication of increased mean fixation durations, thus no evidence of perseveration or any inability to switch focus throughout the task. Our findings could however be interpreted to support the EMB (Baron-Cohen, 2002), with the detection of social oddities that required empathy being delayed in ASD, however note that higher re-inspection of perceptual oddities that could be detected on the basis of systematic rules, was also found for ASD participants.

If social oddities are more complex to detect in ASD, then the Complex Information Processing theory (Minshew & Goldstein, 1998) might explain the failure to detect the social oddity on first fixation. This lack of immediate detection could reflect the less obvious and more 'inferential' nature of the social oddities, which required more complex reasoning, at least in the ASD group, for detection. It is important to note that social rules are often implicit, sometimes ambiguous, and cannot always be understood by following a script or flow chart as in the case for logical rule based tasks. At a neurobiological level, it has been postulated that that impairments in cognitive processing in ASD reflect slow information transmission rates for high level cognitive tasks, resulting from underconnectivity between frontal-posterior cortical regions (Just et al., 2013; Just et al., 2012; Minshew & Williams, 2007). Since underconnectivity reduces the rate of inter-region information transfer, it could be that in social communication tasks that rely on the fast detection of implicit, often ambiguous cues, a failure to be able to transmit information across different cortical areas quickly, might mean that these cues are missed, rendering inappropriate responses in ASD.

The findings of repeated scanning of the target areas, coupled with an inability to immediately recognise social violations upon initial fixation, reflect how eye movements can reveal subtle processing differences in ASD. In everyday social communication in the real world
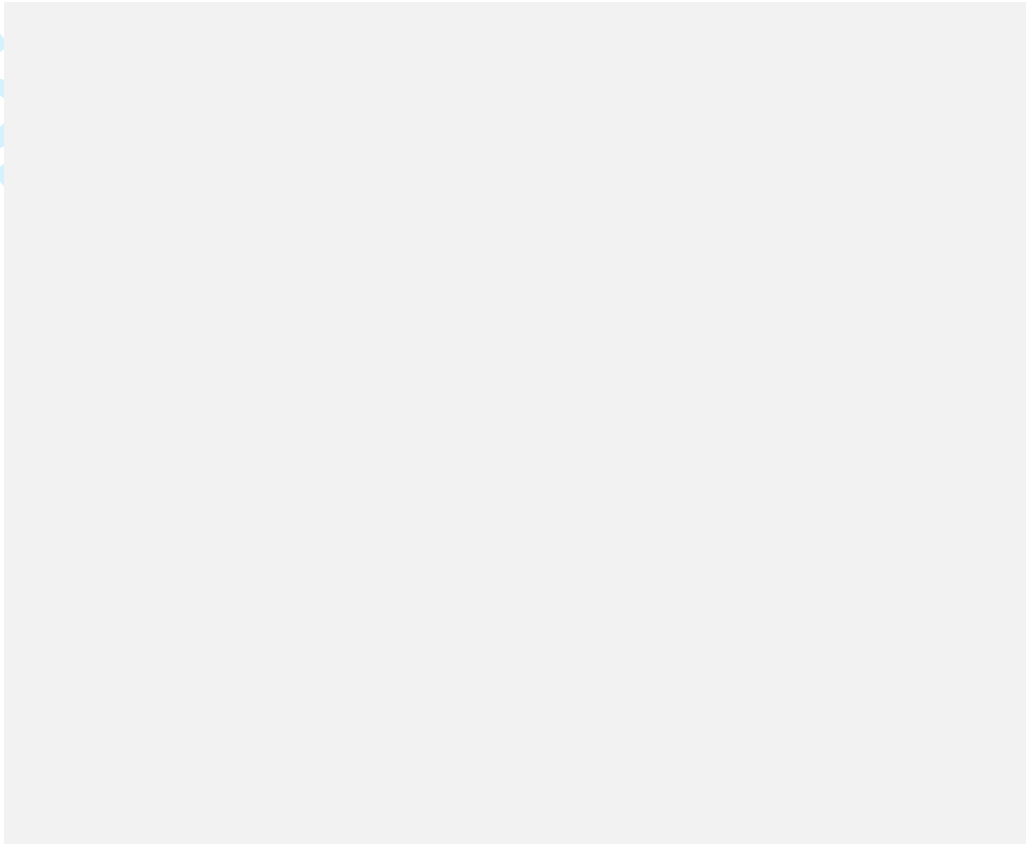
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there is no opportunity to 'go back' to check if one has missed an important cue. Social processing in such circumstances must be carried out on-line, and our eye movement data clearly show that ASD are unable to do this quickly. The strategy of re-checking their interpretation, and thus not believing what they have seen, before responding, may be related to cortical underconnectivity in ASD. In everyday terms, these findings have obvious consequences for fast dynamic social interactions, and offer an account as to why high functioning adults with ASD experience difficulty in the social domain.

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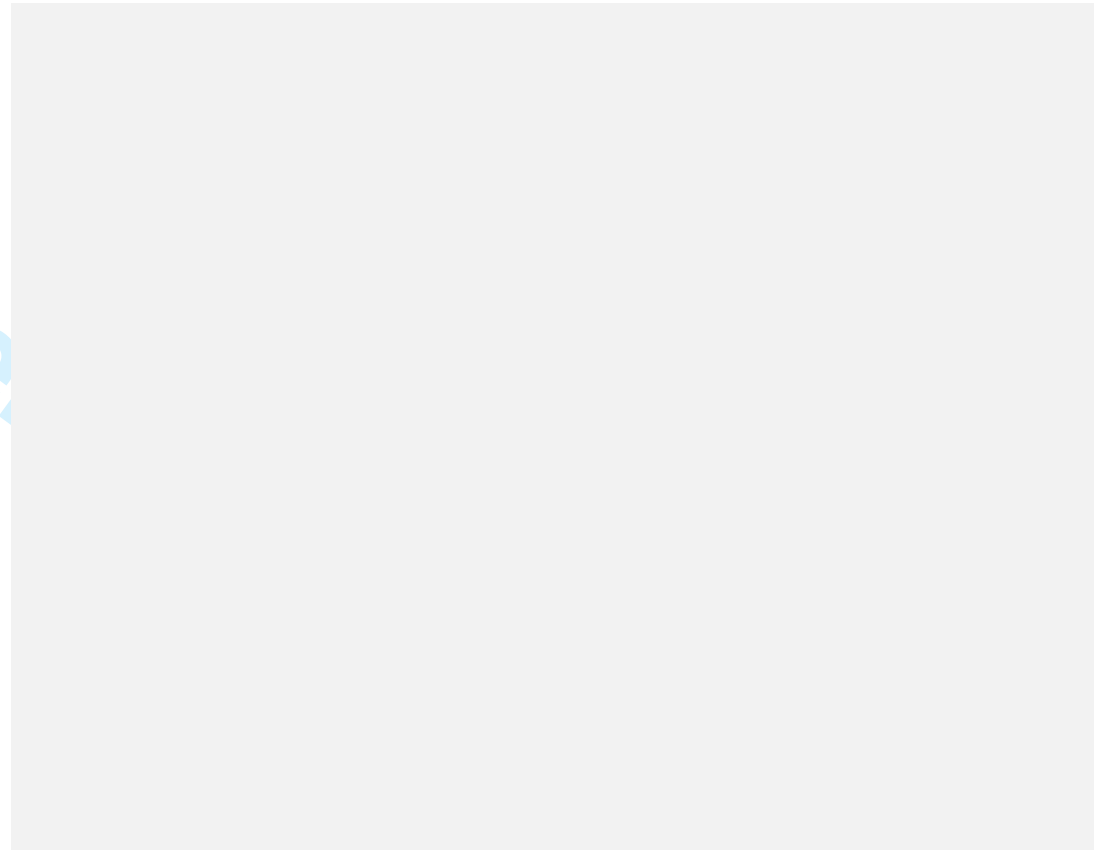
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Footnotes

1. Accuracy errors for the excluded scenes were either a result of a failure to detect a subtle

oddity, or were a result of participants thinking the control version of the scenes were odd.

Removing these items from analysis did not change the pattern of effects, but reduced variation

in reaction time and eye movement data.

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Tables

Table 1.

Accuracy and reaction time means (standard deviations).

	Perceptual				Social			
	Normal		Weird		Normal		Weird	
	TD	ASD	TD	ASD	TD	ASD	TD	ASD
Accuracy	0.81 (0.20)	0.86 (0.10)	0.84 (0.20)	0.77 (0.17)	0.80 (0.17)	0.83 (0.12)	0.80 (0.21)	0.76 (0.24)
Reaction Time (ms)	5289 (2372)	6024 (2560)	3697 (1703)	5184 (2228)	5117 (2443)	6053 (2884)	3056 (1270)	4633 (2131)

Table 2.

Eye movement measure means in ms (standard deviations).

		Perceptual Oddity		Social Oddity	
		TD	ASD	TD	ASD
Mean Fixation Duration (overall)		250 (31)	257 (29)	241 (26)	252 (33)
Mean Fixation Count (overall)		11 (4)	15 (6)	9 (4)	13 (7)
Elapsed time to target region	ELT	551 (235)	557 (144)	600 (235)	679 (284)
Fixation count before target region	FCT	2.32 (0.72)	2.49 (0.67)	2.62 (0.76)	2.68 (0.73)
First fixation duration in target region	FFD	224 (52)	237 (42)	232 (45)	210 (41)
First gaze duration in target region	FGD	808 (250)	924 (437)	630 (163)	715 (208)
Mean fixation duration in target region	MFD	262 (43)	274 (34)	281 (38)	282 (45)
Mean fixation count in target region	MFC	5.78 (2.28)	7.72 (2.84)	3.97 (1.81)	5.47 (2.14)
Mean number of entries into target region	MNE	1.93 (0.64)	2.32 (0.73)	1.62 (0.52)	2.07 (0.66)
Mean total time in target region	TT	1522 (729)	2065 (809)	1040 (527)	1450 (664)

Figures captions

Figure 1. Example of social normal (A), social weird (B), perceptual normal (C) and perceptual weird (D) stimuli. The black square represents the target region. Note the black square is not visible during the experiment.

Figure 2. Interaction for first fixation duration (ms) between group and oddity type. Error bars denote +/-1 SE.

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Looking, Seeing and Believing in Autism: Eye Movements reveal how subtle

cognitive processing differences impact in the social domain.

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Lay Abstract

Adults with High Functioning Autism (ASD) viewed scenes with people in them, whilst having their eye movements recorded. The task was to indicate, using a button press, whether the pictures were normal, or in some way weird or odd. Oddities in the pictures were categorized as violations of either perceptual or social norms. Compared to a Typically Developed (TD) control group, the ASD participants were equally able to categorise the scenes as odd or normal, but they took longer to respond. The eye movement patterns showed that the ASD group made more fixations and revisits to the target areas in the odd scenes compared to the TD group. Additionally, when the ASD group first fixated the target areas in the scenes, they failed to initially detect the social oddities. These two findings have clear implications for processing difficulties in ASD for the social domain, where it is important to detect social cues on-line, and where there is little opportunity to go back and recheck possible cues in fast dynamic interactions.

Scientific Abstract

Autistic Spectrum Disorder (ASD) and Typically Developed (TD) adult participants had to

decide whether scenes were 'odd', 'unusual' or 'weird'. All scenes contained people, with

'oddness' operationally defined as either perceptual or social. There were no group differences in

accuracy, but the ASD group were slower overall to respond manually. Eye movements revealed

that the ASD group made more fixations overall and more re-fixations into the target regions of

the pictures, for both conditions. Importantly, as indexed by the first fixation duration the ASD

group failed to 'pick up' immediately on what was 'odd' for the social violations. The propensity

to 'go back' and re-fixate targets, coupled with a failure to initially detect social violations, has

obvious significance for ASD in fast dynamic social communication.

Key phrases: Autism Spectrum Disorder, Eye movements, On-line cognitive processing, Social

and Perceptual Oddities.

Looking, Seeing and Believing in Autism: Eye Movements reveal how subtle cognitive

processing differences impact in the social domain.

Autism spectrum disorders (ASD) are lifelong neuro-developmental conditions characterized by repetitive behaviours and impairments in interaction and communication (American Psychiatric Association, 2013). Incidence rates are rising across the globe with the prevalence rate in the UK approximately 10 per 1000 (1%) individuals (Brugha et al., 2011) and the UK National Audit office recently called for more research into adults with ASD (Clark et al., 2009).

High functioning adults with ASD are similar to typically developed (TD) adults in terms of performance on pencil and paper and IQ tests, however in the social domain evidence suggests an inability to process social information in a typical fashion. Eye movement studies report unusual gaze behaviour for faces appearing on their own (Dalton et al., 2005), in social scenes (Riby & Hancock, 2009) or in dynamic movie clips (Klin & Jones, 2006; Speer et al., 2007). Research consistently reports a lack of spontaneous gaze fixation towards the eyes (Jones et al., 2008; Klin et al., 2002a; Pelphrey et al., 2002). However, where one study reports impairments, say for face processing (Klin et al., 2002b), another study does not (Fletcher-Watson et al., 2009). Moreover, lack of attentional modulation for social stimuli (Bird et al., 2006) may be overridden, as when cued, attention may be allocated to faces in a more 'typical' manner (Bar-Haim et al., 2006).

A recent scene perception study (Louwerse et al., 2014) reported that abnormal autonomic responses in ASD are unlikely to underpin social processing impairments. It is interesting then to ask whether impairments in the cognitive domain in ASD (Happé & Frith, 2006; Minshew et al., 1997; Russell, 1997) could account for impairments in the social domain?

Current cognitive theories of ASD include, among others, Weak Central Coherence (WCC) theory (Frith & Happé, 1994; Happé & Frith, 2006) which proposes that a reduced sensitivity to global context in favour of focussing on details, results in integration difficulties in ASD. Executive function theory (Russell, 1997), proposes that ASD are impaired at switching their focus of attention, and may engage in perseverative behaviour. Alternatively, the Complex Information Processing theory (Minshew & Goldstein, 1998) proposes that individuals with ASD have impairments in processing complex information with intact processing for tasks that require simple (rule based) processing. Finally, the Extreme Male Brain (EMB) theory (Baron-Cohen, 2002) posits that individuals with ASD have above average levels of systemizing, that contribute to the non-social characteristics of the disorder, coupled with below average levels of empathizing, which results in atypical social functioning. These contemporary theories of ASD can, for different reasons, offer some account of ineffective social functioning in ASD. However, to date very few investigations have examined online processing differences in ASD.

Our studies investigating cognitive processing in adults with ASD (Au-Yeung et al., 2011; Au-Yeung et al., 2013; Benson et al., 2012; Benson et al., 2009; Benson & Fletcher-Watson, 2011) have found subtle on-line processing differences, as revealed by eye movements, for a range of tasks that are more in line with Minshew and Goldstein's (1998) theory, than with any other. For example, there are more similarities than differences in eye movements between TD and ASD groups for simple rule based tasks in the attentional (Kuhn et al., 2010) and the social domains (Benson & Fletcher-Watson, 2011). Whereas for more complex abstract reasoning tasks where there is ambiguity with relation to target items (Au-Yeung et al., 2013), or where value judgements rely on top down knowledge (Benson et al., 2012), there are early processing differences indicating that initial orienting to, and immediate detection of weird target

items in scenes is absent in ASD. Moreover, the time to respond and to locate the weird target items was modulated by whether or not the pictures had people in them (Benson et al., 2012). These differences have potential for impact on everyday activities, since the time course for detection of socially relevant information is crucial for successful everyday interactions.

The aim of the present study was to examine whether increased times to find and initially detect an unusual target in a scene would be modulated by whether the violation that rendered the target unusual or odd could be categorised as social or perceptual. We employed a similar paradigm to that used in a previously reported study (Rayner et al., 2009) where single scenes, all with people in them, were presented in isolation and the task was to indicate whether each picture was normal or in some way weird unusual or odd.

Insert Figure 1. about here

Social oddities in the pictures were operationally defined as violations of social norms e.g. someone in the picture throwing a baby in the air. Access to top down knowledge is required in that condition to inform a subjective value judgement as to whether a social violation is present in the picture. No value judgement as to whether a violation infringes some implicit or explicit social rule is needed for the perceptual oddities in this study, which are operationally defined as physical violations e.g. someone in the picture has a limb positioned back to front. See supplementary information for Materials. Figure 1 shows an example of the stimuli.

Method

Participants

ASD participants (n = 24 age 18 – 52 years, 20 males), with a formal diagnosis of either Autistic Disorder (n = 3) or Asperger's Syndrome were recruited from local charitable

organisations. TD participants (n = 24, age 20– 52 years, 20 males) were volunteers from the

local community. All participants were paid and had normal or corrected to normal vision. Each

ASD participant completed module 4 of the Autism Diagnostic Observation Scale 2 (Lord et al.,

2012) and five (3 males and 2 females with a diagnosis of Asperger's Syndrome) failed to meet

the Autism Spectrum criteria. To ensure maximum homogeneity in our study those five

participants were excluded from the analyses, resulting in a final sample of 19 ASD participants.

Both groups completed the Autism-spectrum Quotient (AQ; Baron-Cohen et al., 2001) and the

ASD participants reported a higher number of autistic traits t (41) = 8.04, p < .001 (TD M =

15.42, SD = 7.55; ASD M = 35.32, SD = 8.45). The two groups did not differ in age t (41) =

0.31, p = .759 (TD M = 30.29, SD = 10.20; ASD M = 31.26, SD = 10.29), performance IQ t (41)

= 0.21, p = .832 (TD M = 111.79, SD = 12.01; ASD M = 110.95, SD = 13.84), verbal IQ t (41) =

1.21, p = .234 (TD M = 116.96, SD = 10.65, ASD M = 112.26, SD = 14.84), or full scale IQ t

(46) = 0.87, p = .392 (TD M = 116.04, SD = 9.98, ASD M = 112.95, SD = 13.48), as measured

by two performance (Block Design and Matrix Reasoning) and verbal components (Vocabulary

and Similarities) of the Weschler Abbrevated Scale of Intelligence (The Psychological

Corporation, 1999).

Eye movement recording

Eye movements were sampled at 1000Hz using an Eyelink tracker with spatial accuracy

of less than 1/4th degree (S.R. Research Ltd, Canada). The start and end of saccades were

detected automatically using a default velocity criterion of 30degrees per second using the

Eyelink software. See Stampe (1993) for an in depth technical description of how the software

detects saccades and fixations. A chin rest and forehead support, were used to stabilize head

position. Viewing was binocular but data were analysed for the right eye only. Individual

participants were calibrated using a nine point matrix that covered the dimensions of the screen

(1024 x 768 pixels), with each point fixated sequentially, followed by a validation procedure to

ensure that fixation was within 0.5 degrees of each calibration point. Calibration was checked

using a validation procedure prior to each trial, whereby participants fixated five dots, presented

at five different locations that covered the dimensions of the screen and recalibration was

performed if the eyes were off centre for any of these dots.

Materials

   In total, 96 full-colour photographs were used as stimuli, all of which contained people.

In both the perceptual and social oddity conditions there were 48 pictures (24 weird and 24

normal). Perceptual oddities in the pictures violated a physical norm e.g. someone in the picture

has a limb positioned back to front, or a vehicle was in an unexpected position e.g midway

through the upper wall of a building. Social oddities in the pictures violated a social norm e.g.

someone in the picture throwing a baby in the air, or someone with a cabbage on a lead. A small

number of the pictures were from a previous study (Benson et al., 2012) and the remainder were

collected from the internet and included either a perceptual or social oddity. Adobe Photoshop

was used to prepare a normal version of each scene in which the oddity was replaced with either

the background elements or with another suitable object. The scenes typically had a focal object

or a central group of objects. Figure 1 shows an example of a normal and a socially odd scene,

and below those examples, a normal and a perceptually odd scene. The target regions for these

scenes are outlined in black – but these black outlines were not visible during the presentation of

the scenes in the experiment.

A norming study was conducted to verify the validity of the images used to examine the processing of social and perceptual violations. Twenty undergraduates from Queen's university participated (*M* age: 19.8years, *SD*: 1.71, 10 Females) with five participants in each of the four conditions (counterbalanced conditions: weird/normal and right/left button response). Stimuli were displayed on a 21inch CRT monitor with a refresh rate of 100Hz and the experiment was run using E-Prime software. Participants were presented with a fixation cross for 500ms followed by the presentation of the image for 20 seconds or until a keyboard "Y' (yes) or "N" (N) was made. Participants had to indicate as quickly as possible whether the presented image was "odd", "weird" or "unusual" in some way. The proportion of identified images indicated that on average, the social normal (*M* = 0.86, *SD* = 0.15) and social weird (*M* = 0.84, *SD* = 0.17), perceptual normal (*M* = 0.82, *SD* = 0.17) and perceptual weird (*M* = 0.77, *SD* = 0.19) images were identified correctly.

Design

For the behavioural measures of Accuracy and RT a mixed design with Picture Type (weird versus normal) and Oddity Type (social versus perceptual) as within participants variables, and Group (ASD versus TD) as a between participants variable was employed for the experiment. On condition that accuracy was equivalent for both normal and weird pictures, for the eye movement measures the main focus of interest was to compare social versus perceptual oddities in both groups. Therefore a mixed design with Oddity Type (social versus perceptual) as a within participants variable, and Group (ASD versus TD) as a between participants variable was employed in the eye movement analysis.

Procedure

All participants were shown a hard copy of an example picture from each condition prior to completing the task, to ensure comprehension of the task and the ability to respond appropriately. The specific instruction was 'for each of the following pictures, please indicate whether you think the picture is odd, unusual or strange in some way'.

For the task, 48 pictures were presented randomly to either the left or the right of the centre of a 19inch colour monitor, at a distance of 65cm for 20s or until a button press response was made. Prior to the onset of a picture, participants fixated a cross that was presented on the opposite side of the screen to where the picture was set to appear, to ensure all participants started at the same point in each trial. Once participants fixated this cross, the experimenter initiated each trial. Picture type (normal vs. weird) and, the position of the picture (left or right on the display) were counterbalanced across items. The buttons used to respond either yes or no (left or right trigger button) was counterbalanced across participants.

Data preparation and analyses

For each 'odd' picture we created an interest region around the target item and the corresponding region of the same size in the counterpart 'normal' picture. Regions of interest were created using the approximate average regions from those identified and manually selected by participants who took part in the norming experiment.

Eyelink software was used to detect saccades and fixations using a default velocity criterion and in-house software was used to calculate the distribution of fixations falling into the target region. Five items were removed from analysis because for these scenes, participant accuracy scores were significantly below chance[1]. In addition, each participant was asked whether they had seen

any of the scenes previously, and if so these scenes were also removed. This resulted in a loss of 2.3% of trials. Fixations below 90ms and above 1200ms were classed as outliers and removed; resulting in a loss of 5.13% of the fixation data.

Results

For the principal analyses we compared manual reaction times and accuracy (see Table 1), as well as a number of eye movement measures, such as, the time taken to begin fixating in the target region (ELT), the duration of the first fixation when the eyes landed in the target region (FFD) and the mean time (MFD) spent fixating in the target area (see Table. 2). Global eye movement measures for the target region, such as mean fixation duration and mean number of fixations over all trials were also analysed, Finally, baseline measures (not just target related), were calculated across the duration of the trials, to check for overall sampling differences between the ASD and TD participants (see Table 2). See supplementary information for methods and materials.

Behavioural Data

Accuracy. There was no effect of oddity type (perceptual vs. social) $F (1, 41) = 1.44$, $p = .237$, $\eta_p^2 = .03$, picture type (normal or weird) $F (1, 41) = 0.94$ $p = .339$, $\eta_p^2 = .02$, or group, $F (1, 41) = .06$, $p = .808$, $\eta_p^2 < .01$ on accuracy rates, and no interactions ($Fs < 2.39$, $p's > .130$). At least in terms of accuracy, performance was the same for both groups. For means and standard deviations for behavioural data see Table 1.

Response Time (RT). A main effect of oddity type $F (1, 41) = 8.16$, $p = .007$, $\eta_p^2 = .17$, showed participants took longer to respond when presented with a perceptual oddity in

comparison to a social oddity. Longer response times for perceptual oddities could reflect that these 'impossible', physical violations were so unusual that they resulted in more time spent looking at them prior to responding. See below for confirmation of that in the eye movement data. There was also a main effect of picture type $F(1, 41) = 24.03$, $p < .001$, $\eta_p^2 = .37$, with participants taking longer to respond when the picture was normal in comparison to when it was weird, in line with longer reaction times for target absent trials in standard visual search tasks (Wolfe, 1998). A significant oddity type x picture type interaction $F(1, 41) = 4.22$, $p = .046$, $\eta_p^2 = .09$, demonstrated that the difference between RTs for perceptual and social pictures was reliable for odd (TD; $t(23)$ 2.62, $p = .015$, ASD; $t(18) = 2.98$, $p = .008$) but not for normal pictures (TD; $t(23)$ 0.94, $p = .355$, ASD: $t(18) = 0.08$, $p = .935$). A main effect of group $F(1, 41) = 4.07$, $p = .050$, $\eta_p^2 = .09$, showed the ASD participants had longer reaction times, in line with a previous study (Benson et al., 2012). There were no significant group interactions ($Fs < 1$) demonstrating both groups to be slower for normal versus odd pictures, and for perceptual vs social oddities. See Table 1 for the means. The eye movement data below reveals subtle processing differences that contribute to this overall slowed manual responding in the ASD group.

Eye Movement Data

       Having shown that all participants could distinguish between 'odd' and 'normal' pictures, normal picture trials were excluded from the eye movement analyses resulting in a 2 (group: ASD versus TD) X 2 (oddity type: social versus perceptual) design to investigate on-line processing differences between the two groups for the two types of oddities.

Baseline eye movement measures, calculated across the full length of trials indicated no group difference in mean fixation duration F (1, 41) = 1.14, p = .293, η_p^2 = .03, but the ASD group made more fixations overall F (1, 41) = 9.44, p = .004, η_p^2 = .19, corresponding to the increased RT's reported above. Table 2 presents a summary of all the eye movement measures.

Elapsed time to the target region (ELT). A marginal effect of oddity type F (1, 41) = 3.99, p = .053, η_p^2 = .09, on the time taken from the onset of each trial display to the start of the first fixation on the target region, revealed both groups took less time to fixate the target region when the oddity was perceptual in comparison to social in nature. There was no effect of group F (1, 41) = 0.59, p = .446, η_p^2 = .01, and no interaction F (1, 41) = 0.72, p = .401, η_p^2 = .02.

First Fixation Duration (FFD) on target region. There was no effect of oddity type F (1, 41) = 1.84, p = .182, η_p^2 = .04 or group F (1, 41) = 0.15, p = .699, η_p^2 < .01 but a significant interaction F (1, 41) = 6.72, p = .013, η_p^2 = .14 (See Figure 2) revealed that FFDs were equivalent for perceptual and social oddities for TD participants t (23) = 0.86, p = .399, d = .16, but for ASD participants FFDs for social oddities were significantly shorter, in comparison to perceptual oddities, t (18) = 2.99, p = .008, d = .65, see Figure 2. Given that the FFD is a measure of early processing *(*Liversedge & Findlay, 2000; Rayner, 1998; Rayner, 2009*)*. this finding indicates that the ASD group did not detect the social oddities as quickly as the perceptual oddities on initial fixation, whereas TD participants detected both types of oddity equally fast.

Insert Figure 2. about here

First gaze duration (FGD) in the target region. The FGD is the elapsed time from when the target region is first fixated until the eye moves on to a new location. FGD includes multiple fixations in the target region reflects an overt strategy to re-examine an area. A main effect of oddity type, $F(1, 41) = 12.10$, $p = .001$, $\eta_p^2 = .23$ demonstrated that both groups spent more time inspecting perceptual oddities, again highlighting the salience of the perceptual oddities in comparison to social oddities in this study. However, there was no group effect $F(1, 41) = 2.43$, $p = .127$, $\eta_p^2 = .06$, or interaction $F(1, 41) = .08$, $p = .785$, $\eta_p^2 < .01$.

Mean Fixation Count in the target region. If the ASD are slower to respond manually, but do not take longer to begin inspecting the target region, then extra time to respond might reflect more fixations in the target region. A main effect of oddity type $F(1, 41) = 64.27$, $p < .001$, $\eta_p^2 = .61$, demonstrated more fixations in the target region when the oddity was perceptual, rather than social. A main effect of group $F(1, 41) = 6.99$, $p = .012$, $\eta_p^2 = .15$ showed that the ASD group made more fixations than the TD group in the target regions, for both types of oddities. However no interaction was observed $F(1, 41) = 0.77$, $p = .386$, $\eta_p^2 = .02$ indicating that the ASD group made more fixations in the target regions for both types of oddities.

Mean Fixation Duration in the target region. Longer mean fixation durations indicate that more processing has been done during the task. A main effect of oddity type $F(1, 41) = 8.22$, $p = .007$, $\eta_p^2 = .17$ showed significantly longer fixations for social, compared to perceptual oddity target regions. This suggests that processing social oddities was more effortful, and since there was no main effect of group $F(1, 41) = 0.34$, $p = .562$, $\eta_p^2 < .01$, and no interaction $F(1, 41) = 1.12$, $p = .297$, $\eta_p^2 = .03$, both groups on average fixated the social oddity target region for longer

than the perceptual target region. Thus, while the perceptual oddities attracted more fixations overall, individual fixations were longer for the social target region.

This interesting juxtaposition, although unrelated to the main aim of this study, suggests that difficulty associated with processing each oddity type manifests in different eye movement patterns: one reflecting an overt strategy (fixation count) to re-inspect the target area, and one reflecting more in depth on-line cognitive processing (fixation duration) on the target areas.

Mean Number of Entries to the target region. Since there were no group differences in FGD, and no increased MFD, both reported above, the delayed RT in ASD might reflect repeated visits to inspect the target region?

A main effect of oddity type was found $F(1, 41) = 9.83$, $p = .003$, $\eta_p^2 = .19$, with the target region entered more often for perceptual oddities in comparison to social oddities. In addition, a main effect of group was found $F(1, 41) = 5.72$, $p = .021$, $\eta_p^2 = .12$, with ASD participants entering the target regions significantly more than the TD group, before making a response. There was no interaction $F(1, 41) = 0.13$, $p = .717$, $\eta_p^2 < .01$.

Mean Total Time in the target region. A higher mean total time means that more attention to, and processing of, information in that region was carried out overall. This measure should complement the measures reported above – namely, that if there are more fixations overall in ASD then the Total Time spent fixating in the target region should be longer in ASD.

A main effect of oddity type $F(1, 41) = 34.89$, $p < .001$, $\eta_p^2 = .46$, showed perceptual oddities received more overall processing time, in line with the previous measures for the perceptual oddities. In addition, a main effect of group $F(1, 41) = 6.41$, $p = .015$, $\eta_p^2 = .14$

revealed that the ASD participants spent a longer period of time inspecting the target regions for both perceptual and social oddities. There was no interaction $F(1, 41) = 0.51$, $p = .481$, $\eta_p^2 = .01$.

As above, this finding reflects a greater number of entries to the target region overall by the ASD group prior to making their decision as to whether the picture under inspection was weird, odd or unusual, irrespective of the nature of the violation (perceptual or social).

Discussion

A principal aim of the study was to investigate whether increased times in ASD to find and initially detect an unusual target in a scene containing people would be modulated by whether the violation could be categorised as social or perceptual.

Accuracy rates were equivalent and high for both groups, but the ASD group took longer to respond manually. It was hypothesised that the eye movement data would reveal the cause of this delayed response in ASD, since eye movements reflect how information is processed on-line (Liversedge & Findlay, 2000; Rayner, 1998; 2009). The data showed that our ASD group did not take longer to find the target regions, but that they scanned the scenes more prior to responding manually, as shown by an increased number of fixations throughout each scene presentation. Furthermore, these increased fixations were not random, but were made to the target regions of both social and perceptually odd pictures. Thus, increased fixations reflect a propensity to re-inspect the target regions prior to making a response in ASD, regardless as to the type of oddity in the scenes. It should be noted here that the oddity detection task in the current study provides the ASD participants with structure that is not typically available in real-life. As such, the task is not implicit and the knowledge that oddities might be present could also be a factor that drives the repeated scanning in ASD.

The eye movement patterns also showed that our ASD group failed to immediately detect social oddities, thus looking at but not seeing them. An obvious question from this finding is whether the failure to quickly spot subtle social oddities in ASD reflects an inability to react or respond appropriately to social cues in everyday communication? This one impairment in itself could potentially account for the significant problems experienced in dynamic social interactions in this high functioning population. For example, a failure to immediately spot social cues would result in a failure to react or respond to such cues thus resulting in an inability to both keep track of what is going on in social interactions, and a failure to engage appropriately or effectively with other people.

If social oddities are more complex to detect in ASD, then the Complex Information Processing theory (Minshew & Goldstein, 1998) might explain the failure to detect the social oddity on first fixation. This lack of immediate detection could reflect the less obvious and more 'inferential' nature of the social oddities, which required more complex reasoning, at least in the ASD group, for detection. It is important to note that social rules are often implicit, sometimes ambiguous, and cannot always be understood by following a script or flow chart as in the case for logical rule based tasks. At a neurobiological level, it has been postulated that that impairments in cognitive processing in ASD reflect slow information transmission rates for high level cognitive tasks, resulting from underconnectivity between frontal-posterior cortical regions (Just et al., 2013; Just et al., 2012; Minshew & Williams, 2007). Since underconnectivity reduces the rate of inter-region information transfer, it could be that in social communication tasks that rely on the fast detection of implicit, often ambiguous cues, a failure to be able to transmit information across different cortical areas quickly, might mean that these cues are missed, rendering inappropriate responses in ASD.

The findings of repeated scanning of the target areas, coupled with an inability to immediately recognise social violations upon initial fixation, reflect how eye movements can reveal subtle processing differences in ASD. In everyday social communication in the real world there is no opportunity to 'go back' to check if one has missed an important cue. Social processing in such circumstances must be carried out on-line, and our eye movement data clearly show that ASD are unable to do this quickly. The strategy of re-checking their interpretation, and thus not believing what they have seen, before responding, may be related to cortical underconnectivity in ASD. In everyday terms, these findings have obvious consequences for fast dynamic social interactions, and offer an account as to why high functioning adults with ASD experience difficulty in the social domain.

Acknowledgments

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Footnotes

1. Accuracy errors for the excluded scenes were either a result of a failure to detect a subtle

oddity, or were a result of participants thinking the control version of the scenes were odd.

Removing these items from analysis did not change the pattern of effects, but reduced variation

in reaction time and eye movement data.

Tables

Table 1.

Accuracy and reaction time means (standard deviations).

| | Perceptual | | | | Social | | | |
| | Normal | | Weird | | Normal | | Weird | |
	TD	ASD	TD	ASD	TD	ASD	TD	ASD
Accuracy	0.81 (0.20)	0.86 (0.10)	0.84 (0.20)	0.77 (0.17)	0.80 (0.17)	0.83 (0.12)	0.80 (0.21)	0.76 (0.24)
Reaction Time (ms)	5289 (2372)	6024 (2560)	3697 (1703)	5184 (2228)	5117 (2443)	6053 (2884)	3056 (1270)	4633 (2131)

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Table 2.

Eye movement measure means in ms (standard deviations).

		Perceptual Oddity		Social Oddity	
		TD	ASD	TD	ASD
Mean Fixation Duration (overall)		250 (31)	257 (29)	241 (26)	252 (33)
Mean Fixation Count (overall)		11 (4)	15 (6)	9 (4)	13 (7)
Elapsed time to target region	ELT	551 (235)	557 (144)	600 (235)	679 (284)
Fixation count before target region	FCT	2.32 (0.72)	2.49 (0.67)	2.62 (0.76)	2.68 (0.73)
First fixation duration in target region	FFD	224 (52)	237 (42)	232 (45)	210 (41)
First gaze duration in target region	FGD	808 (250)	924 (437)	630 (163)	715 (208)
Mean fixation duration in target region	MFD	262 (43)	274 (34)	281 (38)	282 (45)
Mean fixation count in target region	MFC	5.78 (2.28)	7.72 (2.84)	3.97 (1.81)	5.47 (2.14)
Mean number of entries into target region	MNE	1.93 (0.64)	2.32 (0.73)	1.62 (0.52)	2.07 (0.66)
Mean total time in target region	TT	1522 (729)	2065 (809)	1040 (527)	1450 (664)

Figures captions

Figure 1. Example of social normal (A), social weird (B), perceptual normal (C) and perceptual weird (D) stimuli. The black square represents the target region. Note the black square is not visible during the experiment.

Figure 2. Interaction for first fixation duration (ms) between group and oddity type. Error bars denote $\pm$/- 1 SE.