A study of impaired judgment of eye-gaze direction and related face-processing deficits in autism spectrum disorders

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Abstract. The purpose of this study was to examine whether individuals with autism spectrum disorders (ASD) use the same cognitive strategies as typically developing individuals when processing eye-gaze direction. Subjects viewed pictures of whole faces, the eye region alone, and pairs of arrows presented for 40, 70, or 100 ms, and responded according to the direction the eyes were looking or the arrows pointing (left, right, or straight ahead). Experiment 1 demonstrated that typically developing adults (n = 41) were more accurate and showed shorter reaction times when judging direction of averted eye gaze in the context of the whole face than when only the eyes were visible (eye-region-alone condition). Furthermore, in the eye-region-alone condition participants were more accurate and faster at judging direct eye gaze than averted eye gaze. The same task was used in experiment 2 to compare the performance of a group of individuals with ASD (n = 24) with that of a group of IQ-matched typically developing individuals (n = 26). The performance of the control participants was identical to that observed in experiment 1. Individuals with ASD were able to judge eye-gaze direction accurately at short exposure duration; however, they failed to show the typical advantage for judging averted gaze in whole faces and the increased sensitivity to direct gaze in the eye-region-alone condition. The findings are discussed in terms of impairments to discrete gaze-processing and face-processing mechanisms, and the connectivity between these mechanisms.

1 Introduction

Individuals with autism spectrum disorders (ASD) have difficulty forming reciprocal social relationships, show abnormal patterns of language development, and engage in repetitive and circumscribed behaviours (Volkmar et al 2004). Anecdotal reports from parents and clinicians, as well as experimental findings, suggest that individuals with ASD look less frequently at other people and for shorter periods of time (Tantam et al 1993; Volkmar and Mayes 1990), in particular at the face and eyes (Hobson and Lee 1998; Klin et al 2002), instead tending to look at the lower parts of the face (Langdell 1978). The importance of monitoring and responding to faces during typical development has led researchers to study face processing in ASD, and impairments have been reported in the identification of recently seen faces (Boucher and Lewis 1992; Klin et al 1999), recognition of facial expressions (Hobson et al 1988; Pelphrey et al 2002), and judgments of eye-gaze direction (Howard et al 2000). There has been little effort, however, to investigate whether these three deficits in face processing are the consequence of impairments to a single mechanism or to multiple independent mechanisms.

Few studies have investigated the ability of individuals with ASD to judge eye-gaze direction. Leekam et al (1997) found that individuals with autism were able to use a geometric analysis or feature-based strategy to judge eye-gaze direction when deciding which peg a person was looking at, but that they were impaired when spontaneously monitoring another’s gaze. Howard et al (2000) detected impairments in adults and adolescents with ASD when the task was to identify whether eye gaze was directed at them.
rather than averted by varying degrees of visual angle. A recent suggestion is that the impairment in gaze detection is restricted to abnormal processing of direct eye gaze (Senju et al. 2003). Volkmar et al. (1989) provided three explanations for avoidance of direct gaze in ASD: first, it causes over-arousal; second, individuals with ASD fail to understand the social meaning of direct gaze; and, third, the use rather than the understanding of direct gaze is disordered. A recent fMRI study by Dalton et al. (2005), which simultaneously tracked eye movements to face stimuli, showed correlations between the length of time individuals with ASD looked at the eyes and the amount of amygdala activation (a region of the brain that is typically activated by emotionally salient stimuli). These data arguably lend support to the proposal that eye contact causes over-arousal in individuals with ASD.

An alternative approach to the study of eye-gaze detection in ASD has been to investigate reflex shifts of attention to a target when cued by a picture of eye gaze averted left or right. Typically developing infants (Farroni et al. 2000; Hood et al. 1998), children (Swettenham et al. 2003), and adults (Driver et al. 1999; Hietanen 1999; Langton and Bruce 2000) show these reflexive shifts. In children with ASD, both Swettenham et al. (2003) and Kylliainen and Hietanen (2004) observed reflex orientation of attention when cued by eyes looking left or right.

It remains unclear whether individuals with ASD are impaired at making judgments of eye-gaze direction, but one possibility that has not been fully explored is whether any putative deficit is associated with impairments in other aspects of face processing. Research of typically developing individuals suggests that judgment of eye-gaze direction may not proceed completely independently of processing other aspects of the face (Farroni et al. 2002; Haxby et al. 2000; Johnson 1994). Studies of typically developing infants and adults have found superior judgments of eye-gaze direction when the other facial features are in their veridical arrangement, rather than inverted (Campbell et al. 1990; Farroni et al. 2003) or jumbled (Vecera and Johnson 1995). These findings are in line with the data on holistic face processing, which have shown greater recognition accuracy of facial features when they are presented in whole faces rather than in isolation (Tanaka and Farah 1993); a processing advantage which may be stronger for eyes than for other facial features (Farah et al. 1998). It is of note that individuals with ASD do not show this holistic processing effect when processing information from the eyes but they do if processing information from the mouth (Joseph and Tanaka 2003).

It has also been suggested that the processing of direct and averted eye gaze may activate separate face-processing mechanisms (George et al. 2001). Neonates look longer at a face with direct eye gaze compared to a face with gaze averted (Farroni et al. 2002), and children and adults find it easier to remember faces with direct rather than averted eye gaze (Hood et al. 2003; Macrae et al. 2002; von Grünewald and Anston 1995). Pictures of direct eye gaze activate fusiform gyrus, medial and superior temporal gyri (Calder et al. 2002; Wicker et al. 1998), and right amygdala (George et al. 2001; Kawashima et al. 1999). By contrast, faces with averted eye gaze activate intraparietal sulcus (George et al. 2001; Hoffman and Haxby 2000)—a cortical region typically activated when attention is shifted (Coull and Frith 1998). George et al. (2001) reported activation of fusiform gyrus (a cortical region involved in face processing) and greater correlative activity between fusiform gyrus and amygdala when observers looked at whole faces with direct but not with averted gaze. Individuals with ASD show reduced activation of fusiform gyrus when looking at face stimuli (see Schultz 2005) but it remains unclear whether this is a consequence of impaired processing of faces and/or direct eye gaze (Dalton et al. 2005).

The purpose of this study was to investigate whether individuals with ASD can utilise information from the whole face when they make judgments of eye-gaze direction and, also, whether they are more sensitive to direct than to averted gaze. The exposure duration of the stimuli was very short (40, 70, or 100 ms) in order to restrict the use
of a feature-based strategy to judge eye-gaze direction (Leekam et al 1997) and to
minimise the ceiling effects reported previously (Campbell et al 1990). Previous studies
of face processing in typical development have shown that exposure durations of 40 ms
restrict participants to employing parallel processing strategies, ones reliant on the low-
spatial-frequency properties, whereas when faces are presented at exposure durations
\(~100\) ms serial processing strategies can be used (Coin et al 1992, Loffler et al 2005).
Because of the very short exposure durations used to study gaze processing, in exper-
iment 1 we first examined the performance of a sample of non-clinical adults. We aimed
to test for the presence of two face-processing mechanisms: one that was sensitive to the
whole face and the other sensitive to direct eye gaze. First, we predicted that judgments
of eye-gaze direction would be more accurate and faster when participants viewed the
whole face rather than the eyes as an isolated feature. Second, we predicted that partic-
ipants would be more accurate and faster at judging direct eye gaze than averted eye gaze.
Third, we predicted that there would be no changes in performance across exposure
duration.

2 Experiment 1
2.1 Method
2.1.1 Participants. Forty-one (fourteen female; age range 16 – 54 years) participants com-
prised academic and non-academic staff and students from the Institute of Psychiatry,
London and Sheffield University. All participants had normal or corrected-to-normal
vision. Written informed consent was received from participants aged under 18 years.

2.1.2 Stimuli. Experimental stimuli were pictures of the whole face, the eye region alone,
or pairs of arrows. The eyes were directed either left, right, or straight ahead, whereas
the arrows pointed left, right, or upwards (equivalent to the eyes-straight-ahead condi-
tion). Arrow pictures were chosen as non-social control stimuli; although they were
not similar in terms of visual complexity to the whole-face and eyes-alone pictures,
they did index a participant’s ability to judge directional cues at very short exposure
durations.

A set of 12 whole-face pictures (8 male), looking straight ahead, was selected from
a database of high-quality pictures of adult faces. To ensure that head direction and
position were consistent regardless of eye direction, the direction of gaze in whole-
face pictures was altered with image-processing techniques. The eyes were consistently
altered so that they were looking either fully left or fully right (figure 1), so, if the
participant could perceive the stimulus at short exposure durations, there was little
uncertainty over the judgment to make. The eye-region-alone stimuli were obtained by
selecting the region of the whole face— from where the top of the eye socket and the
outer canthus of the left eye intersect to where the bottom of the eye socket and the outer
canthus of the right eye intersect. The arrow stimuli were constructed in Adobe Photoshop
to be pointing left, right, and straight ahead. The design of the straight-ahead arrow
stimulus was chosen as it had psychophysical properties that were similar to eyes
(a dark centre flanked either side by white). 36 whole-face, 36 eye-region-alone, and 36
arrow pictures (looking or pointing left, right, or straight ahead) were used, giving a
total stimulus set of 108 pictures. The whole-face pictures measured 250 \( \times \) 325 pixels,
whereas the eye-region alone and arrow pictures measured 170 \( \times \) 40 pixels. Examples of
all the stimuli are shown in figure 1.

2.1.3 Procedure. Stimuli were presented for one of three exposure durations (40, 70,
or 100 ms). The range of exposure times was chosen on the basis of findings from
a pilot study. The 40 ms exposure duration required participants to respond, despite
reduced awareness of the picture (Curran and Hintzman 1995; Shepard and Muller
1989). The 70 and 100 ms durations were chosen because they permitted an increasing
use of a serial-processing strategy (Coin et al 1992). The pictures from each stimulus type (whole face, eye region alone, arrows), cueing left, right, or straight ahead, were evenly assigned to each of the three exposure-duration conditions (eg the 12 whole-face pictures looking left were evenly distributed between the 40, 70, and 100 ms exposure-duration conditions).

Experimental stimuli were presented by means of the bit-block transfer functions of the Windows Application Programmer's Interface (API). Timing accuracy of stimuli presentations and response recording was validated with Exacticks (http://www.ryledesign.com) timing software. The experimental program was run via a Dan Pentium Pro PC. Participants sat at a viewing distance of 55 cm from a Vision Master Pro 400 monitor. A fixation cross was displayed for 350 ms. The test stimulus subsequently appeared at one of three exposure durations (40, 70, or 100 ms), followed immediately by a pattern mask of dots for 350 ms. The pattern mask limited the participants' ability to process the test image after stimulus offset (Costen et al 1994; Loffler et al 2005). After the mask had disappeared from the screen, the participants were required to respond with a button press and the reaction time was recorded. There was an interval of 1500 ms between each trial (see figure 2).

Participants were informed that pictures would appear very briefly on the computer screen and that their task was to decide in which direction the eyes were looking or the arrows pointing, and to respond by using a mouse with three buttons. If the cueing stimulus was directed toward the left-hand side of the computer screen, participants...
were told to press the left mouse button; if the cue was directed towards the right-hand side, they were told to press the right mouse button, and if the cue was directed straight ahead, they were told to press the middle button. 8 practice trials were presented to familiarise the participants with the procedure. There were a total of 108 experimental trials, with a break after 54 trials for the participants to rest.

2.2 Results

There were three independent variables: stimulus type (whole face, eye region alone, and pairs of arrows), cue direction (averted and straight ahead), and exposure duration (40, 70, and 100 ms). The dependent variables were reaction time and accuracy. Outliers were removed during calculation of means and prior to data analyses. Parametric tests were used, as the group means were normally distributed. In the averted condition, participants were not more accurate or faster at judging eye gaze in one direction over another (i.e. left versus right). No significant differences in performance were found between males and females and so the results from both sexes were combined. Planned comparisons were made to test the predictions that participants would be faster and more accurate at judging eye-gaze direction in whole faces and when eye gaze was directed straight ahead.

A 2 (stimulus type: whole face, eye region alone) × 2 (direction of gaze: averted, straight ahead) × 3 (exposure duration: 40, 70, or 100 ms) repeated-measures ANOVA was performed with reaction time as the independent variable. There was a significant main effect of stimulus type ($F_{1,40} = 6.776, p < 0.05$) but there was no main effect of direction of gaze ($F_{1,40} = 1.209$). Unpredicted findings were a main effect of exposure duration ($F_{2,39} = 8.526, p = 0.01$) and a significant interaction of stimulus type × direction of gaze ($F_{2,39} = 4.335, p < 0.05$).

**Figure 2.** On each trial a fixation cross was presented for 350 ms before being replaced immediately by the target stimulus, which appeared for one of three exposure durations (40, 70, or 100 ms). The target was replaced immediately by a pattern mask presented for 350 ms and finally a blank screen appeared and the participant could respond. There was an inter-trial interval of 1500 ms.
Planned pairwise t-tests showed that participants were faster at judging direction of eye gaze in whole faces compared to the eye region alone (t_{40} = 2.325, p < 0.05), but they were not faster at judging eyes directed straight ahead compared to averted. A posteriori pairwise t-tests, with a Bonferroni-corrected α of 0.0167, showed that participants were slower at judging eye-gaze direction (summed across the whole-face and eye-region-alone stimulus types) in the 40 ms condition than in the 70 ms condition (t_{40} = 3.115, p < 0.01), but there was no significant difference in reaction times between the 70 and 100 ms conditions. A posteriori t-tests, with a Bonferroni-corrected α of 0.025, were used to explore the significant interaction of stimulus type with eye-gaze direction. There was a whole-face to eye-region-alone advantage for judging averted (t_{40} = 4.046, p < 0.001) but not direct eye gaze. In the eye-region-alone condition participants were significantly faster at judging eye gaze directed straight ahead compared to averted (t_{40} = 2.468, p < 0.025), but in the whole-face condition they were not (see table 1).

Table 1. Exposure duration by stimulus type. Mean percentage accuracy and mean reaction time (RT) from experiment 1 (standard deviations are given in parentheses).

<table>
<thead>
<tr>
<th>Stimulus type</th>
<th>Exposure duration/ms</th>
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<tbody>
<tr>
<td></td>
<td>40</td>
<td>70</td>
<td>100</td>
<td>40</td>
<td>70</td>
</tr>
<tr>
<td></td>
<td>accuracy/% RT/ms</td>
<td>accuracy/% RT/ms</td>
<td>accuracy/% RT/ms</td>
<td></td>
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</tr>
<tr>
<td>Whole face</td>
<td>87.8 (14)</td>
<td>732 (298)</td>
<td>94.8 (8)</td>
<td>706 (253)</td>
<td>97.7 (6)</td>
</tr>
<tr>
<td>Eye region alone</td>
<td>83.8 (18)</td>
<td>774 (319)</td>
<td>90.5 (10)</td>
<td>731 (291)</td>
<td>91.1 (13)</td>
</tr>
<tr>
<td>Pairs of arrows</td>
<td>93.4 (11)</td>
<td>665 (270)</td>
<td>98.4 (4)</td>
<td>636 (270)</td>
<td>98.8 (4)</td>
</tr>
</tbody>
</table>

A second 2 (stimulus type: whole face, eye region alone) × 2 (direction of gaze: averted, straight ahead) × 3 (exposure duration: 40, 70, or 100 ms) repeated-measures ANOVA was performed with percentage accuracy as the independent variable. As predicted, there were significant main effects of stimulus type (\(F_{1,40} = 16.146, p < 0.001\)) and direction of gaze (\(F_{1,40} = 14.197, p = 0.001\)). Unpredicted findings were a main effect of exposure duration (\(F_{2,30} = 17.622, p < 0.001\)) and a significant interaction of stimulus type × direction of gaze (\(F_{1,40} = 6.382, p < 0.05\)).

Planned pairwise t-tests showed that participants were more accurate at judging direction of eye gaze in whole faces compared to the eye region alone (t_{40} = 4.018, p < 0.001) and when eye gaze was straight ahead compared to averted (t_{40} = 3.768, p = 0.001). A posteriori pairwise t-tests, with a Bonferroni-corrected α of 0.0167, showed that participants were less accurate at judging eye-gaze direction (summed across the whole-face and eye-region-alone stimulus types) in the 40 ms condition compared to both the 70 ms (t_{40} = 3.971, p < 0.001) and 100 ms (t_{40} = 5.087, p < 0.001) conditions, but there was no significant difference in accuracy scores between the 70 and 100 ms conditions. A posteriori pairwise t-tests, with a Bonferroni-corrected α of 0.025, were used to explore the significant interaction of stimulus type with eye-gaze direction. There was a whole-face to eye-region-alone advantage for judging averted (t_{40} = 4.001, p < 0.001) but not direct eye gaze. In the eye-region-alone condition the participants were significantly more accurate judging eye gaze directed straight ahead compared to averted (t_{40} = 3.584, p = 0.001), but in the whole-face condition they were not.

No a priori predictions were made about performance on the arrow condition. Participants were faster making judgments of arrow direction than of eye-gaze direction (t_{40} = 7.575, p < 0.001) and were slower judging straight-ahead arrows than averted ones (t_{40} = 2.736, p < 0.025). Results where percentage accuracy was used are not presented because performance was at ceiling (see table 2).
2.3 Discussion of experiment 1

The findings from experiment 1 showed that typically developing individuals were more accurate and faster at judging eye-gaze direction in whole faces than in the eye region alone, and were more accurate but not faster at judging direct compared to averted eye gaze. Participants were slower and less accurate at judging direct than averted arrows, most likely as a consequence of direct arrows being a novel stimulus. An unpredicted finding was an interaction between stimulus type and direction of eye gaze. There was a whole-face to eye-region-alone advantage judging averted but not direct eye gaze. An alternative way of describing the interaction is that participants were not more accurate or faster at judging direct compared to averted eye gaze in the whole-face condition but they were in the eye-region-alone condition. Both these interpretations will be discussed.

The findings went some way towards supporting our first prediction of a whole-face processing advantage but this was found only when the gaze was averted. Because the eye stimuli in the eye-region-alone and whole-face conditions were the same (ie the former was selected and cut out from the latter), the observed processing advantage of averted eye gaze in whole faces must be associated with either the context of the other facial features or the facial contour. An advantage for processing features in the context of the whole, rather than as an isolated feature, has been observed in studies of face recognition but not of object recognition, and is the consequence of using holistic processing strategies (Farah et al 1998). In the case of the current study, the importance of the whole face for judging averted gaze may be that it is greatly influenced by information about head orientation or facial contour, which is reduced in the eye-region-alone condition.

The data from experiment 1 partially supported our second prediction that participants would more accurately detect direct than averted eye gaze. In the whole-face condition there was no reduction in reaction times or increased accuracy in the direct-gaze condition. In the eye-region-alone conditions, however, participants were faster and more accurate in their response to direct than to averted gaze. Quite why sensitivity to direct gaze is preserved in the eye-region-alone condition is currently unclear. One possibility is that isolated direct (but not averted) eyes are a sufficient stimulus to activate the normal whole-face-processing mechanism. Alternatively, direct gaze may be a unique facial feature that is sufficiently salient to be processed out of the context of the other features. The failure to find an advantage for detecting direct eye gaze in whole faces is inconsistent with previous studies that have reported facilitation of face recognition when eyes are directed straight ahead compared to averted (Hood et al 2003; Macrae et al 2002). However, the inconsistencies in the findings may be explained by differences in task demands, and direct eye gaze may facilitate memory of whole faces but not their perception.

Finally, there was a significant main effect of exposure duration: accuracy and response times improved significantly between the 40 and 70 ms conditions but not between the 70 and 100 ms conditions. This finding suggests that there is a change in how eye gaze is

### Table 2. Cueing direction by stimulus type. Mean percentage accuracy and mean reaction time (RT) from experiment 1 (standard deviations are given in parentheses).

<table>
<thead>
<tr>
<th>Stimulus type</th>
<th>Cue direction</th>
<th>accuracy/%</th>
<th>RT/ms</th>
<th>accuracy/%</th>
<th>RT/ms</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>averted</td>
<td></td>
<td></td>
<td>straight ahead</td>
<td></td>
</tr>
<tr>
<td>Whole face</td>
<td>91.9 (9)</td>
<td>705 (299)</td>
<td>94.9 (9)</td>
<td>714 (246)</td>
<td></td>
</tr>
<tr>
<td>Eye region alone</td>
<td>82.1 (19)</td>
<td>763 (328)</td>
<td>93.2 (10)</td>
<td>719 (282)</td>
<td></td>
</tr>
<tr>
<td>Pairs of arrows</td>
<td>97.8 (5)</td>
<td>630 (257)</td>
<td>95.5 (7)</td>
<td>661 (283)</td>
<td></td>
</tr>
</tbody>
</table>
processed between 40 and 70 ms exposure durations (ie an increased use of serial processing) but, thereafter, there is no further advantage as exposure duration increases. This finding suggests that shifts from parallel to serial processing of face stimuli may occur at earlier exposure durations than previously reported (Coin et al 1992; Loffler et al 2005).

The finding of an interaction between stimulus type and direction of eye gaze suggests that we may have identified two separate face-processing mechanisms in typically developing individuals: one associated with an advantage for processing averted gaze in whole faces and a second associated with processing direct eye gaze when the rest of the face is not visible. Our aim in experiment 2 was to use the same experimental design to test whether individuals with ASD are able to use these mechanisms. Our first hypothesis was that the clinical group of individuals with ASD would not show an advantage for judging averted eye gaze in whole faces compared to the eye-region-alone condition. Our second hypothesis was that the clinical group would not show an advantage for processing direct relative to averted gaze in the eye-region-alone condition. Based on the finding of Leekam et al (1997), that individuals with ASD use a feature-based strategy to judge eye-gaze direction, our third hypothesis was that the clinical group would be impaired relative to controls in the 40 ms condition but not in the 100 ms condition. No prediction was made about the 70 ms condition, as some individuals may still use parallel-processing strategies at this duration. Our fourth hypothesis was that there would be no group differences in judgments of arrow direction.

3 Experiment 2
3.1 Method
3.1.1 Participants. A total sample size of fifty-six participants (twenty-eight clinical and twenty-eight control) was calculated with GPOWER software, generating statistical power of 0.84 by an analysis of variance. The clinical group comprised of twenty-eight adolescents and adults (twenty-six males) with previous diagnoses of autism or ASD. Participants were recruited either as a result of their prior involvement in studies at the Institute of Psychiatry or through advertising on the National Autistic Society UK website. Two of the clinical participants were not included in the final analysis because of concerns about the reliability of their diagnosis, while a further two were not included because of inattentiveness during the experiment. All participants from the clinical group had a diagnosis of autism or Asperger’s syndrome, according to ICD-10 criteria, were aged 16 years or above, and had a performance IQ above 75. The diagnoses of twenty out of the twenty-four (twenty-one male) individuals included in the final analysis were confirmed by using the Autism Diagnostic Interview—Revised (ADI—R) with parents (Lord et al 1994). However, interviews could not be conducted with the parents of the remaining four participants because they were either deceased or of ill health. Twenty-eight (twenty-five male) non-clinical control participants were recruited either through their previous involvement in studies at the Institute of Psychiatry or through advertisements in local shops. Two individuals were not included in the final analyses because their performance IQ was below 75. Therefore, data on twenty-six (twenty-three male) participants were included in the final analysis. Written informed consent was received from all participants.

Twenty-four individuals with ASD were matched with twenty-six non-clinical control participants on level of cognitive functioning by means of the Raven’s Progressive Matrices (RPM; Raven et al 1992) and the British Picture Vocabulary Scale (BPVS; Dunn et al 1982) as performance and language measures, respectively. The two groups were also matched for chronological age and handedness (attained from self-report of hand preference). There were no significant differences between the groups on BPVS raw score, RPM IQ, or chronological age (see table 3). Even with the reduced sample size, statistical power was at 0.8 when analysis of variance was used.
3.2 Results

As in experiment 1, there were three independent variables: stimulus type (whole face, eye region alone, pairs of arrows), cue direction (averted and straight ahead), and exposure duration (40, 70, 100 ms). The dependent variables were reaction time and accuracy. Outliers were removed during calculation of means and prior to data analyses. Parametric tests were employed as the group means were normally distributed, except where otherwise stated. In the averted condition neither the control nor the clinical participants were more accurate or faster at judging eye gaze in one direction over another (eg left versus right). No significant differences in performance were found between males and females and so the results from the two sexes were combined. Planned comparisons were made to test the predictions that individuals with ASD would not be faster or more accurate at judging averted eye-gaze direction in the whole-face condition, or when eye gaze was directed straight ahead in the eye-region-alone condition, and that group differences in judgments of eye-gaze direction would be found in the 40 ms condition but not in the 100 ms condition.

A 2 (stimulus type: whole face, eye region alone) × 2 (direction of gaze: averted, straight ahead) × 3 (exposure duration: 40, 70, or 100 ms) ANOVA was performed with reaction time as the independent variable. There were no significant group interactions with exposure duration, stimulus type, or direction of eye gaze. Within-group analyses by means of planned pairwise t-tests showed that control participants were faster at judging averted-eye-gaze direction in whole faces than in the eye region alone ($t_{25} = 4.426, p < 0.001$). They were also faster at judging eyes directed straight ahead than averted eyes in the eye-region-alone condition ($t_{25} = 2.078, p < 0.05$). The clinical participants were not significantly faster at judging averted-eye-gaze direction in whole

<table>
<thead>
<tr>
<th>Group</th>
<th>control ($n = 26$)</th>
<th>clinical ($n = 24$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age/years</td>
<td>31 (9)</td>
<td>32 (9)</td>
</tr>
<tr>
<td>RPM performance IQ</td>
<td>98 (12)</td>
<td>102 (18)</td>
</tr>
<tr>
<td>BPVS raw score</td>
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Table 3. Mean age, Raven’s Progressive Matrices (RPM) performance IQ, and the British Picture Vocabulary Scale (BPVS) raw score, for the control ($n = 26$) and clinical ($n = 24$) groups (standard deviations are given in parentheses).

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</table>

3.2 Results

As in experiment 1, there were three independent variables: stimulus type (whole face, eye region alone, pairs of arrows), cue direction (averted and straight ahead), and exposure duration (40, 70, 100 ms). The dependent variables were reaction time and accuracy. Outliers were removed during calculation of means and prior to data analyses. Parametric tests were employed as the group means were normally distributed, except where otherwise stated. In the averted condition neither the control nor the clinical participants were more accurate or faster at judging eye gaze in one direction over another (eg left versus right). No significant differences in performance were found between males and females and so the results from the two sexes were combined. Planned comparisons were made to test the predictions that individuals with ASD would not be faster or more accurate at judging averted eye-gaze direction in the whole-face condition, or when eye gaze was directed straight ahead in the eye-region-alone condition, and that group differences in judgments of eye-gaze direction would be found in the 40 ms condition but not in the 100 ms condition.

A 2 (stimulus type: whole face, eye region alone) × 2 (direction of gaze: averted, straight ahead) × 3 (exposure duration: 40, 70, or 100 ms) ANOVA was performed with reaction time as the independent variable. There were no significant group interactions with exposure duration, stimulus type, or direction of eye gaze. Within-group analyses by means of planned pairwise t-tests showed that control participants were faster at judging averted-eye-gaze direction in whole faces than in the eye region alone ($t_{25} = 4.426, p < 0.001$). They were also faster at judging eyes directed straight ahead than averted eyes in the eye-region-alone condition ($t_{25} = 2.078, p < 0.05$). The clinical participants were not significantly faster at judging averted-eye-gaze direction in whole

<table>
<thead>
<tr>
<th>Exposure duration/ms</th>
<th>accuracy/%</th>
<th>RT/ms</th>
<th>accuracy/%</th>
<th>RT/ms</th>
<th>accuracy/%</th>
<th>RT/ms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whole face</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>control group</td>
<td>87.5 (16)</td>
<td>724 (167)</td>
<td>93.6 (14)</td>
<td>722 (158)</td>
<td>94.6 (13)</td>
<td>698 (160)</td>
</tr>
<tr>
<td>clinical group</td>
<td>70.8 (28)</td>
<td>1113 (575)</td>
<td>79.9 (26)</td>
<td>1022 (552)</td>
<td>79.5 (27)</td>
<td>1062 (584)</td>
</tr>
<tr>
<td>Eye region alone</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>control group</td>
<td>78.8 (19)</td>
<td>804 (185)</td>
<td>85.9 (18)</td>
<td>786 (266)</td>
<td>88.5 (18)</td>
<td>721 (184)</td>
</tr>
<tr>
<td>clinical group</td>
<td>66.3 (27)</td>
<td>1113 (536)</td>
<td>78.5 (23)</td>
<td>1055 (535)</td>
<td>79.5 (22)</td>
<td>1050 (547)</td>
</tr>
<tr>
<td>Arrows</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>control group</td>
<td>92.3 (10)</td>
<td>691 (176)</td>
<td>99.0 (3)</td>
<td>656 (150)</td>
<td>99.4 (2)</td>
<td>656 (149)</td>
</tr>
<tr>
<td>clinical group</td>
<td>85.8 (20)</td>
<td>954 (473)</td>
<td>96.5 (7)</td>
<td>911 (460)</td>
<td>97.6 (8)</td>
<td>889 (443)</td>
</tr>
</tbody>
</table>

Table 4. Exposure duration by stimulus type. Mean percentage accuracy and mean reaction time (RT) for the clinical and control groups in experiment 2 (standard deviations are given in parentheses).
faces or direct gaze in the eye-region-alone condition. Between-group analyses by independent samples t-tests showed that the control group was faster than the clinical group at judging eye-gaze direction (summed across the whole face and eye-region-alone stimulus types) in the 40 ($t_{25} = 2.402, p < 0.05$), 70 ($t_{25} = 2.353, p < 0.05$), and 100 ms ($t_{25} = 2.416, p < 0.05$) conditions.

A second 2 (stimulus type: whole face, eye region alone) × 2 (direction of gaze: averted, straight ahead) × 3 (exposure duration: 40, 70, or 100 ms) repeated-measures ANOVA was performed with percentage accuracy as the independent variable. There was no significant group interaction with exposure duration. There was a significant group interaction with stimulus type ($F_{1,45} = 7.958, p < 0.01$). There was no significant group interaction with direction of gaze.

**Table 5.** Cue direction by stimulus type. Mean percentage accuracy and mean reaction time (RT) for the clinical and control groups in experiment 2 (standard deviations are given in parentheses).

<table>
<thead>
<tr>
<th>Cue direction</th>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>averted</td>
<td>straight ahead</td>
<td>averted</td>
<td>straight ahead</td>
<td></td>
</tr>
<tr>
<td><strong>Whole face</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>control group</td>
<td>92.1 (10)</td>
<td>741 (179)</td>
<td>95.3 (8)</td>
<td>763 (202)</td>
<td></td>
</tr>
<tr>
<td>clinical group</td>
<td>77.6 (26)</td>
<td>1081 (672)</td>
<td>75.0 (28)</td>
<td>1088 (609)</td>
<td></td>
</tr>
<tr>
<td><strong>Eye region alone</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>control group</td>
<td>79.1 (23)</td>
<td>829 (254)</td>
<td>93.3 (11)</td>
<td>765 (185)</td>
<td></td>
</tr>
<tr>
<td>clinical group</td>
<td>72.9 (27)</td>
<td>1102 (651)</td>
<td>78.8 (27)</td>
<td>1081 (569)</td>
<td></td>
</tr>
<tr>
<td><strong>Arrows</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>control group</td>
<td>97.5 (5)</td>
<td>670 (171)</td>
<td>92.0 (7)</td>
<td>705 (169)</td>
<td></td>
</tr>
<tr>
<td>clinical group</td>
<td>94.4 (11)</td>
<td>885 (445)</td>
<td>84.0 (27)</td>
<td>982 (540)</td>
<td></td>
</tr>
</tbody>
</table>

Within-group analyses via planned pairwise t-tests showed that control participants were more accurate at judging averted eye gaze in whole faces compared to the eye region alone ($t_{25} = 3.553, p < 0.01$) and they were more accurate judging eyes directed straight ahead compared to averted in the eye-region-alone condition ($t_{25} = 3.087, p < 0.01$). The clinical group was not significantly more accurate at judging averted-eye-gaze direction in whole faces or direct eye gaze in the eye-region-alone condition. Between-group analyses by independent samples t-tests showed that the control group was more accurate than the clinical group at judging eye-gaze direction (summed across the whole-face and eye-region-alone stimulus types) in the 40 ($t_{25} = 2.501, p < 0.05$), 70 ($t_{25} = 2.344, p < 0.05$), and 100 ms ($t_{25} = 2.817, p < 0.05$) conditions.

Between-group analyses were conducted with one-way ANCOVAs to explore the group interaction with stimulus type. Performance on the arrow condition was included as a covariate to control for potential group differences in judging directional cues at short exposure durations. The control group was significantly more accurate than the clinical group at judging direction of eye gaze in the whole-face condition ($F_{1,49} = 7.437, p < 0.01$) but not in the eye-region-alone condition.

Participants from both the control ($t_{25} = 5.771, p < 0.001$) and the clinical ($t_{23} = 3.347, p < 0.001$) groups were faster at making judgments of arrow direction compared to eye-gaze direction. Participants from both the control ($t_{25} = 2.080, p < 0.05$) and the clinical ($t_{23} = 3.277, p < 0.01$) groups were slower at judging straight-ahead arrows compared to averted. Between-group differences in performance on arrow conditions could not be explored with reaction times as the clinical group is generally slower.
on computerised experiments. Accuracy scores were not normally distributed so group comparisons were made by means of non-parametric independent samples analyses but no group differences were identified judging arrows averted or straight ahead.

The relationship between task performance and level of cognitive functioning was investigated. Linear regression analysis revealed no significant relationship between performance on the BPVS or RPM and any of the stimulus types in either group.

3.3 Discussion of experiment 2

The pattern and level of performance of the control group in experiment 2 was almost identical to that observed in the participant group in experiment 1. The control group was more accurate and faster at judging averted-eye-gaze direction in the whole-face condition than when the eye region alone was presented. The control group was also more accurate at judging direct gaze than averted gaze in the eye-region-alone condition. This pattern of performance was not seen in the individuals with ASD.

Although individuals in the clinical group were able to judge eye-gaze direction accurately when stimuli were presented for as little as 40 ms, the pattern and level of their performance was quite different from that seen in typically developing individuals. Individuals with ASD failed to show a whole-face to eye-region-alone advantage when judging averted-eye-gaze direction, suggesting that they are not activating a processing mechanism which is sensitive to the configuration of the surrounding facial features or the face contour. Individuals with ASD also did not show increased sensitivity to detect straight-ahead compared to averted gaze in the eye-region-alone condition, suggesting that there may also be an impairment in a mechanism sensitive to direct gaze. Between-group analyses of percentage accuracy revealed that individuals in the clinical group were significantly poorer than those in the control group at judging eye-gaze direction in the whole-face condition but not in the eye-region-alone condition, a finding which is in line with a previous report of children with ASD failing to show a holistic processing effect when recognising eyes embedded in a whole upright face rather than in an inverted face (Joseph and Tanaka 2003). As group differences in performance remained when arrow performance was used as a covariate, only part of the impairment could be attributed to a general difficulty in processing briefly presented visual stimuli.

Compared to controls, individuals with ASD were impaired at judging eye-gaze direction in the 40, 70, and 100 ms conditions, which suggests that impairments are present even when it is possible to use a serial-processing strategy or geometric analyses of eye gaze. It remains unclear what strategy is used by individuals with ASD to detect eye-gaze direction but it is unlikely to be dependent on a fine-detailed analysis of the low-level visual properties, as suggested by Leekam et al (1997).

4 General discussion

In experiments 1 and 2 we found that typically developing individuals were faster and more accurate at judging averted eye gaze in whole faces than when only the eyes were visible. Despite the failure to find a whole-face to eye-region-alone advantage in the direct-eye-gaze conditions, the findings from experiments 1 and 2 do demonstrate that under certain conditions judgments of eye-gaze direction are facilitated by the presence of the surrounding facial features. It has been proposed that this pattern of results is evidence of the use of specialised cortical regions (fusiform gyrus) to facilitate judgments of eye-gaze direction in whole faces (Johnson 1994; Vecera and Johnson 1995). One explanation for the finding that individuals with ASD failed to show a holistic face-processing advantage in experiment 2 is that they do not activate fusiform gyrus. Indeed, several functional imaging studies have suggested that individuals with ASD fail to activate fusiform gyrus when processing faces (Schultz 2005; Pierce et al 2001; Bailey et al 2005). It has recently been suggested, however, that there are multiple regions
of the brain underlying typical face processing (Haxby et al 2000), which include fusiform gyrus as well as superior temporal sulcus and the amygdala, and impaired activation of this distributed network by individuals with ASD may provide an alternative explanation for their failure to show a whole-face-processing advantage when judging averted eye gaze.

The second finding in typically developing individuals is that they are faster and more accurate at judging direct compared to averted eye gaze. This finding is consistent with previous reports of faster detection of direct compared to averted eye gaze (von Grünau and Anston 1995), suggesting that direct and averted eye gaze may be processed by different mechanisms. Individuals with ASD failed to show increased sensitivity to direct relative to averted eye gaze in the eye-region-alone condition, suggesting that they are not activating a mechanism sensitive to direct gaze. Clinical observations and experimental studies have reported that individuals with ASD avoid direct eye contact (Hobson and Lee 1998; Klin et al 2002), and the finding of reduced sensitivity to direct gaze in experiment 2 may be related to this avoidance strategy. Gaze avoidance could be explained by a model by Baron-Cohen et al (2000) which suggests that atypical activation of the amygdala can explain the social impairment in ASD (including difficulties interpreting and responding to the eyes). An alternative explanation for eye-gaze avoidance is that it is the consequence of poorly developed connectivity between regions of the brain that underlie the social processing of faces and direct eye gaze. George et al (2001) reported greater correlative activity between fusiform gyrus and the amygdala when typically developing individuals look at faces with direct compared to averted eye gaze. A failure to develop this connectivity between fusiform gyrus and the amygdala in individuals with ASD may indeed explain both the impairments in general face processing (identification and discrimination) and in social aspects of face processing (engaging in eye contact, identifying facial expressions).

The findings from experiment 2 provide evidence that individuals with ASD are not activating mechanisms sensitive either to the whole face or to direct gaze, or that there is impaired functional connectivity between the face-processing and gaze-processing mechanisms. This study highlights the importance of investigating whether deficits in face processing and judgments of gaze direction are the consequence of impairments to separate mechanisms or the connections between them. Our findings suggest that future psychological and neurobiological studies of face processing should aim to investigate how sensitivity to direct eye gaze is associated with activation of fusiform gyrus. The ability of adults with ASD to make judgments to briefly presented stimuli validates the use of psychophysical presentation techniques to restrict the strategies participants can use to make judgments.

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