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Neuropsychologia 40 (2002) 769–777

NEUROPSYCHOLOGIA

www.elsevier.com/locate/neuropsychologia

A left visual field advantage in perception of gaze direction

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Received 15 November 2000; accepted 4 September 2001

Abstract

Previous work has found a left visual field (LVF) advantage for various judgements on faces, including identity and emotional expression. This has been related to possible right-hemisphere specialisation for face processing, and it has been proposed that this might reflect configural processing. We sought to determine whether a similar LVF advantage may also exist for *gaze* perception. In two experiments, normal adult subjects made judgements for seen gaze direction (left, right or straight). To assess how visual field may influence perception of gaze direction, eye stimuli were briefly presented unilaterally or bilaterally. In the latter case, the gaze direction of the two seen eyes could be congruent or incongruent (i.e. the two eyes could gaze in the same or different directions). For unilateral displays, performance was more accurate for LVF stimuli than RVF. With bilateral incongruent gaze, the LVF eye influenced judgements more strongly than the RVF eye. No such LVF advantage was found in a control experiment, in which subjects judged *pupil size* for similar eye stimuli. Taken together, these results reveal a LVF advantage for perception of gaze direction. Since only the eye region was visible, our results cannot be due to a LVF bias in processing the entire face context. Instead they suggest lateralisation specifically in processing the direction of seen gaze.

Keywords: Gaze; Facial asymmetry; Visual field perceptual asymmetries; Right-hemisphere specialisation

1. Introduction

In everyday life, the gaze direction of other people is important in many respects. It can provide critical information in social situations about emotional states (e.g. [1]) and also about the direction of attention of another individual, or their goals and intentions [2,20]. Given the importance of perceiving the gaze of others' eyes (and of perceiving faces in general), one might expect that they receive specialised processing in the brain. Although this is still controversial (e.g. see [16,26]), some recent work suggests that certain neural structures may be particularly involved in the perception of such biologically relevant stimuli. Some of this evidence also suggests possible lateralisation of function.

Possible right-hemisphere dominance in processing of faces was suggested on the basis of neuropsychological data on deficits in patients [4,12]. Lesions in the inferior occipitotemporal region can lead to selective deficits in face processing, or 'prosopagnosia' (see [7] for review). Although bilateral lesions are most common in prosopagnosia, it has been suggested that in unilateral cases the deficit may be more common after right-hemisphere damage [8,9]. In healthy people, additional evidence comes from functional neuroimaging. For instance, Clark et al. [6], McCarthy et al. [22], and Kanwisher et al. [17] all found stronger activation of right than left occipitotemporal regions when viewing faces. Event-related potential (ERP) methods have also revealed face-selective responses, e.g. the N170 component, which registers as largest in amplitude over posterior temporal scalp, and is typically larger over the right hemisphere [3,11].

Further neuroscience evidence suggests the possibility of specialised neural circuits for gaze processing in particular. Bentin et al. [3] observed a larger N170 for eyes presented in isolation, versus a whole face, which they interpreted as possible activation of an eye sensitive region around the right-occipitotemporal sulcus (but see [11]). Hoffman and Haxby [15] used fMRI to compare processing of gaze direction versus face identity, and found superior temporal sulci activation for the former, versus inferior occipital and fusiform activation for the latter. Wicker et al. [27] found evidence for right-hemisphere predominance in processing of gaze, within a network including posterior fusiform gyrus, the right-parietal lobule, and the right-inferior temporal gyrus plus middle temporal gyrus. Finally, Kawashima et al.

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0028-3932/02/$ – see front matter
PII: S0028-3932(01)00190-7

[18] reported a larger emotional response to direct gaze in the amygdala, specific to the right hemisphere. Thus, different brain areas may be involved in different aspects of face processing (e.g. face identity versus gaze perception), but with possible right-hemisphere dominance in both cases.

A traditional source of purely behavioural evidence for possible hemispheric specialisation in face processing has been visual field effects, specifically left visual field (LVF) advantages. Better performance for LVF than RVF stimuli has been found in several face-processing tasks (e.g. judging face identity or emotional expression, e.g. [5]), and interpreted in terms of the LVF projecting directly to the putatively specialised right-contralateral hemisphere. Such visual field effects are particularly evident when chimeric faces are used (made of two halves from different pictures, joined together; [13,5]). Such LVF advantages for faces have been interpreted in terms of right-hemisphere predominance for configural processing, as contrasted with left-hemisphere predominance for featural or part-based processing. In apparent support of this, while many tasks on whole faces can show LVF advantages, tasks performed on individual face features can show RVF advantages instead (see [14,24]).

No previous study has examined whether any visual field advantage arises for gaze perception, which was examined here. A critical feature of our experiments was that only the eye region was visible, so that any LVF advantage could not reflect configural processing of an entire face. Given the recent neuroscience evidence (e.g. [18,27]) suggesting right-hemisphere dominance in processing of gaze direction, one might expect a LVF advantage, even though a whole face was not shown. On the other hand, if gaze direction judgements behave like non-configural judgements on other individual face-features, a RVF advantage might be found instead (as in [14]). Our experiments sought to distinguish these contrasting predictions empirically for the first time.

2. Experiment 1

We presented either just one eye (unilateral displays) or two eyes (bilateral). A previous conference abstract by Ehrlich and Field [10] reported that seeing two eyes can lead to more accurate judgements of gaze direction than seeing just one, which implies that both members of a seen pair of eyes can contribute to gaze perception. We sought to determine whether one of the two seen eyes is more dominant. We therefore included some "chimeric" bilateral displays, in which one of the two eyes looked straight at the subject while the other eye deviated. Thus, each seen eye could look in different directions, so that bilateral trials could yield two "incongruent" eyes. People were asked to judge the overall direction of seen gaze (i.e. whether the pictured person looked left, right, or straight). If any visual field dominance was present, this could become apparent with the unilateral displays and/or the bilateral incongruent conditions. In the latter case, it should be reflected in a greater percentage of responses in the direction of the dominant seen eye (e.g. with LVF dominance, a higher percentage of straight responses should be found when only the LVF eye looked straight, compared to when just the RVF eye looked straight in incongruent bilateral displays).

2.1. Method

2.1.1. Participants

Eight subjects (two females and six males, mean age 28) participated; seven were right-handed and one left-handed by self report (the left-handed subject did not alter the pattern of results). All had normal or corrected vision by self report. Participants were volunteers who replied to an advert and received UK£ 2.50 for participation in a 30 min session. They were unaware of the purpose of the experiment.

2.1.2. Materials

The stimuli were made from a digitised set of photos of the same person. Her gaze was either direct (i.e. looking straight at a digital camera), or deviated 15° from this direct position either to the left or right of the camera. Subsequently, by means of Adobe Photoshop 4.0, just a rectangular window around the eyes was clipped from the image of the face (see Fig. 1). A technique similar to the hemifacial duplication method proposed by Kowner [19], for creating chimeric faces, was used to generate all the present gaze stimuli, with only the right side of the original face being employed. This ensured that none of the stimuli used contained any intrinsic, unintended asymmetries, because corresponding LVF and RVF stimuli were perfect mirror-images of one another. Two different sets of stimuli were made, the first consisting of just one eye (unilateral stimuli, in the LVF or RVF), the other consisting of a pair of eyes (bilateral stimuli). From the original deviated and straight gaze photos, only the eye on the right of the original image was used to create all the unilateral stimulus conditions, either straight or deviated. The original left eye was cut out in Adobe Photoshop 4.0 and replaced with a gray patch (see Fig. 1a). Moreover, the deviated right eye was constructed by cutting out only the iris and sclera of the deviated right eye stimulus and then pasting onto exactly the same face-photo as the straight right eye, to ensure that all aspects of the image were always held constant except for the seen eye itself.

All the resulting unilateral RVF stimuli were then mirror-reversed to create the unilateral LVF stimuli. For the bilateral stimulus conditions, one-third of the stimuli showed bilateral straight gaze, made by combining the two unilateral straight eyes that had been produced by mirror-imaging (see Fig. 1b). For the remaining two-third of bilateral trials, the two eyes shown looked in different directions (i.e. one eye looked either to the subject's right or left, while the other looked straight at the subject, to yield "incongruent" trials, see Fig. 1c). These bilateral stimuli could also be mirror-reversed (in their entirety). Therefore, on an equal proportion of trials the right eye was deviated while the

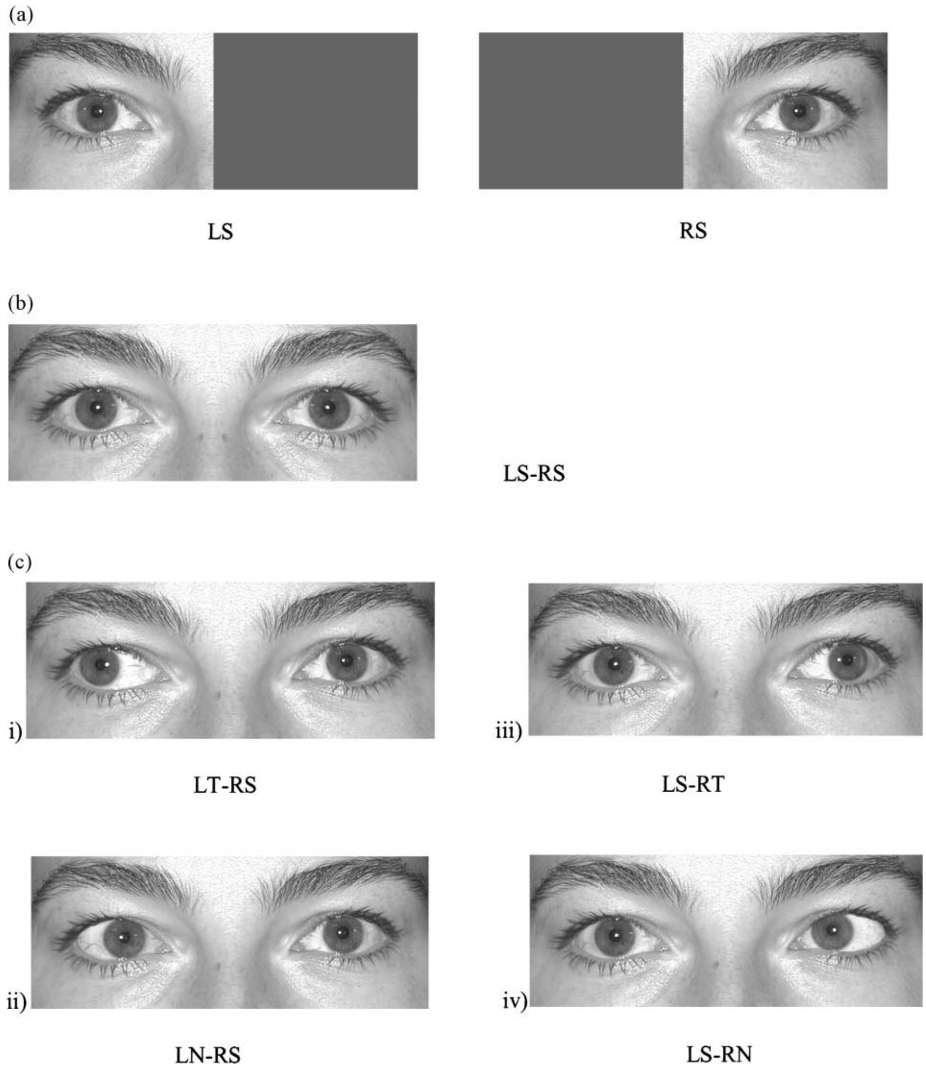

Fig. 1. (a) Examples of unilateral stimulus displays; left visual field eye straight (LS) or right eye straight (RS); (b) bilateral stimulus display, with both the left and right eye straight (LS–RS); (c) example of bilateral ‘incongruent’ stimulus displays: (i) the left eye deviated temporally and the right eye straight (LT–RS); (ii) the left eye deviated nasally and the right eye straight (LN–RS); (iii) the left eye straight and the right eye deviated temporally (LS–RT); (iv) the left eye straight and the right eye deviated nasally (LS–RN). Note that the white region of the eye (i.e. sclera) in the nasally deviated eye is larger than in temporally deviated and straight eye conditions. Note also that the surrounding regions (i.e. bridge of the nose and eyebrows, etc.) yield no information for the task, being identical (and symmetrical) for all conditions.

left eye was straight, or vice versa. Crucially for the aim of the experiment, all stimuli were presented within a narrow “letter box” format ($4.20^\circ \times 1.60^\circ$) so that only the region near the eyes were visible, other features of the face were excluded (see Fig. 1a–c). Note also that all regions around the eyes (i.e. eyebrows, bridge of the nose, etc.) were perfectly symmetrical (due to the mirror-imaging procedure) and were also held constant across all bilateral conditions, so they could give no information about gaze direction.

2.1.3. Design

There were two main display types: unilateral and bilateral. The unilateral eyes were equally likely to appear in the LVF or RVF, and to look left, right or straight. In the bilateral stimuli, the two eyes could both look straight at the subject, or one looked straight and the other deviated either temporally or nasally, i.e. towards the temple or nose near the eye in the photographed face (see Fig. 1b and c). Finally, due to other ongoing experiments, the colour of the eyes was also manipulated in the first study, so that in unilateral trials the iris of the eyes was equally likely to be green or brown. In bilateral trials, one-third of the stimuli contained two brown eyes, one-third contained a left brown eye and a right green eye, and the remaining one-third contained a left green eye and a right brown eye. This irrelevant colour factor was entirely orthogonal to the different conditions of gaze direction, and to the various combinations of direction that were possible on bilateral incongruent trials. Moreover, it had no impact on the present results, and the colour factor was totally eliminated in a subsequent experiment. The total number of possible stimuli was 27.

2.1.4. Apparatus and procedure

The experiment lasted approximately 30 min, and took place in a sound proof booth to avoid distraction. The subject sat in front of a PC laptop computer (PC Toshiba Satellite 300/310 with 12 in. colour LCD screen) at a distance of 57 cm from the monitor, arranged so as to face the subject directly close to eye level. The graphic mode was set to 640 × 480 pixel resolution with 24 bit colours using the Borland C++ and Genus Microprogramming Library software packages. Subjects were instructed to fixate the centre of the screen and to use their preferred hand to make their response. They were told to press three different buttons on the computer keyboard according to where they perceived the displayed eyes to be looking (the “B” button for gaze perceived as looking to the subject’s left; “N” button for direct gaze; and “M” button for gaze towards the subject’s right). The subsequent trial appeared only after response, and subjects were told to make their response as naturally as possible with no hurry. The experiment began with a practice block of 27 trials (one trial for each of the possible display types, in random order), followed by a total of 540 experimental trials. Each trial began with a central fixation point for 500 ms, followed by the gaze stimulus for 300 ms. All stimuli were presented on a black background, and all conditions were randomly intermixed.

Table 1
The mean percentage of subjects’ responses for all the unilateral stimulus conditions in experiment 1[a]

Eye deviation	Each response type (left, right, straight) made (%)		
	Left (%)	Straight (%)	Right (%)
Left visual field eye only			
Temporal	**83.56**	16.25	0.31
Straight	10.63	**86.25**	3.13
Nasal	3.75	18.13	**78.13**
Right visual field eye only			
Nasal	**74.38**	20.94	4.69
Straight	2.5	**86.25**	11.25
Temporal	0.31	21.25	**78.44**

[a] Bold numbers represent the percentage of correct responses, on which the main statistical analysis were performed.

Table 2
The mean percentage of subjects’ responses for all the bilateral stimulus conditions in experiment 1[a]

Deviated eye	Eye deviation	Each response type made (%)		
		Left (%)	Straight (%)	Right (%)
Left (right straight)	Temporal	27.92	**71.04**	1.04
	Nasal	1.67	**68.75**	29.58
Right (left straight)	Temporal	1.46	**80.42**	18.13
	Nasal	12.71	**86.46**	0.83
None (both straight)	None	2.5	93.75	3.75

[a] Bold numbers represent the percentage of straight responses on which the main statistical analyses were performed.

2.2. Results and discussion

We first assessed performance on the unilateral trials (see Table 1). An ANOVA on the percentage of correct responses had two within-subject factors: visual hemifield (i.e. left versus right) and stimulus direction (i.e. seen eye deviated nasally, towards the nose region in the photo; or gazing temporally, away from the nose; or straight). Significantly better performance ($F(1, 7) = 8.55$, $P = 0.02$) was found for LVF versus RVF stimuli (82.65 versus 79.69% correct), regardless of gaze direction which showed no main effect, nor any interaction with visual hemifield (both $F < 1$).

For the results from bilateral displays (see Table 2 and Fig. 2), the percentage of straight responses on incongruent trials (where only one of the two eyes actually looked straight) yields a straightforward measure of any visual field dominance (as explained earlier). These percentages were entered into a two-way within-subject ANOVA, with the factors of which eye was deviated rather than straight (i.e. LVF or RVF), and of the direction in which this eye was de-

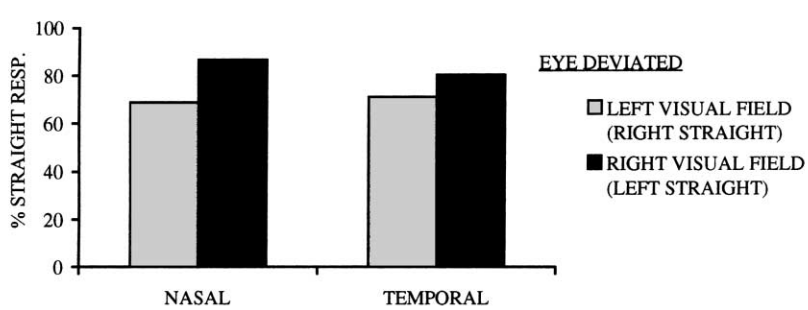

Fig. 2. Graph of the mean percentage of straight responses in judging the direction of gaze for the bilateral incongruent stimulus displays in experiment 1. Percentages are plotted as a function of the direction of eye deviation, separately for a deviated left visual field eye vs. a deviated right eye. Note that there were more straight responses when the eye in the right visual field was deviated (i.e. when just the eye in the left visual field was straight; black bars).

viated (i.e. nasal versus temporal; see Fig. 1c). The results showed a significant main effect of which eye was deviated ($F(1, 7) = 8.62$, $P = 0.02$), with an increased percentages of straight responses when the only straight eye appeared in the LVF (83.44%), rather than in the RVF (69.90%). There was no main effect or interaction involving nasal versus temporal deviation ($F < 1$).

Finally we assessed whether, as reported in the previous conference abstract by Ehrlich and Field [10], performance improved when both eyes were present, versus just one eye. To test this, we compared straight bilateral stimuli with straight unilateral stimuli in a one-way ANOVA. The results showed significantly more accurate performance ($F(1, 7) = 6.19$, $P < 0.05$) for judgements of direct-gaze based on both eyes (93.75%) compared to when the judgements were based on just one eye (86.25%); see Tables 1 and 2. As suggested by Ehrlich and Field [10], this might be due to additional symmetry cues from the eyes in bilateral stimuli with both eyes gazing straight.

3. Experiment 2

Our second experiment aimed to corroborate the LVF advantage in judgements of gaze direction. We sought to generalise it across further subjects. Moreover, while the stimuli had been briefly presented (for 300 ms) in the previous study, this duration might still have allowed just sufficient time for stimulus-triggered saccades during the display. We therefore now presented the stimuli even more briefly (<200 ms) so that saccades could not be made. A simpler design was used, dropping the unilateral conditions (since the left visual field dominance was particularly pronounced for the bilateral conditions in experiment 1), and removing the irrelevant colour manipulation entirely.

3.1. Method

3.1.1. Participants

Eight new subjects (four females and four males, mean age of 26.88), all right-handed by self report, took part. All were naive as to the purpose of the experiment and received UK£ 2.50 for participation.

Table 3
The mean percentage of subjects' responses for all the bilateral stimulus conditions in experiment 2[a]

Deviated eye	Eye deviation	Each response type made (%)		
		Left	Straight	Right
Left (right straight)	Temporal	73.75	**24.12**	2.13
	Nasal	1.63	16.5	81.88
Right (left straight)	Temporal	2.63	**46.88**	50.5
	Nasal	64	**32.88**	3.13
None (both straight)	None	10.89	82.86	6.25

[a] Bold numbers represent the percentage of straight responses on which the statistical analysis were performed.

3.1.2. Design

To simplify the design, the previous unilateral conditions were dropped, as was the irrelevant manipulation of eye colour. No green eyes were presented, only pairs of brown eyes. Hence, the resulting design had only two factors, which both concerned the critical incongruent bilateral displays. The factors were: which of the two eyes was deviated rather than straight (LVF or RVF); and the direction of that deviation (temporal versus nasal).

3.1.3. Apparatus and procedure

These were identical to the previous experiment, except that each stimulus now lasted only 184 ms (i.e. one screen refresh shorter than the figure of 200 ms which is commonly reported as a typical minimum latency for saccades). Hence, no stimulus-responsive eye movements should be possible before the stimulus disappeared.

3.2. Results and discussion

As before, the percentage of straight responses on "incongruent" bilateral trials (see Table 3 and Fig. 3), where one eye was straight and the other deviated, were entered into a two-way within-subject ANOVA with

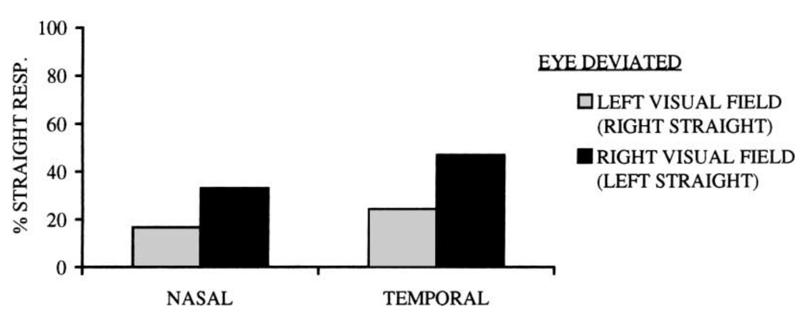

Fig. 3. Graph of the mean percentages of straight responses in judging the direction of gaze for the bilateral incongruent displays in experiment 2. Percentages are plotted as a function of the direction of eye deviation, separately for a deviated left visual field eye vs. a deviated right eye. Note the increase in straight responses when the eye in the right visual field was deviated (i.e. when just the eye in the left visual field was straight; black bars).

deviated eye (LVF or RVF), and its direction of deviation (temporal/nasal), as the factors. The critical previous result was confirmed, namely a significant main effect of which eye was deviated ($F(1, 7) = 7.84$, $P = 0.025$, see Table 3), with an increased percentage of straight responses when the eye in the LVF was straight rather than that in the RVF (39.88 versus 20.31%). This time, the main effect of temporal/nasal deviation was also significant ($F(1, 7) = 15.21$, $P < 0.01$), with more straight responses when the other eye was deviated temporally (35.50%) rather than nasally (24.69%), regardless of where the deviated eye appeared (i.e. LVF or RVF). There was no interaction between the two factors ($F < 1$). The effect from direction of deviation, found in the present study but not experiment 1, is probably due to the present use of briefer displays. This may have made the extent of the white part of the eye (i.e. the sclera) more salient, for a cruder judgement. Note that the extent of visible sclera on one side was indeed larger for nasal than temporal deviation (see Fig. 1c). The briefer displays may also explain the reduced overall rate of straight responses on bilateral trials, in comparison with experiment 1. But the important point is that LVF dominance was replicated for the bilateral incongruent displays, in a different group of subjects, without the irrelevant colour manipulation, and with displays too brief for stimulus-triggered saccades during them.

To assess the consistency of this result across the two experiments (and any differences), a mixed ANOVA was performed on the percentage of straight responses for incongruent stimuli. Experiment (i.e. experiment 1 versus experiment 2) now served as a between-subject factor, while the eye that deviated (i.e. in the LVF or RVF), plus its direction of deviation (nasal/temporal) again served as within-subject factors. This analysis showed a significant ($F(1, 14) = 34.22$, $P < 0.001$) main effect of experiment, with a decrease in the overall percentage of straight responses between experiments 1 and 2, presumably due to the reduced display duration. There was no main effect of nasal/temporal deviation overall ($F < 1$), but a marginal interaction between experiment and nasal/temporal deviation ($F(1, 14) = 3.88$, $P = 0.07$). This arose because experiment 2 (only) showed a stronger influence of nasally compared to temporally deviated eyes on the percentage of straight response (as discussed earlier, this was probably due to the use of faster displays). The critical visual field effect was confirmed by the significant main effect of which eye deviated ($F(1, 14) = 15.63$, $P = 0.001$), due to the increase in straight responses when the LVF eye was straight and the RVF eye deviated, rather than vice versa (62 versus 45%, respectively overall). Importantly, this effect did not interact with experiment, confirming its robustness across the two studies ($n = 16$).

Following the suggestions of a reviewer, additional analyses were carried out to investigate possible differences between first and second experimental halves. This was to assess whether any of the important results are restricted to later stages of performing the task, perhaps in relation to learning of the stimuli used. For each experiment, the percentages of straight responses for the critical bilateral, incongruent trials were entered into a three-way within-subject ANOVA, with the factors of experimental half; which eye was deviated; and the direction of its deviation. For experiment 1, the results showed only a significant main effect of which eye was deviated ($F(1, 7) = 8.62$, $P = 0.02$). Neither of the other factors nor any of the interactions approached significance, showing that no difference in our critical effect was found between experimental halves. Moreover, the LVF advantage remained reliable ($P = 0.012$) when just the first experimental half of experiment 1 was considered alone. For experiment 2, this analysis again showed the critical main effect of which eye was deviated ($F(1, 7) = 7.84$, $P = 0.03$), plus the effect of the direction of its deviation ($F(1, 7) = 15.21$, $P < 0.01$) as before for this study. No other main effects or interactions approached significance, again confirming that the critical LVF advantage did not differ between experimental halves. Finally, the LVF advantage remained significant ($F(1, 7) = 7.43$, $P < 0.01$) when just the first experimental half of experiment 2 was considered alone.

4. Experiment 3

The final experiment was a control study, designed to investigate to what extent the LVF advantage found in experiments 1 and 2 is specific to perception of *gaze direction*, rather than simply to perception of *any* spatial properties of seen eyes. We now asked subjects to judge the *pupil size* (large versus small) of seen eyes. Note that, as with gaze direction, pupil size is a property of potential social and biological significance, since it can indicate interest from a conspecific. Moreover, people have been shown to be very sensitive to pupil size (for instance, it affects their judgements of attractiveness; see [1]). If the LVF advantage is found for *any* judgements on eye stimuli (perhaps because such stimuli automatically engage specialised right-hemisphere systems), the LVF advantage should be replicated once more in judgements of pupil size. However, if for eye stimuli the LVF advantage is specific to judgements of gaze direction in particular, it should no longer be found.

Bilateral displays were used once more, in which the two eyes could again be congruent or incongruent, but now in terms of pupil-size only (see Fig. 4).

4.1. Method

4.1.1. Participants

Twelve new subjects (seven female and five male, mean age 27) participated. All were right-handed and had normal or corrected vision by self report. Participants were volunteers. They were unaware of the purpose of the experiment and did not take part in any of the previous experiments.

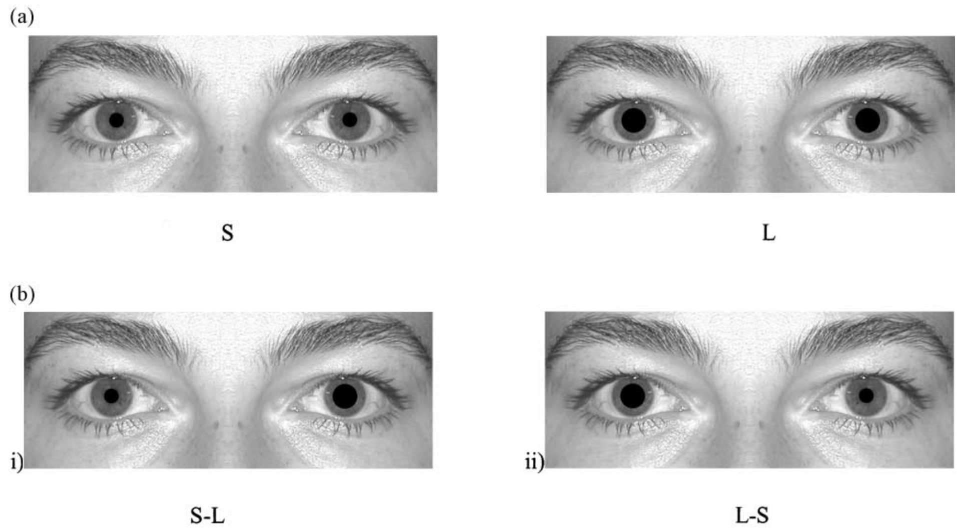

Fig. 4. (a) Example of bilateral congruent displays in experiment 3, with pupils either both small (S) or both large (L); (b) example of bilateral 'incongruent' stimulus displays in experiment 3: (i) the left eye has a small pupil and the right eye has a large pupil (S–L); (ii) the left eye has a large pupil and the right has a small pupil (L–S).

4.1.2. Materials

The stimuli were generated from the bilateral straight gaze stimulus used in experiments 1 and 2 (see Fig. 1b). Four different stimuli were made (see Fig. 4, which is to scale). The stimulus with "small pupils" was made by pasting a solid black circle (15 pixels in diameter) onto the two eyes, centred where the real pupil had been. A stimulus with "large pupils" was made in the same manner but with larger black circles (25 pixels). The two remaining incongruent stimuli were made by first pasting a large solid circle onto the LVF eye, but a small circle onto the RVF eye; and then by flipping this horizontally to create a mirror-reversed version also (i.e. large RVF pupil and small LVF pupil). As before, all stimuli were presented within a narrow "letter box" format (see Fig. 4), so that the overall face configuration was not visible. Moreover, the region immediately around the eyes was constant across all conditions, and hence uninformative for the judgement.

4.1.3. Design

The conditions were all bilateral and could be either "congruent" or "incongruent". There were two possible congruent displays in which the two pupils had the same size as each other, i.e. both large, or both small; and two possible incongruent displays, where the two eyes had different pupil sizes, with the large pupil being either in the LVF or the RVF eye (see Fig. 4).

4.1.4. Procedure

The experiment lasted about 20 min, and took place in a dark room. Subjects again sat in front of the monitor at a distance of 57 cm, kept constant by the use of a chin-rest. Participants were told to fixate the centre of the screen and were instructed to press the space bar on the computer keyboard when they perceived the display as having small pupils, or to press the "H" button for a perception of large pupils. As before, subjects were told to make their judgement naturally and with no hurry. The experiment began with a practice block of 32 trials, followed by a total of 160 experimental trials presented in random order. Each trial began with a central fixation point lasting 500 ms, followed by the gaze stimulus lasting 184 ms, as in experiment 2.

4.2. Results and discussion

We first calculated the subjects' accuracy for congruent conditions (i.e. both-large or both-small trials; see Table 4 and Fig. 5). Although the percentage of correct responses was slightly higher for displays with large pupils (92.5 versus 89.38%), this was not significant ($t(1\ 1) = 1.04$, $P = 0.32$). Then we analysed performance on the critical incongruent trials, using the percentage of "large" responses (equivalent to the inverse of "small" responses) as our measure of any visual field dominance (this is analogous to our use of percentage straight responses in the previous two studies). A

Table 4
The mean percentage of subjects' responses for all the bilateral stimulus conditions in experiment 3[a]

Conditions	Pupil size	Responses made (%)	
		Large (%)	Small (%)
Congruent	Large pupil	92.5	7.5
	Small pupil	10.62	89.38
Incongruent	LVF large	**53.75**	46.25
	RVF large	**71.67**	28.33

[a] Bold numbers represents the percentage of large responses on which the statistical analysis were performed.

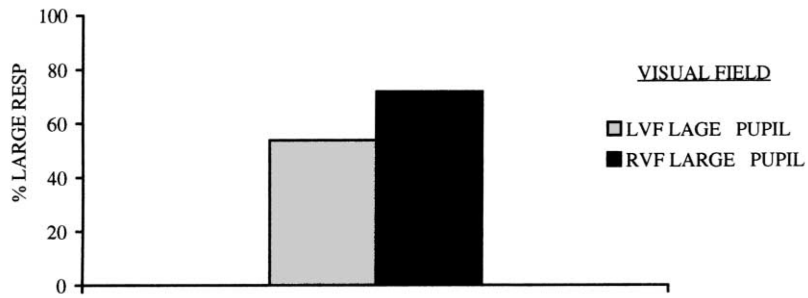

Fig. 5. Graph of the mean percentages of "large" responses in judging the size of the pupil for the bilateral incongruent stimulus displays in experiment 3. Percentages are plotted as a function of the visual field where the large pupil appeared.

paired *t*-test found no effect from the visual field of the large pupil on incongruent trials ($t(1\ 1) = -1.37$, $P = 0.20$). Moreover, any trend was opposed to the visual field dominance observed in the previous two gaze direction experiments (i.e. numerically, responses now went along with the RVF eye more often than the LVF eye: 71.67 versus 53.75%, see Table 4). Thus, the LVF dominance that had emerged for judgements of gaze direction in the previous two experiments was no longer found when subjects made a judgement of pupil-size instead, for very similar stimuli. Hence, LVF advantages are not invariably found with eye stimuli.

5. General discussion

This study found a visual field effect on perception of gaze direction, for the first time. Normal observers were more influenced by the LVF eye than the RVF eye when asked to judge the direction of gaze. No such effect was apparent when observers judged pupil size instead, for very similar stimuli (if anything, the RVF eye now had somewhat more influence).

LVF advantages in various previous tasks performed on *whole faces* [5,13,21], rather than just on eyes, have commonly been attributed to right-hemisphere specialisation for *configural* processing of the many different face features in an entire face (i.e. not just the eyes, but also their relation to the nose, mouth, etc.; e.g. see [14,24,25]). However, the present visual field effect on judgements of gaze direct cannot have been due to any such configural processing of the whole face. Only the regions immediately around the eyes were used for the gaze stimuli. Moreover, only the eyes themselves were informative for the task. Finally, the present LVF advantage for judgements of gaze direction was found even with unilateral presentation of just a single eye (experiment 1), so it does not depend solely on processing the configuration made by a pair of eyes in bilateral displays.

It could be suggested that at least some of the previous findings of LVF dominance when processing whole faces might actually relate to the LVF dominance found here for processing gaze. That is, in principle at least, just the eye region of whole-face stimuli might have triggered some of the previous effects on face judgements. This seems particularly relevant for previously observed LVF advantages in emotional expression tasks, given the importance of the eye region in such expressions (e.g. [1,2]). The possibility that the eye region alone could be contributing to some of the LVF advantages previously found in tasks with whole faces (as when judging identity or emotion) might be tested in further research, by manipulating whether the eyes themselves are visible during judgements.

One might try to argue that, rather than reflecting specific mechanisms for processing gaze, the LVF dominance found here might simply reflect a general LVF bias affecting perception of face components in general (even though whole faces were not shown). However, against this it should be noted that non-gaze tasks on isolated facial features have shown right visual field advantages in past behavioural studies [14], unlike the left visual field advantage found here for gaze. Moreover, matching of individual facial features, rather than entire faces, has recently been found to activate left-hemisphere structures (in the fusiform gyrus) more strongly than the right-hemisphere structures activated for judging whole faces [24]. Finally, no left-visual field advantage was found here for judgements of pupil size in eye stimuli, even though this task concerned face components just as for the gaze direction task.

Our results thus do not appear to fit with any laterality accounts that invoke a simplistic dichotomy between feature-based versus configural processes. Instead, they seem most consistent with laterality (i.e. right-hemisphere dominance) in neural mechanisms that are specialised for encoding seen gaze direction. This possibility appears consistent with recent neuroscience findings (e.g. see [3,15,18,27]). For instance, Wicker et al. [27] specifically found evidence for right-hemisphere predominance in processing of gaze, within a network including the posterior fusiform gyrus, the right-parietal lobule, and the right inferior temporal gyrus plus middle temporal gyrus. Our study is the first to provide convergent behavioural evidence for laterality effects in the perception of gaze, and to show that this laterality is not found for all properties that can be extracted from eyes (e.g. not for pupil size), but may be specific to the encoding of gaze direction.

Future behavioural studies could manipulate the exact visual properties present in the eye stimuli (perhaps using artificial stimuli, or even simplified cartoons, rather than the realistic photographs used here), to uncover exactly which visual cues trigger gaze perception [23], and which of these are responsible for the LVF advantage we have uncovered.

Acknowledgements

This work was supported by European TMR grant ERBFMBICT971928 award to PR and by a Human Frontiers Science Program award to JD. Thanks to Charlotte Russell for being the looker and to the two anonymous referees for their helpful comments.

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