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# Sex differences in eye gaze and symbolic cueing of attention

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Observing a face with averted eyes results in a reflexive shift of attention to the gazed-at location. Here we present results that show that this effect is weaker in males than in females (Experiment 1). This result is predicted by the 'extreme male brain' theory of autism (Baron-Cohen, 2003), which suggests that males in the normal population should display more autism-like traits than females (e.g., poor joint attention). Indeed, participants' scores on the Autism-Spectrum Quotient (Baron-Cohen, Wheelwright, Stott, Bolton, & Goodyear, 2001) negatively correlated with cueing magnitude. Furthermore, exogenous orienting did not differ between the sexes in two peripheral cueing experiments (Experiments 2a and 2b). However, a final experiment showed that using non-predictive arrows instead of eyes as a central cue also revealed a large gender difference. This demonstrates that reduced orienting from central cues in males generalizes beyond gaze cues. These results show that while peripheral cueing is equivalent in the male and female brains, the attention systems of the two sexes treat noninformative symbolic cues very differently.

Following the direction of another person's gaze, "joint attention", has been found to emerge as early as 3 months in human infants (Hood, Willen, & Driver, 1998; Scaife & Bruner, 1975) and is seen as a very important step towards establishing strong patterns of social interaction (Argyle & Cook, 1976; Moore & Dunham, 1995). Observing averted gaze has also been found to direct spatial attention reflexively in adults (Driver et al., 1999; Friesen & Kingstone, 1998; Hietanen, 1999; Langton & Bruce, 1999). The orienting of attention based on observed gaze direction is thought to reflect the activation of neural systems dedicated to the decoding of social stimuli (Emery, 2000; Kingstone, Friesen, & Gazzaniga, 2000). For example, Perrett et al. (1985) demonstrated that cells in STSa of the monkey code for observed gaze direction. Homologous regions in humans have been shown to be active in experiments that involve the observation of eye gaze (Allison, Puce, & McCarthy, 2000; Hoffman & Haxby, 2000; Hooker et al., 2003; Pelphrey, Singerman, Allison, & McCarthy, 2003; Wicker, Michel, Henaff, & Decety, 1998). The close relationship between activity in STS and areas involved in the attention system (e.g., inferior parietal sulcus), suggests that STS and IPS form a

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network responsible for encoding and acting upon direction of social attention (Pelphrey et al., 2003).

If orienting toward the direction of another's gaze reflects "social" processing, rather than some lower level system that orients attention based on simple geometric properties (Hommel, Pratt, Colzato, & Godijn, 2001; Tipples, 2002), then the amount of cueing should depend upon the strength of signal from this "social module". The "extreme male brain" hypothesis of autism (Baron-Cohen, 2000, 2002, 2003) suggests that the male information-processing system is less well adapted to understanding the mental states of others than is the female brain. In its extreme state, the male brain is expressed in people with autism, the majority of whom are male (Rutter, 1978), as "mindblindness" (Baron-Cohen, 1995). Reduced sensitivity to eye gaze information and poor joint attention abilities in people with autism may be examples of inactivity of a module for social stimuli (Baron-Cohen, Campbell, Karmiloff-Smith, Grant, & Walker, 1995; Baron-Cohen, Wheelwright, & Jolliffe, 1997a; Charman et al., 1997; Roeyers, Van Oost, & Bothuyne, 1998). Compared to normal children, children with autism make fewer attention shifts, and of shorter duration, to people. Instead, children with autism show a preference for orienting to nonsocial objects in the world (Swettenham et al., 1998). McGuinness and Symonds (1977) presented mechanical objects and human figures stereoscopically, so that two images occupied the same area of the visual field. Normal adult males reported seeing more objects than people, with the opposite bias in females. In fact, an interest in mechanical objects reflects another feature of the hypothetical extreme male brain, since it indicates proficiency in understanding systems ("systemizing"). Indeed, fathers and grandfathers of children with autism are twice as likely to have been engineers as are fathers of children without autism (Baron-Cohen, Wheelwright, Stott, Bolton, & Goodyear, 1997b). Children with autism are also better than normally developing children at understanding mechanical event sequences, while normally developing children are better at understanding behavioural and intentional events (Baron-Cohen, Leslie, & Frith, 1986). This may reflect a strong ability in processing local details compared to global processing in people with autism (Happé, 1999; Mottron, Burack, Iarocci, Belleville, & Enns, 2003).

Many studies have shown gender differences on a wide range of cognitive skills (see Geary, 1998, for review). Males outperform females in spatial tasks, such as the water level test where a tilted glass of water is presented, and the subject is required to judge where the water level would be if the glass were placed upright (Robert & Ohlmann, 1994), reflecting better processing of physical systems in males. Other examples are mental rotation (Geary, Gilger, & Elliott-Miller, 1992) and line-angle judgement (Collaer & Nelson, 2002). Females have been found to perform better in episodic memory tasks involving face recognition (Yonker, Eriksson, Nilsson, & Herlitz, 2003) and object recognition (McGivern et al., 1998). With reference to face processing, the ERP component N170, which has been associated with processing of faces, has been found to occur later in males (Taylor, Itier, Allison, & Edmonds, 2001). Furthermore, males are more vulnerable to prosopagnosia, a disorder where familiar faces cannot be recognized following brain damage (Mazzucchi & Biber, 1983). However, while some behavioural studies show an overall advantage for females in face recognition, the effect seems to be moderated by same-gender biases (Wright & Sladden, 2003), especially in females (Lewin & Herlitz, 2002). Furthermore, in a metanalysis, Hall

(1978) found that males were less sensitive to visual and auditory nonverbal cues to emotion than were females. Interestingly, this interaction was the same whether a male or a female was the source of the nonverbal cue.

Many of the sex differences described above have also been found to be present in childhood and infancy. This relates very well to the idea that the developmental disorder of autism is an extreme expression of an overall cognitive style that is found more in males than females. With regard to attending to social stimuli, female neonates were found to spend more time looking at a human face than at a mobile, while male neonates showed the opposite preference (Connellan, Baron-Cohen, Wheelwright, Batki, & Ahluwalia, 2000). More eye contact is made by female infants than by male infants at 12 months old (Lutchmaya, Baron-Cohen, & Raggatt, 2002a). The amount of eye contact in these infants was found to be inversely correlated with prenatal levels of the male hormone testosterone. If these sex differences are present from birth, and have a strong biological component, then the effects of such differences in cognitive style may continue into adulthood. Just as males continue to outperform females in spatial cognition, females should continue to show greater joint attention abilities and tendencies, which rely on social cognition. Hence, the following series of experiments investigates the performance of males and females in different modes of attentional orienting.

## EXPERIMENT 1

This experiment was designed to evaluate whether male participants will show weaker attention shifts to the direction of another's eye gaze. These particular paradigms were specifically adopted to avoid low-level motion cues, which are normally available as the pupils move during gaze shifts. Thus any orienting of attention is produced by central/symbolic gaze direction, rather than motion signals detected in early visual analysis. To ensure that our results were generalizable, two procedures were used.

In the first procedure, "head moves", the participants observed a male or female face with direct gaze. The eyes then were presented looking to the left or the right. In order to avoid the possibility that the physical motion of the pupils would result in orienting towards the direction of motion, the gaze cue was presented in a face that had been translated one pupil's width to the left or right. Therefore, the pupils remained static throughout a trial, and the physical motion in the display was produced by the whole head moving one pupil's width right or left. This head motion was of course in the opposite direction to the direction of eye gaze (see Figure 1a, upper panel). This method of producing a gaze cue has been used before with infants (Farroni, Johnson, Brockbank, & Simion, 2000) and with neglect patients (Vuilleumier, 2002). The target letter would appear randomly to the left or right of the screen. Participants were required to make a speeded discrimination response to the target.

The second paradigm, "pupils appear", which a separate set of participants viewed, had the eyes covered at the start of the trial. The pupils would then appear in the averted gaze position, as in Driver et al. (1999). Via this method there were no low-level motion signals, as the face and eyes remained static throughout the trial (see Figure 1b, lower panel).

The use of male and female faces allowed us to also control for any modulation of the hypothesized sex difference by whether the participant was viewing a face of the same or different gender, since it is possible that there may be an own-gender bias, as with face

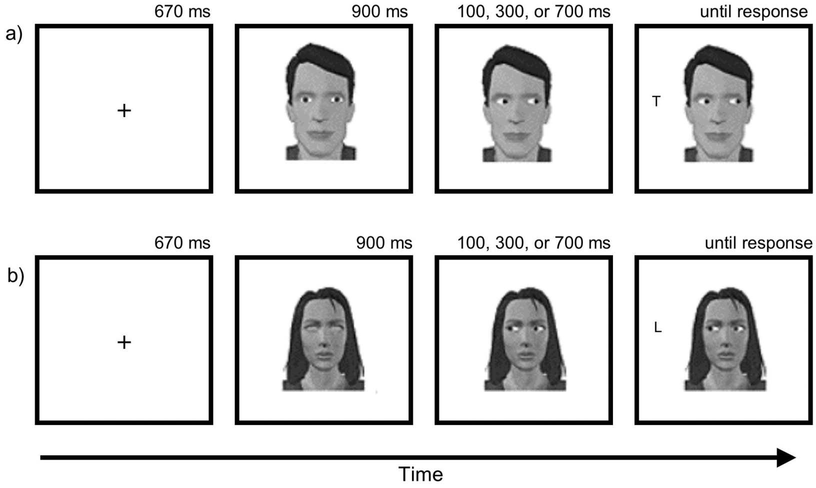

**Figure 1.** Examples of time course of stimulus presentation in Experiment 1. Panel (a) illustrates an invalid trial, with a male face in the head moves condition. The face moves a pupil's width to the left in this case, resulting in a rightward cue. Panel (b) illustrates a valid trial in the pupils appear condition, with the female face.

recognition (Wright & Sladden, 2003). The central hypothesis is that responses will be quicker to targets appearing at gazed-at locations, despite the noninformative nature of the cue, and that this attentional effect will be smaller in males than in females.

## Method

### Participants

A total of 80 university students participated in the study; 40 were males (mean age = 21.9 years, *SD* = 4.7 years), and 40 were females (mean age = 20.0, *SD* = 2.2 years). All were naive to the purpose of the study, gave written consent, and were paid £5 or given course credit for participation.

### Apparatus and materials

The male face measured 11 × 18 cm, each eye was 2 × 0.8 cm, and the pupils were 0.9 × 0.8 cm. The female face measured 10.9 × 16.5 cm, and eyes measured 1.8 × 0.7 cm, with the pupils at 0.8 × 0.7 cm. The letters, uppercase "T" and "L", both measured 1.0 × 1.6 cm and presented 12.5 cm from the centre of the screen. In the pupils appear condition the face stimuli remained static throughout a trial. In contrast, in the head moves condition the pupils remained static but the head moved to the right or left 0.9 cm in the male face and 0.8 cm in the female face displays. Participants were positioned 60 cm from the centre of the screen.

### Design

A total of 40 participants viewed the eyes appearing from behind grey occluders (pupils appear), with 40 observing the head moves condition. Half of each group viewed a male face, and half a female face. There were equal numbers of males and females in each group. The first within-subject factor was validity, whereby valid trials were when the direction of the pupils pointed to the location of the target. Invalid trials were those where the target was presented in the opposite hemifield to the direction of gaze. The second within-subject factor was the stimulus onset asynchrony (SOA), whereby the presentation of the target followed the gaze cue after a variable amount of time: 100, 300, or 700 ms.

### Procedure

Participants were instructed to fixate the fixation cross, which appeared for 670 ms in the centre of the screen. The face then appeared in the centre of the screen for 900 ms. The face either was looking at the participant (head moves) or had grey patches over the eyes (pupils appear); see Figure 1. Participants were urged to maintain fixation at the centre of the screen and to ignore the gaze direction as this did not predict subsequent target location. The gaze cue then appeared (pupils positioned in either the right or the left corners of the eyes), followed by a target letter to the left or right, after a variable SOA. The participant was required to respond with a key-press as quickly and as accurately as possible to the presentation of the target. Up or down identification key-press responses were required (keys "h" and "spacebar", corresponding to T and L, respectively) to ensure that these responses were orthogonal to the left–right target loci. Each trial type could occur randomly with equal probability. Each participant completed 288 experimental trials over three blocks.

## Results and discussion

Errors (3.48%) and responses slower than 1,000 ms, faster than 250 ms, or 2 standard deviations above or below the mean (7.13%), were removed from reaction time (RT) analysis. A mixed-factor analysis of variance (ANOVA), with sex of participant, gender of viewed face, and cue type (i.e., the head moves or pupils appear condition) as between-subjects factors and validity and SOA as within-subjects factors, was performed.

This showed that the main effect of validity reached significance, $F(1,\ 72) = 42.7$, $MSE = 268.9$, $p < .001$, with faster responses in valid trials (519 ms vs. 529 ms), as did the effect of SOA, $F(2,\ 144) = 128$, $MSE = 396.2$, $p < .001$, with RT decreasing at longer SOAs. The validity by SOA interaction also reached significance, $F(2,\ 144) = 3.76$, $MSE = 196.2$, $p = .026$, with the beneficial effect of valid trials changing over time (6 ms cueing at 100-ms, 15 ms at 300-ms, and then 8 ms at 700-ms SOA). Participants viewing a female face responded quicker, $F(1,\ 81) = 4.30$, $MSE = 19{,}984$, $p = .042$ (510 ms vs. 538 ms). The cue type by sex of participant by gender of face interaction was significant, $F(1,\ 72) = 4.32$, $MSE = 19{,}984$, $p = .041$, where it appears that female participants respond faster when viewing female faces, but only in the pupils appear condition (see Table 1). Since these effects did not interact with validity, they are not considered further.

The critical validity by sex of participant interaction was significant, $F(1,\ 72) = 8.00$, $MSE = 268.9$, $p = .006$, illustrating larger cueing in females than males (14 ms vs. 6 ms). Independent-samples $t$ tests showed that at 100-ms and 300-ms SOAs, this difference was not significant: $t(78) < 1$; $t(78) = 1.56$, $p = .124$, respectively. Females showed significantly larger cueing than males at 700-ms SOA, however, $t(78) = 3.55$, $p < .001$ (see Figure 2).

Overall, the findings of Driver et al. (1999) were replicated, since cueing toward the direction of gaze was found to emerge strongly at the two later SOAs. In addition, the present study has demonstrated reliable gender differences in a target discrimination task

TABLE 1
Reaction times, in ms, for each group of participants in Experiment 1

| *Sex of participant* | *Gender of face* | *Head moves gaze cue* | *Pupils appear gaze cue* |
|---|---|---|---|
| Male | Male | 521 | 523 |
| | Female | 515 | 522 |
| Female | Male | 525 | 581 |
| | Female | 526 | 480 |

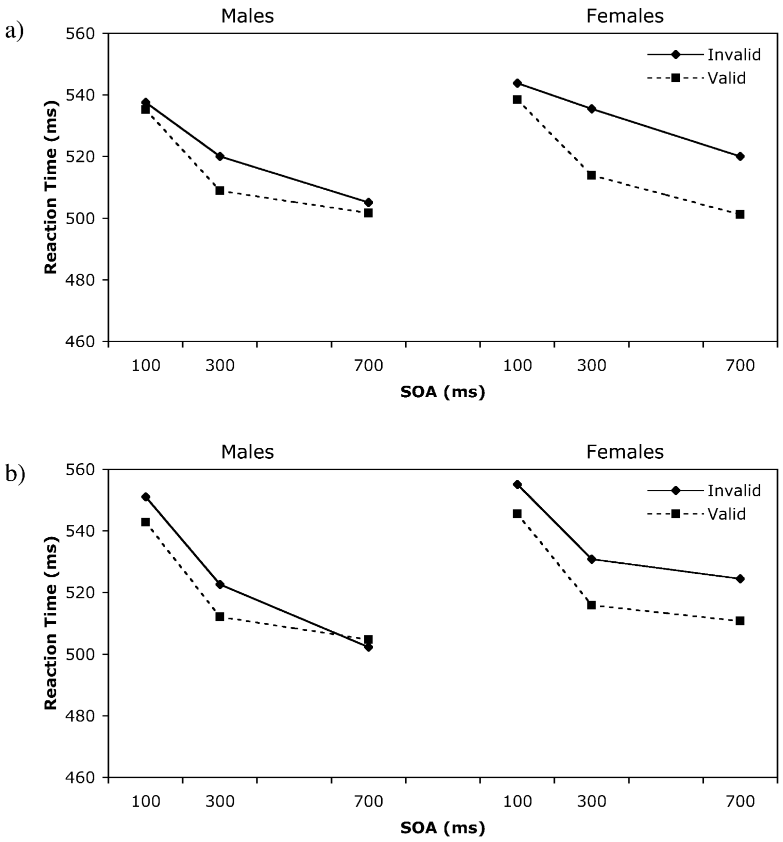

**Figure 2.** Graph illustrating reaction times to valid and invalid trials for males and females at each SOA and for each gaze cue type. Panel (a) shows RTs for the head moves condition. Panel (b) illustrates RTs from the pupils appear condition.

involving the presentation of a nonpredictive gaze cue. That is, the RT advantage for targets presented in gaze-congruent loci was greater in females than in males. This means that spatial attention of male participants was much less influenced by observing a central face looking to the left or right than was the spatial attention of female participants. This result is in direct accordance with research, mainly on infants, which suggests that males pay less attention to social stimuli, such as faces and eyes (Connellan et al., 2000; Lutchmaya & Baron-Cohen, 2002; Lutchmaya et al., 2002a). This suggests that the bias toward the processing of social stimuli in females continues into adulthood. However, at this point it is difficult to conclude that this difference is due to attenuated social processing in general in males. Thus, the following experiment was conducted in order to investigate the possibility that gender differences are present in the distribution of *exogenously* cued attention, in a context devoid of socially relevant stimuli.

## EXPERIMENT 2

This experiment used the same target identification task and presentation time courses as those for the gaze cue in Experiment 1. However, no face was present to produce a cue. Rather, the cue was the transient enlargement (perceived as a flash) of one of two peripheral squares presented at the possible target locations. This method of attentional cueing produces robust facilitatory effects at early (e.g., < 300-ms) SOAs. In a detection task, this effect rapidly disappears due to inhibition of return (IOR), evidenced by an increase of RT to validly cued targets presented more than 300 ms after cue onset (Posner & Cohen, 1984). IOR is thought to reflect a mechanism that facilitates visual search, by preventing attention from remaining at a previously attended location (see Klein, 2000, for review).

IOR has not been found in standard eye gaze cueing experiments (e.g., Driver et al., 1999). The reason for this may be that while gaze cues and peripheral cues share many properties, IOR is thought only to follow exogenous cueing, while gaze cues are in many ways endogenous cues. Friesen and Kingstone (2003) demonstrated that exogenous peripheral cues and central gaze cues produce independent effects on behaviour, suggesting they do not share common mechanisms. Gaze cueing is thought to be underpinned by primarily cortical networks (Kingstone et al., 2000; Wicker et al., 1998), while exogenous orienting following peripheral cues is thought to be controlled by phylogenetically older structures such as the superior colliculus (Rafal, Posner, Friedman, Inhoff, & Bernsrein, 1988). It is therefore predicted that the sex differences found in Experiment 1 will not generalize to reveal sex differences in exogenous cueing effects. Hence, cueing magnitude and time course will not differ between males and females when attention is cued by the onset of a peripheral stimulus.

In using a discrimination task for this experiment, it is noted that studies of peripheral cueing have not always found IOR with a discrimination task (e.g., Terry, Valdes, & Neill, 1994), while other authors have demonstrated that IOR takes longer to emerge in such tasks (Cheal, Chastain, & Lyon, 1998; Lupianez, Milan, Tornay, Madrid, & Tudela, 1997). However, since this study aims to assess the relative magnitude and time course of attentional cueing in males and females, the direction of any cueing effect is not of central interest. Nevertheless, an additional study (Experiment 2b) is also reported here, which involves a target detection task—a procedure that more reliably reveals IOR. This allows the assessment of both facilitatory and inhibitory components of exogenous visuospatial orienting in males and females.

# EXPERIMENT 2A

## Method

### Participants

A total of 40 university students (20 males, mean age = 25.0 years, *SD* = 4.8 years; 20 females, mean age = 22.6 years, *SD* = 4.9 years) volunteered for this study. All had normal or corrected-to-normal vision and were naïve to the purpose of the experiment. Participants gave informed written consent and received either payment or course credits for their participation.

### Apparatus and materials

A fixation cross was presented at the centre of the screen (0.9 × 0.9 cm), with two placeholder boxes, indicated by black lines (0.3 cm thick), of dimensions 5.8 × 5.8 cm at either side. The centres of these boxes served as target locations and were 12.5 cm from the centre of the screen. The target letters, T and L, measured 1.0 × 1.6 cm. The peripheral cue was achieved by doubling the thickness of the lines, internally, to 0.6 cm thick. Participants were positioned 60 cm from the screen with a chinrest.

### Design

As with Experiment 1, there were two within-subjects factors. First, validity of the peripheral cue was manipulated, with targets appearing in cued locations on valid trials and appearing in the opposite side of the screen to the cue on invalid trials, with equal probability. The SOA was also manipulated within subjects, with the target appearing 100, 300, or 700 ms after the onset of the peripheral cue. Sex of participant was a between-subjects factor.

### Procedure

Participants were instructed to fixate the fixation cross, which appeared for 670 ms in the centre of the screen. The peripheral squares then appeared for 900 ms. The peripheral cue was then presented for 100 ms on the left or right of the screen, followed by a target letter to the left or right, after a variable SOA (100, 300, or 700 ms). The remainder of the procedure is identical to that of Experiment 1 (see Figure 3).

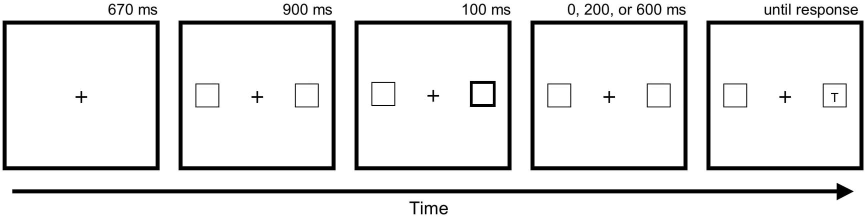

**Figure 3.** Illustration of time course in a valid cue trial of Experiment 2a. Cues and targets could appear in either the left or the right placeholder locations.

## Results and discussion

Errors (2.64%) and trials with RTs less than 250 ms or more than 1,000 ms were removed, followed by trials with RTs more than 2 standard deviations above or below each participant's mean (6.68%). Remaining data contributed to cell means, which were submitted to a mixed-factor ANOVA, with validity as the first within-subjects factor and SOA as the second within-subjects factor. Sex of participant was the between-subjects factor.

The main effect of validity was significant, $F(1, 38) = 49.6$, $MSE = 345.2$, $p < .001$, with faster responses to validly cued targets (506 ms vs. 523 ms). The main effect of SOA was significant, $F(2, 76) = 16.3$, $MSE = 311.5$, $p < .001$, with slower responses to targets at the early SOA (524 ms) than to those at the later SOAs (both at 510 ms). The interaction between validity and SOA also reached significance, $F(2, 76) = 4.62$, $MSE = 151.4$, $p = .014$. Contrasts performed on the validity effect scores (invalid–valid) revealed that this interaction was due to significantly more cueing at the 300-ms SOA (22-ms cueing) than at the 700-ms SOA (11-ms cueing), $t(39) = 2.72$, $p = .010$.

There were no main effects or interactions involving the between-subjects factor sex of participant. Specifically, validity by sex of participant was not significant, $F(1, 38) < 1$, $MSE = 345.2$; cueing effects were the same in each gender (males, 525 ms vs. 509 ms, 16-ms cueing; females, 521 ms vs. 503 ms, 18-ms cueing). The validity by SOA by sex of participant interaction was also not significant, $F(2, 76) = 1.06$, $MSE = 151.4$, $p = .352$ (see Figure 4). Nevertheless, independent-samples $t$ tests were performed on the data to establish whether the cueing effect size was different in males versus females at each SOA. Cueing was not significantly different between the genders, at any SOA. At 100-ms SOA, $t(38) < 1$; at 300-ms SOA, $t(38) = 1.32$, $p = .196$; at 700-ms SOA, $t(38) < 1$.

This experiment investigated peripheral cueing in males and females, in order to evaluate whether, like gaze cues, nonpredictive peripheral cues have little effect on the male attention system. Cueing magnitude and time course was found to be equivalent in males and females, in contrast to the effect of nonpredictive central gaze cues. Thus, consistent facilitatory effects were present in both sex groups. This is taken as evidence that males' and females'

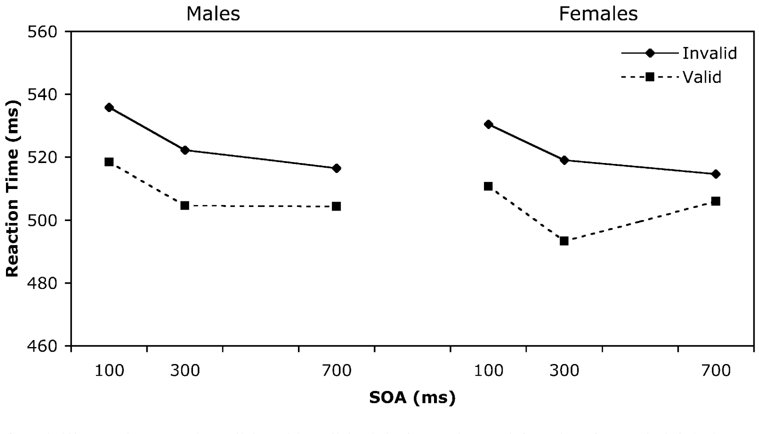

**Figure 4.** Graph illustrating RTs in valid and invalid trials for males and females, for each SOA, in Experiment 2a.

attention systems treat exogenous sudden onset peripheral cues in similar ways. This therefore suggests that gaze cueing is unique in its differential effect on the two sexes.

However, it should be noted that IOR was not observed in this experiment. The facilitatory cueing does appear to be declining from 300-ms SOA to 700-ms SOA, and hence IOR may have emerged at longer intervals in this study. However, to confirm that there are no sex differences in IOR effects evoked by exogenous cues, the next study examined exogenous cueing effects when detection of targets was required. This detection task is known to produce robust IOR effects in the range of SOAs investigated here.

## EXPERIMENT 2B

This experiment was similar to Experiment 2a, except that instead of letters requiring identification, a black square served as the target, which the participants were required to detect with a single key-press. This target detection procedure allows the evaluation of exogenously cued attention in the two sexes with a design that will be more likely to reveal the behavioural effects of IOR. Hence, in accordance with Experiment 2, no difference with cueing magnitude or time course is expected between males and females—both are expected to display significant facilitation at the early SOA and significant inhibition at the later SOA.

## Method

### Participants

A total of 40 university students participated in the experiment: 20 males (mean age = 27.0 years, *SD* = 4.5 years) and 20 females (mean age = 22.6 years, *SD* = 4.2 years), with normal or corrected-to-normal vision, for which they received £5. All were naive to the purpose of the study.

### Apparatus

Apparatus was the same as that in Experiment 2a, except the target was a black square, measuring 0.9 × 0.9 cm.

### Design

A mixed-factor design was employed, with validity and SOA (in this procedure, SOAs were either 200 or 800 ms) as within-subjects factors. Sex of participant was a between-subjects factor.

### Procedure

The procedure was the same as that in Experiment 2a, except that a simple spacebar response was required to the presentation of the target, with no response required on catch trials ($n = 20$). The 80 probe trials were split equally between trials with left or right cues, left or right targets, and short (200-ms) or long (800-ms) SOAs (see Figure 5).

## Results and discussion

Incorrect (0.4%), fast (less than 150 ms), and slow (more than 1,000 ms) responses were excluded from analyses, as well as RTs that were 2 standard deviations above and below each

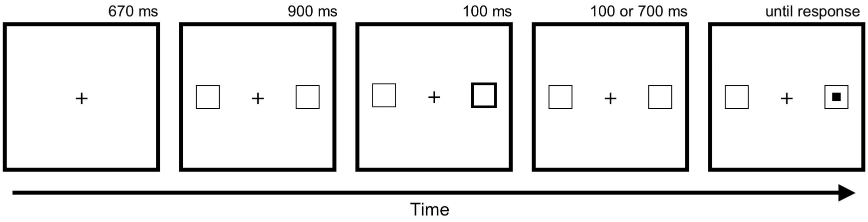

Figure 5. Illustration of the time course of a valid cue trial in Experiment 2b.

participant's mean (4.6%). Participants' means for each condition were submitted to a mixed-factor ANOVA, with validity and SOA as within-subject factors and sex of participant as a between-subject factor.

A significant effect of SOA was found, $F(1, 36) = 28.1$, $MSE = 841.7$, $p < .001$, with faster responses to targets presented at 800-ms SOA than to those at 200-ms SOA (376 ms vs. 351 ms). A significant interaction of SOA by validity, $F(1, 36) = 35.1$, $MSE = 207.1$, $p < .001$, was investigated by planned contrasts, which showed faster responses to valid target locations at 200-ms SOA, $t(39) = 2.85$, $p = .007$, and slower responses to valid target locations at 800-ms SOA, $t(39) = -4.48$, $p < .001$ (see Figure 6). Hence, significant facilitation was found at 200-ms SOA, followed by significant inhibition at 800-ms SOA. No interaction with sex of participant approached significance; most importantly, SOA by validity by sex of participant, $F(1, 36) < 1$, illustrated that sex of participant did not interact with the magnitude of the cueing or time course effects (see Figure 6). Facilitation was the same at 200 ms in either gender, as was inhibition at 800 ms (independent *t* tests, *t*s $< 1$).

Therefore, this experiment demonstrates again that peripheral/exogenous cues have the same effect on attention in males and females. The additional finding to that of Experiment 2a is that the IOR component of exogenous orienting was found to be equivalent in males and females.

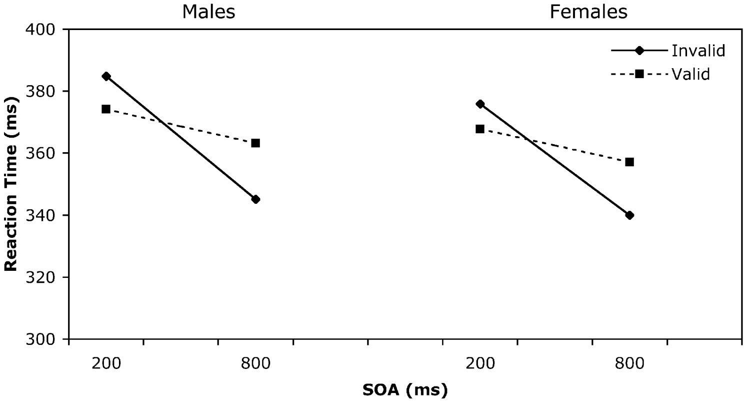

Figure 6. Graph illustrating RTs to valid and invalid trials for males and females, at each SOA, in Experiment 2b.

# EXPERIMENT 3

One issue that has not been addressed thus far is the relevance of these findings to studies showing that gaze cues are not the only type of central stimulus that can direct spatial attention. Nonpredictive arrows have been shown to be effective cues to attention (Eimer, 1997; Hommel et al., 2001; Ristic, Friesen, & Kingstone, 2002; Shepherd, Findlay, & Hockey, 1986; Tipples, 2002). A face with a laterally protruding tongue has also been shown to produce attentional orienting (Downing, Dodds, & Bray, 2004). Therefore, it seems that any asymmetric stimulus that implies a direction is sufficient to evoke a shift of attention in an observer.

However, even symmetrical stimuli such as numbers (e.g., 1 or 8), presented centrally can cue attention (Fischer, Castel, Dodd, & Pratt, 2003), due to the internal representation of number in terms of spatial relationships (when a number low in the stimulus set is presented, attention orients to the left; a high number results in a rightward shift). Hence, attentional orienting from central cues can be due to activation of internal symbolic representations. The question of whether males fail to produce attention shifts according to centrally presented arrows is therefore of great interest, in order to contextualize the results of Experiment 1.

If orienting to the direction of another person's eye gaze is functionally different to the symbolic cueing seen with arrows, for example, then no gender difference would be obtained with arrow cues: Males and females should display attention shifts of equivalent magnitude. This would strongly suggest that the reason that females show more orienting towards the direction of another's gaze is due to their greater processing of social stimuli. In sharp contrast, the persistence of a gender difference when cueing with arrows would suggest that the difference between males and females in these experiments is more general than just differences in processing of social stimuli. This experiment therefore uses the same procedure as that in Experiment 1, but with an arrow as a central cue, to assess the possibility that the reduced orienting in males generalizes to another symbolic cue.

## Method

### *Participants*

A total of 40 university students (20 males, mean age = 22.7 years, *SD* = 5.1 years; 20 females, mean age = 21.2 years, *SD* = 3.7 years) participated in this experiment in return for payment (£5) or course credit. All had normal or corrected-to-normal vision and were naïve to the purpose of the experiment.

### *Apparatus*

Stimuli and apparatus were identical to those used for the gaze experiments, with the exception that an arrow was used in place of the face. The arrow consisted of a line (5.5 cm) and arrowheads (1.0 × 2.0 cm) drawn with 0.3-cm thickness.

### *Design and procedure*

Design and procedure were identical to those in Experiment 1, except that an arrow cue was used (see Figure 7).

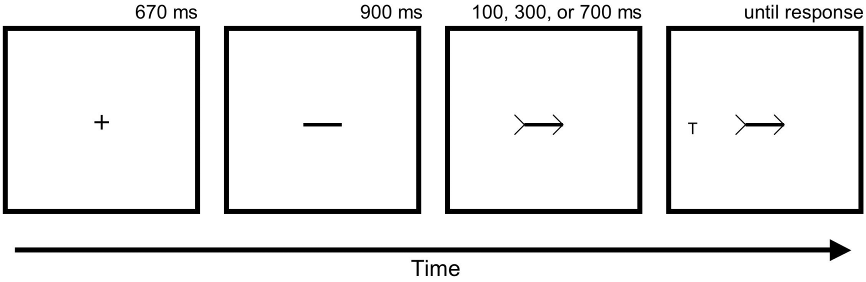

**Figure 7.** Illustration of an invalid trial in Experiment 3.

## Results and discussion

Errors (3.44%) and RT outliers (6.92%) were removed from further analysis, as in Experiment 1. Mean RTs for each participant in each condition were submitted to mixed-factor ANOVA. The factors validity, SOA, and sex of participant contributed to the analysis, which revealed a significant effect of validity, $F(1, 38) = 15.3$, $MSE = 191.2$, $p < .001$, with faster responses to validly cued targets (522 ms vs. 529 ms). SOA also reached significance, $F(2, 76) = 88.7$, $MSE = 400.6$, $p < .001$, with faster responses at later SOAs (548 ms vs. 520 ms vs. 507 ms). The between-factor variable, sex of participant, interacted with validity, $F(1, 38) = 4.70$, $MSE = 191.2$, $p = .037$, with the benefit for RT to valid targets being larger in females (11 ms), than in males (3 ms). This interaction was further investigated with independent $t$ tests on the cueing effects at each SOA. Cueing was not different at the 100-ms SOA, $t(38) = -1.15$, $p = .258$. At the 300-ms SOA, females were cued more (19 ms) than males (2 ms), $t(38) = 3.27$, $p = .002$. At the 700-ms SOA, the difference in cueing effects was marginal, $t(38) = 1.73$, $p = .092$ (females = 14 ms; males = 2 ms).

The only other effect to reach significance, in contrast with Experiment 1, was the sex of participant by validity by SOA interaction, indicating a different time course of cueing in the different gender groups, $F(2, 76) = 4.77$, $MSE = 151.0$, $p = .011$ (see Figure 8). The source of this interaction was the amount of cueing in females changing across SOAs, but the male participants' cueing not changing over time. This was shown by performing ANOVAs on the two sex groups independently. The validity by SOA interaction was significant in females, $F(2, 38) = 6.43$, $MSE = 151.0$, $p = .004$, but not in males, $F(2, 38) < 1$.

One other feature of the data is of note. While the main effect of sex of participant did not reach significance, $F(1, 38) = 1.66$, $MSE = 30{,}114$, $p = .205$, (males = 511 ms, females = 540 ms), this difference of 29 ms in the overall reaction time to identify targets may have influenced the data. For example, slower RTs may magnify cueing effects and contribute to the gender difference we present. To investigate this possibility, the 40 participants were reclassified as "fast" (mean RT = 471 ms) and "slow" (mean RT = 579 ms). The RTs of the two new groups were significantly different, $F(1, 38) = 54.4$, $MSE = 12{,}920$, $p < .001$. In a new ANOVA with RT group replacing sex of participant as the between-subjects factor, RT group did not interact with validity, with both groups showing equivalent cueing effects, $F(1, 38) < 1$, $MSE = 214.9$, $p > .9$ (cueing effect in both groups = 7.0 ms). Cueing effects were also equal across SOA, $F(2, 76) < 1$, $MSE = 170.0$,

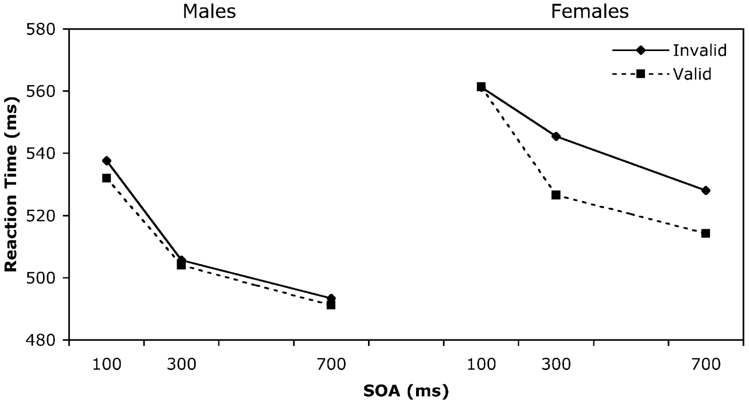

**Figure 8.** Graph illustrating RTs to valid and invalid targets for males and females at each SOA, in Experiment 3.

$p > .9$. This shows that faster responses overall did not result in attenuated cueing, and that the sex differences in arrow cueing are not due to males generally being quicker to respond to targets.

Therefore, these data demonstrate that observing a nonpredictive central arrow cue has little effect on males' attention systems. This failure of central arrow cues to evoke orienting of attention in male subjects is very similar to the failure of gaze cues to evoke strong attention shifts in this population. In contrast, females again show significantly larger cueing effects than males. In fact, the sex difference appears even stronger in this arrow cueing experiment than in the gaze cueing study of Experiment 1. This shows that the sex difference described in Experiment 1 generalizes to symbolic cues such as arrows and is not confined to sociobiological stimuli such as averted eye gaze.

## THE AUTISM-SPECTRUM QUOTIENT

With respect to the extreme male brain theory of autism, from which we made our experimental predictions, a link to the symptomology of the autistic spectrum disorders was made by administering a questionnaire to a subset of our participants. Since only a subset of participants from Experiments 1 (15 males, 10 females), most from Experiments 2a ($n = 40$) and 3 (19 males, 19 females), and none from Experiment 2b completed the questionnaire, strong conclusions are difficult to draw.[1] Nevertheless, even though we do not have a full data set, we feel it is of interest to mention here.

The questionnaire was the 50-item Autism-Spectrum Quotient (AQ), developed by Baron-Cohen, Wheelwright, Skinner, Martin, and Clubley (2001). This questionnaire lists 50 statements and requires the participant to indicate whether he or she "definitely agrees", "slightly agrees", "slightly disagrees", or "definitely disagrees" with the statement. The AQ aims to assess five traits, which pertain to social and cognitive functioning styles often found to be in the extreme ranges in people with autism-spectrum disorders.

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[1] We were unaware of this questionnaire before we started data collection.

Therefore, 10 questions were aimed at assessing each of the following traits: social skills, attention switching, attention to detail, communication, and imagination. The questionnaire is scored out of 50 points, with high scores meaning that more autism-like traits are reported.

Two aspects of the questionnaire data are of note: First, males tended to score higher than females in Experiment 1 (males = 18.9, females = 15.1), Experiment 2a (males = 17.2, females = 15.5), and Experiment 3 (males = 18.4, females = 15.4). This confirms the sex differences observed by Baron-Cohen et al. (2001) and supports the potential link between autism and the extreme male brain hypothesis. The second observation of note is that there was a significant negative correlation between score on the AQ and cueing in the eye gaze cueing study of Experiment 1 at the 700-ms SOA, $r = -.451$, $n = 25$, $p = .024$, two-tailed. That is, those individuals scoring higher on the autism quotient tended to produce less joint attention when viewing gaze shifts. The lack of a correlation between AQ and cueing in Experiment 2a was expected, as peripheral exogenous cues do not show individual differences. However, the lack of such a relationship between AQ and cueing in the arrow cueing study of Experiment 3 is somewhat surprising.

It is very interesting that the responses to the AQ correlate with magnitude of attention shifts only in the gaze cue condition of Experiment 1. It suggests that those who rate themselves as relatively poor communicators, having poor social skills, and so on, also show weaker reflexive gaze following. While conclusions drawn from the AQ data are limited, due to small sample sizes, this new research approach may prove to be a useful explanatory tool in the study of individual differences in normal social cognition (Baron-Cohen, Richler, Bisarya, Gurunathan, & Wheelwright, 2003; Baron-Cohen et al., 2001).

## GENERAL DISCUSSION

The experiments presented here demonstrate consistent sex differences in attentional cueing following the presentation of a central noninformative cue. When either averted eyes (Experiment 1) or an arrow (Experiment 3) is presented in the centre of the screen, females show greater cueing effects than males. These sex differences do not generalize to peripheral exogenous cues to attention, since cueing was found to be equivalent in both sexes in Experiments 2a and 2b. This lack of sex differences with exogenous cues is not surprising, since exogenous cueing is thought to be controlled by very different orienting mechanisms to that of joint attention evoked by eye gaze. A cortical network involving the superior temporal sulcus and the inferior parietal lobule is thought to encode another's gaze direction and direct attention shifts (Pelphrey et al., 2003; Wicker et al., 1998). In contrast, a subcortical system is thought to be involved in exogenously driven attention shifts, with the superior colliculus interacting with parietal cortex (Klein, 2000; Rafal et al., 1988).

Hence, in replicating the basic effect of attention orienting towards another's gaze (e.g., Driver et al., 1999) we find a gender difference, which is entirely predicted by the extreme male brain theory of autism and psychological sex differences. It seems that males do not process eye gaze as efficiently as females do and therefore do not orient to the direction of gaze. This effect was due to a larger difference between RTs to targets presented in valid and invalid trials in females than in males. This difference in magnitude of cueing effects in Experiment 1 seems to be due to relatively slow responses to invalidly cued targets by females (see Figure 2). This seems to be an interference effect: Females are slower to respond to targets on the opposite side to gaze direction.

Note that participants were informed that gaze direction did not predict subsequent target location. Therefore, the task goal involved ignoring the irrelevant gaze cue. In this sense, males can be considered more efficient, being able to ignore gaze shifts. In contrast, females encode gaze in such an automatic and hence efficient manner that they cannot ignore this irrelevant social stimulus. This is analogous to Stroop interference, for example. The more highly efficient, fluent, and automatic reading systems suffer from greater interference when words have to be ignored. Good focused attention and attention to details are associated with the male brain's systemizing skills. It is therefore perhaps unclear whether a weaker sensitivity to social cues or a stronger ability to inhibit the influence of social cues underlies these sex differences.

It would be of interest to investigate whether this general effect for smaller cueing in males might be context dependent. For example, males viewing a male face may show differential effects as a function of emotional expression. With neutral faces in this study, no modulation of cueing effects was found as a function of gender of viewed face. However, aggressive male faces, for example, might elicit male–male competition, resulting in modulation of cueing effects (Geary, 1998). However, in gaze cueing studies such as these, emotional expression seemingly does not modulate cueing magnitude (Hietanen & Leppanen, 2003), unless state and trait anxiety scores are taken into account, whereby people with high levels of anxiety are strongly cued by averted gaze in the context of a fearful face (Mathews, Fox, Yiend, & Calder, 2003). Hence, gender, prevalence of autistic-like traits, levels of anxiety, and facial expression context are all interesting factors to consider in assessing the impact of social cues on attention in clinical and nonclinical populations.

Reflexively following the direction of an arrow also seems to be much weaker in males than in females, suggesting a global sex difference in the way symbolic cues are treated by the attention system (Experiment 3). Initially, this result seems to be at odds with the prediction of an extreme male brain hypothesis, since it is difficult to see how inefficiency in processing faces, emotions, and eye gaze might be related to smaller attention shifts evoked by arrows. However, although arrows are not biological stimuli, they are symbols used by humans for the interpersonal communication of spatial information. Hence, like eye gaze, arrows often carry information that may be important for ongoing behaviour. As such, attending to the direction of both cues seems an adaptive behaviour that appears to have developed to a stronger degree in the female brain.

Indeed, the similarities between gaze and arrow cueing are striking. In this study, they share the same time course, same magnitude, and same gender difference. Similarly, Ristic et al. (2002) suggested that following eyes and arrows have a similar developmental time course, by demonstrating that both effects develop by ages 3–5 years. Despite these similarities, there is growing evidence for separate underlying mechanisms. For example, the mechanisms underlying gaze following are lateralized to the face-processing-dominant hemisphere. Kingstone et al. (2000) showed that gaze cues were only effective when presented in one field of vision of three split-brain patients (i.e., the visual field represented by the hemisphere dominating face processing). Ristic et al. (2002), however, showed that cueing by arrows was found in *both* hemifields in the same patients. Interestingly, ipsilesionally presented leftward gaze, but not arrows, can ameliorate extinction of contralesional stimuli in patients with right parietal brain damage (Vuilleumier, 2002). Furthermore, Hooker et al. (2003) showed that interpreting eye gaze as a directional cue results in more STS activation than interpreting an arrow. If STS is less active for the observation of arrows, then STS is an unlikely candidate for the origin of this gender difference. It is possible instead that an as yet unidentified general mechanism is involved in encoding the meaning behind a central directional cue. This would speculatively suggest a difference centred more in the semantic system in males and females, in the way that meaning is automatically extracted from the central cue.

Whatever the link between eye gaze following and arrow following may be, the fact that females *reflexively* attend to the locus of gaze, while males do not, illustrates a difference in processing bias in the two sexes. These results show that sex differences found in infancy, regarding processing of social information, continue to influence cognition in adulthood. Of course, males are perfectly able to know where someone is looking and follow their gaze. However, the lack of a strong system that *automatically* orients attention to the locus of another's attention could have profound effects on the development and cognitive style of the male brain. For example, males develop vocabularies slower than do females (Lutchmaya, Baron-Cohen, & Raggatt, 2002b), and the development of language is correlated with the development of joint attention (Baldwin, 1995; Morales et al., 2000; Morales, Mundy, & Rojas, 1998). Joint attention is also a precursor to theory of mind (Charman et al., 2001). Hence, the female brain, with its greater propensity to orient to direction of gaze, is at an advantage for interpreting subtle social cues while interacting with other people. Such processing biases may facilitate the accurate representation of the mental states of others.

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