

Seen Gaze-Direction Modulates Fusiform Activity and Its Coupling with Other Brain Areas during Face Processing

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Gaze-contact is often a preliminary to social interaction and so constitutes a signal for the allocation of processing resources to the gazing face. We investigated how gaze direction influences face processing in an fMRI study, where seen gaze and head direction could independently be direct or deviated. Direct relative to averted gaze elicited stronger activation for faces in ventral occipitotemporal cortices around the fusiform gyrus, regardless of head orientation. Moreover, direct gaze led to greater correlation between activity in the fusiform and the amygdala, a region associated with emotional responses and stimulus saliency. By contrast, faces with averted gaze (again, regardless of head orientation) yielded increased correlation between activity in the fusiform and the intraparietal sulcus, a region associated with shifting attention to the periphery. © 2001 Academic Press

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INTRODUCTION

Faces constitute a particularly important and frequently encountered class of visual stimulus. Various types of information, such as gender, age, expression, person identity, and gaze-direction can be extracted from faces, in a highly efficient manner (e.g., see Bruce and Young, 1998, 1986; Baron-Cohen *et al.*, 1999). Gaze direction is particularly important for indicating some of the mental states of others (e.g., where they are attending; see Baron-Cohen *et al.*, 1997; Driver *et al.*, 1999; Langton and Bruce, 1999; for review, Emery, 2000; Langton *et al.*, 2000), and also as a precursor to social interaction in the case of direct gaze (Argyle and Cook, 1976; Baron-Cohen, 1995; Kleinke, 1986). Such interaction can take various forms, since direct gaze can signal aggression, attraction, or a desire to communicate, depending on the context (Argyle, 1982; Kleinke, 1986). The meaning of direct gaze must thus

be decoded via other aspects of the seen face, and direct gaze may therefore influence the processing of other aspects of the face.

The idea that seen gaze direction can influence processing for other aspects of the face is supported by single-cell data from monkeys, showing that neurons in temporal cortex which are selectively responsive to faces may also be affected by gaze direction (Perrett *et al.*, 1992, 1985). In humans, numerous functional imaging studies have reported that viewing faces can selectively activate regions of ventral occipitotemporal cortex, around the fusiform gyrus, as compared with viewing other classes of visual object (Clark *et al.*, 1998; Grady *et al.*, 1995; Halgren *et al.*, 1999; Haxby *et al.*, 1999, 1996, 1991; Kanwisher *et al.*, 1997; McCarthy *et al.*, 1997; Puce *et al.*, 1996; Tong *et al.*, 2000). Although the exact function of this fusiform response remains controversial (e.g., Chao *et al.*, 1999; Gauthier *et al.*, 2000, 1999; George *et al.*, 1999; Kanwisher *et al.*, 1999, 1998, 1997), it is clear that seeing faces reliably activates this region. However, the fusiform response has not hitherto been shown to be modulated by seen gaze direction or gaze contact.

Much psychological evidence shows that direct gaze is a particularly salient stimulus for human observers (e.g., Gibson and Pick, 1962; von Grünau and Anston, 1995), and that we are exquisitely sensitive to it (e.g., Anstis *et al.*, 1969). However, most recent functional imaging studies that examined possible brain responses to seen gaze direction focused on responses to averted rather than direct gaze (e.g., Hoffman and Haxby, 2000; Puce *et al.*, 1998; Wicker *et al.*, 1998). Using videos of actors, Wicker *et al.* (1998) showed that conditions of visible gaze, relative to conditions where no actual gaze was visible, activated posterior occipitotemporal cortex, both ventrally and laterally, as well as the superior parietal lobule, but did so regardless of gaze direction. Puce *et al.* (1998) found that seeing eyes shift-

ing their gaze in the horizontal plane, relative to seeing stationary eyes, activated part of the superior temporal sulcus (STS), mainly in the right hemisphere. However, this region was also activated by seen mouth movements, so may not be specific to seen gaze. Hoffman and Haxby (2000) showed that STS and intraparietal sulcus were more activated when subjects judged seen gaze direction, rather than the identity of faces for the same stimuli. These regions also responded stronger to averted than direct gaze in passive viewing. Finally, only Kawashima *et al.* (1999) focused on activations in response to gaze contact (versus averted gaze), using just one face as the stimulus. They found that attending to the vertically moving gaze of one videoed face activated the amygdala bilaterally, with the right amygdala specifically activated for intermittent gaze-contact relative to an averted-gaze condition.

Here, we investigated the neural correlates of gaze processing further by testing whether direct gaze can modulate the fusiform response to seen faces. In daily life, people can look directly at us yet while facing in various different directions. Single-cell studies in monkeys have suggested that gaze direction can be extracted independently of head orientation (Campbell *et al.*, 1990; Perrett and Emery, 1994; Perrett *et al.*, 1992, 1985), and psychophysical studies in humans confirm that our special sensitivity to direct gaze is retained to some extent across different head angles (Anstis *et al.*, 1969; Gibson and Pick, 1962). Therefore we tested for any occipitotemporal neural response to direct versus deviated gaze, which held across different views of a face (i.e., head direct and head deviated). Note that such a neural response could not be driven simply by relatively low-level image properties (e.g., symmetry in the eye region, which holds only for direct gaze in full-face views; see Erhlich and Field, 1993), since the image for direct gaze in a deviated face is very different to that for direct gaze in a frontal face, even within the eye region.

We also tested whether the functional connectivity (condition-dependent coupling; Friston *et al.*, 1997) of ventral occipitotemporal areas with other brain regions might alter depending on the seen gaze direction. Based on other recent findings, and considering the social salience of people who look directly at you, one might predict that a face with direct gaze should induce functional coupling (in the form of correlated activity), between the fusiform regions responding to faces and areas involved in emotional processing and social cognition (e.g., the amygdala; Adolphs, 1999; Adolphs *et al.*, 1998; Baron-Cohen *et al.*, 1999; Brothers and Ring, 1993; Brothers *et al.*, 1990; Morris *et al.*, 1996). By contrast, a face with averted gaze might induce greater coupling with those brain areas (e.g., parietal regions) involved in shifting attention towards

the peripheral location that the seen face gazes toward, since such attentional shifts can be triggered by viewing deviated gaze (see Driver *et al.*, 1999; Friesen and Kingstone, 1998; Hoffman and Haxby, 2000; Langton and Bruce, 1999).

We used static views of eyes looking directly at the viewer, or to one side, within 34 different faces, each seen either in a frontal view or with the head deviated to one side. The factor of gaze direction (direct versus averted) was fully crossed with head direction (frontal versus deviated). Instead of requiring our subjects to discriminate gaze (which might produce strategy-specific activations), they were engaged in a gender discrimination task, so that we could examine the spontaneous effects that gaze direction can produce during face processing, even when task-irrelevant.

METHODS

Subjects

Seven healthy paid volunteers (4 females, 3 males; age = 28 ± 2 years) provided written informed consent to participate in this study, which was approved by the National Hospital for Neurology and Neurosurgery Ethics Committee. All had normal or corrected vision, and were right-handed according to an abbreviated version of the Edinburgh inventory.

Stimuli

Thirty-four different faces were photographed (17 males, 17 females). These produced digitized color images of young adults, with a neutral expression, each taken in full-face frontal view and also with the head rotated toward the right by 30°. For each of these head views, two photographs were taken, one with the subject looking straight at the camera, the other with the subject looking at a point falling at the same distance (120 cm) and level (i.e., eye-level of the looker) as for the camera during direct gaze, but now with the point placed 30° to the right of the camera to produce an image of averted gaze. To avoid any unintended differences in head angle or other aspects of the face, Adobe Photoshop was used to cut-and-paste the averted gaze stimuli into the very same face context used for the direct gaze stimuli, separately for frontal and deviated head-angles (e.g., see Fig. 1 for the resulting four stimuli for one of the 34 photographed people). Each face was carefully centred in the image frame so that the edge of the nose between the two eyes (where faces are usually fixated at first glance; Jeffreys *et al.*, 1992; Yarbus, 1967) always fell in the same location for frontal faces and for deviated faces. No additional fixation point was presented.

Four further stimuli were then generated for each

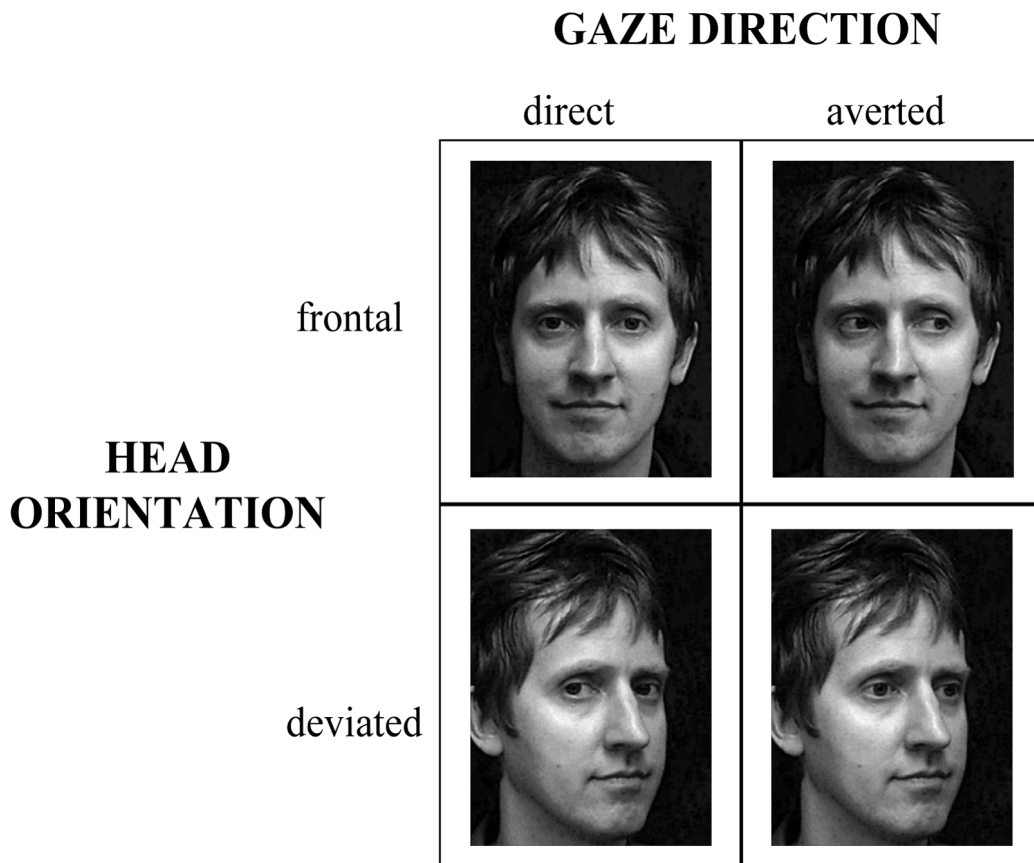


FIG. 1. Example stimulus for each of the four experimental conditions.

face, by using Photoshop to mirror-image those already obtained, so that any deviation in gaze and/or head-angle was now toward the left rather than right in the mirror-images. Our analyses pool over mirror-images, to yield four main conditions in a 2×2 -factorial design, with gaze direction (direct or averted by 30°) as one factor, and head angle (frontal or deviated by 30°) as the other orthogonal factor.

In the MRI scanner, stimuli were backprojected onto a screen via an LCD video-projector, and subjects viewed the projections via a mirror angled at 45° on top of the head-coil. This resulted in a viewing distance of approximately 30 cm. The visual angle subtended by

the face stimuli was about 13° horizontally and 16° vertically.

Procedure

To minimize irrelevant time-effects and time-by-condition interactions within the imaging data, all stimuli (the 34 different faces, each in 8 different views) were first presented to the subject in a random order, outside the scanner, while the gender categorisation task was practiced. The timing of stimulus presentations and the task itself were exactly the same as for the subsequent scanning session.

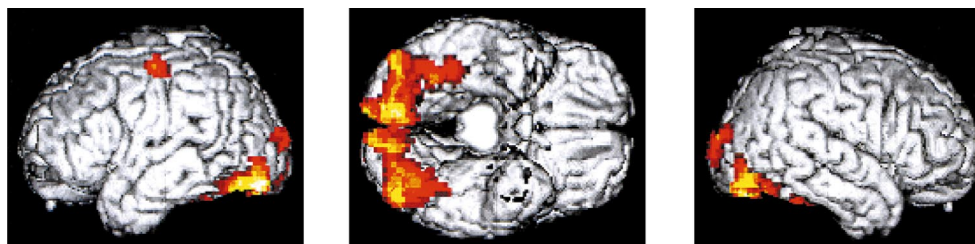


FIG. 2. Activations yielded by all face conditions minus the fixation baseline. These activations are superimposed on the surface of a T1-weighted template, shown under three views: left lateral, ventral, and right lateral; the activated voxels shown passed $P < 0.05$ corrected in the group analysis and were found at $P < 0.0001$ uncorrected in every subject.

Scanning involved blocked presentation of stimuli. The eight subconditions (i.e., the four main conditions, further divided by mirror-imaging of the stimuli) were presented in different random orders across subjects. Stimulus presentation blocks alternated with a low-level blank-screen baseline. The presentation blocks lasted for 41 s, baseline blocks for 20.5 s.

During each stimulation block, all 34 stimuli (i.e., each different face, for one particular condition) were presented once, for 700 ms each, with an interstimulus interval of 492 ms. A different random order of the 34 possible stimuli was used within each block, for each subject. The subject was instructed to fixate centrally and in the stimulation conditions to judge whether each stimulus depicted a male or female face, with a two-alternative button-press response. Half the subjects gave the female response with the index finger and the male response with the middle finger of their right hand; this was reversed for the other half. The gender task ensured attention to the visual stimuli across the entire experiment, but did not enforce any idiosyncratic strategies concerning gaze direction, which was task-irrelevant (indeed unmentioned) throughout.

A Siemens VISION system at 2T acquired both T1 structural and gradient EPI T2* BOLD-contrast images of the entire brain volume (48 transverse, ascending $3 \times 3 \times 3$ -mm slices; TR = 4.1 s; TE = 40 ms). A total of 252 functional images were acquired per subject, in two sessions, and the first 6 vol of each session were discarded to eliminate magnetic saturation effects. This left 240 vol distributed in 10 vol per stimulation block and 5 vol per baseline block. Image processing and statistical analyses used SPM97d (<http://www.fil.ion.ucl.ac.uk/spm>). The imaging time series was realigned, spatially normalized to the stereotactic space of Talairach and Tournoux and smoothed with a Gaussian kernel of 10-mm full-width half maximum.

Statistical Analyses

Data analysis first removed low-frequency drifts in the signal plus global changes in activity. The five different stimulation conditions (full or deviated faces, looking ahead or sideways, plus baseline) were then modelled as boxcar functions, convolved with a hemodynamic response function. Specific effects were tested by applying appropriate linear contrasts to the parameter estimates for each condition, resulting in a *t* statistic for each voxel. When transformed to *Z* statistics, these provide statistical parametric maps. We performed fixed-effect group analyses. As stated earlier, our main hypothesis was that direct gaze would modulate activation by seen faces in occipitotemporal cortices. Significance levels are reported uncorrected for the critical comparisons within these brain regions, given our *a priori* hypotheses. For other brain regions,

correction for multiple comparisons (within the SPM approach, which corrects for comparison at multiple voxels taking into account the smoothness of the data) was conducted where indicated.

Analysis of "Functional Connectivity" (Condition-Dependent Coupling between Brain Areas)

As described below, the initial analysis revealed bilateral fusiform regions modulated by gaze direction. To identify any brain region whose activity covaried differentially with fusiform activity, depending on gaze direction, we performed a further analysis with SPM97d. As the percentage of signal change and its variance were greater in the right than the left fusiform gyrus, we took the time series of the maximally activated right fusiform voxel, adjusted to remove low-frequency drifts, global changes in the signal, and, more importantly, with condition-specific mean response now also removed. The latter eliminates any correlation between areas driven by the stimulus itself, ensuring that the functional-connectivity analysis reveals only differential coupling between brain areas for residual variance. (This is important, as otherwise brain areas might appear to be coupled when in fact they were independently driven by the stimulus, rather than by each other; see Friston *et al.*, 1997). The resulting residual time series of fusiform activity, under the direct and averted gaze conditions, were introduced as supplementary covariates of interest in the design matrix modelling the data. Specific contrasts allowed tests for differential coupling with the fusiform gyrus under different conditions of gaze direction across the whole brain, by means of multiple regression analysis.

RESULTS

The rate of correct responses (%CR) was high for all blocks and all subjects (mean = $95.8 \pm 1.2\%$). Overall mean reaction time (RT) was 564.8 ± 40.6 ms. There was no significant effect on these measures of head orientation, nor of gaze direction, and no interaction between head orientation and gaze direction (for %CR, all $P > 0.20$; for RT, all $F[1,6] < 1$).

Faces versus Baseline and the Effect of Gaze Contact on Brain Activations

We first compared all face conditions against the low-level baseline, to reveal activations during judgments of the face stimuli. As expected, this comparison yielded activation in the ventral visual pathway, extending from occipital peristriate into midfusiform cortices bilaterally (Fig. 2). The activation extended more anteriorly in the right fusiform, to include regions where face-selective responses have been reported in many previous fMRI studies (e.g., Dolan *et al.*, 1997;

TABLE 1

Area	Coordinates	Z	P
(A) Main effect of direct vs averted gaze, across head angles			
Right fusiform gyrus	48, -57, -18	2.89	0.002
Left fusiform gyrus	-45, -45, -24	3.00	0.001
Additional activation			
Right cerebellum	36, -48, -33	3.27	0.001
(B) Main effect of frontal vs deviated head, across gaze directions			
Posterior striate and early extrastriate region (V1/V2)	27, -84, 6	3.20	0.001
Additional activation			
Left motor cortex	-36, -12, 57	3.10	0.001

Halgren *et al.*, 1999; Haxby *et al.*, 1999; McCarthy *et al.*, 1997; Puce *et al.*, 1996; Tong *et al.*, 2000). Activation of left motor cortex was also observed in the comparison with baseline, due to the manual (right hand) response required by the gender task. All these activations exceeded a corrected significance level of 0.05 in group analysis and were highly consistent across subjects (see Fig. 2 legend). Further activations were also observed in striate cortex, left supplementary motor area, inferior medial cerebellum, bilateral dorsolateral prefrontal regions and intraparietal sulci, and in discrete part of the right ($x63, y-42, z3$) and left ($x-48, y-48, z12$) STS; these reached corrected significance level in group analysis but were less consistent across subjects. Our subsequent contrasts in the initial SPM analysis used the comparison of all face-conditions versus baseline (thresholded at $P < 0.0001$) as a mask, to restrict further interrogation of the data to task-responsive brain areas driven when processing the face stimuli.

Our main hypothesis was that since faces with direct gaze constitute a more salient and socially relevant stimulus than faces with averted gaze (Gibson and Pick, 1962; von Grünau and Anston, 1995), they should produce stronger activation in the occipitotemporal regions that process faces, since faces with direct gaze should be processed more deeply and/or receive more attention. For this to be a true effect of seen gaze direction, rather than just a response to low-level stimulus properties (e.g., symmetry, which holds only for direct gaze in a frontally viewed face), the predicted effect of seen gaze direction should be found regardless of seen head orientation, with stronger fusiform responses for direct gaze in both frontal and deviated faces. This hypothesis was tested by examining the main effect of gaze direction (direct vs averted), regardless of head orientation. This yielded bilateral activations in limited regions ($n = 21$ voxels in the right hemisphere, and $n = 6$ voxels in the left) at the lateral border of the fusiform gyrus (Table 1A and Fig. 3).

This activation was maintained even when masked by the two simple effects of gaze direction (i.e., for

direct gaze within frontal faces, and also for direct gaze within deviated faces with both masks set at 0.05; note that adding these masks can only make our analysis more conservative). Moreover, testing for any interaction between gaze direction and head orientation yielded no reliable activation, and no modulation of fusiform activity. Likewise, there was no main effect of face orientation within the fusiform. The main effect of head orientation (frontal vs deviated face) activated only earlier posterior visual regions in striate and early extrastriate cortex (V1/V2; Table 1B).

Functional Connectivity: Areas Showing Differential Coupling with the Fusiform Gyrus for Direct versus Averted Gaze

The results so far reveal a modulation of fusiform activity as a function of seen gaze direction. A further question is whether fusiform activity shows differential coupling with other brain areas, as a function of seen gaze direction. To address this, we performed a second analysis that tested for condition-dependent changes in the correlation between the residual BOLD response in the right fusiform gyrus, and the fMRI signal measured in all other brain areas (see Methods). When regressing the activity of each voxel across the whole brain on the activity of the right fusiform gyrus, it was found that this fusiform region showed significantly greater coupling with the right periamygdalar region, under the straight than the averted gaze condition. This condition-dependent coupling peaked in right anterior temporal cortex ($x24, y12, z-27, Z = 3.16, P < 0.001$) and extended into the right anterior amygdala. At lower threshold, a similar context-dependent coupling was observed in left amygdala ($x-18, y6, z-24; Z = 2.22, P < 0.02$). This interaction between gaze condition and the coupling of particular brain regions was examined further, by examining the correlation between fusiform and amygdala activity for direct gaze, and for deviated gaze, separately. For direct gaze, the relationship with fusiform activity was significant in the right periamygdala region ($x24, y12, z-27, Z = 5.79, corrected P < 0.001$), extending into the right amygdala itself ($x18, y3, z-21$), as well as in the left amygdala ($x-18, y6, z-21; Z = 4.93, corrected P < 0.05$). By contrast, no such correlation between activity in the fusiform gyrus, with activity in amygdala or periamygdala regions, was observed for the averted-gaze conditions, even at a lowered threshold of 0.01 uncorrected (see Fig. 4).

Testing for the reverse direction of condition-dependent coupling with fusiform activity (i.e., stronger coupling for averted than direct gaze), revealed coupling with the right intraparietal sulcus ($x24, y-60, z54; Z = 3.38, P < 0.001$), and the dorsal medial cerebellum ($x-3, y-66, z-18; Z = 3.20, P < 0.001$), but not with amygdala or periamygdala regions.

DISCUSSION

This experiment used fMRI to investigate how neural activity associated with face processing may be modulated by seen gaze-direction, in particular by direct gaze regardless of seen head orientation. We found that specific regions of the fusiform gyrus yielded stronger responses to faces when these looked directly at the subject, regardless of whether the face itself was seen in a frontal or deviated view. Many previous studies have shown that face stimuli produce fusiform activity (Clark *et al.*, 1998; Dolan *et al.*, 1997; Grady *et al.*, 1995; Halgren *et al.*, 1999; Haxby *et al.*, 1999, 1996, 1991; Kanwisher *et al.*, 1997; McCarthy *et al.*, 1997; Puce *et al.*, 1996; Sergent *et al.*, 1992). More recently, it has been shown that the fusiform response can be sensitive to recognition of individuals (Gauthier *et al.*, 2000, 1999; George *et al.*, 1999; Sergent *et al.*, 1994, 1992), and is stronger for attended faces (Wojciulik *et al.*, 1998). The stronger activity found here, for faces with direct gaze, may therefore be interpreted in terms of enhanced attention and deeper encoding for faces with direct (relative to averted) gaze, due to the social significance of gaze contact (Argyle and Cook, 1976; Baron-Cohen, 1995; Gibson and Pick, 1962; Kleinke, 1986).

Indeed, as mentioned earlier, the face context needs to be fully encoded in cases of direct gaze, in order to attribute the correct meaning to the eye-contact (e.g., aggression, attraction, a desire to communicate, or mild interest; Argyle, 1982; Kleinke, 1986). The enhanced fusiform response we found for faces gazing directly at the subject may be the neural correlate of this. Note also that, since all stimuli had already been seen once prior to scanning (see Method), deeper encoding of faces with direct gaze during the practice session might conceivably have induced better recognition memory for such faces, which might also contribute to the observed effect on fusiform responses for faces with direct gaze. It would be interesting to supplement the present fMRI findings with behavioural measures of face recognition, as a function of gaze direction at initial exposure, in future research.

Could attention to peripheral locations in the averted gaze conditions provide an alternative account for our main finding? This seems unlikely, as if attention was driven away from the face in the averted-gaze condition, one might expect worse performance in the gender task for this condition, which was not observed. Similarly, eye-movements by the subjects do not provide a plausible account for our main fMRI finding, since eye-movement structures were not activated differentially by seeing direct versus averted gaze, and nor were early retinotopic visual areas.

The activation for direct gaze was found regardless of whether the face was seen in frontal or deviated view. This makes functional sense, since direct gaze is

always a potent cue to becoming the focus of someone else's attention, regardless of their head angle. Moreover, our result agrees with single-cell findings (Perrett *et al.*, 1992, 1985) that sensitivity to gaze direction can override cues from head orientation. While making considerable sense in this respect, our result is nevertheless striking when one considers that changing the orientation of the face from frontal to deviated is a very substantial alteration to the visual input, much more so than for the subtle differences in the eye regions for different gaze directions. Moreover, direct-gaze stimuli have little in common physically, even within the eye region, across frontal and deviated head-orientations (see Fig. 1); yet we found a similar response to direct versus averted gaze for both types of face, in the fusiform gyrus (see Fig. 2). This suggests that the fusiform modulation by direct gaze has more to do with the psychological significance of direct eye-contact, than with any low-level stimulus properties. Our use of different face orientations allows us to generalize beyond a single view, and thus beyond a particular stimulus property (such as symmetry, which applies for direct gaze only in frontal views).

The similar response in the fusiform for frontal and deviated faces may appear to conflict with recent psychological findings of complex interactions between gaze direction and head direction in experiments on orienting in the direction of seen gaze (Hietanen, 1999; see also Langton, 2000). However, as noted above, our finding may be related to the social significance of gaze contact in particular, which is independent of head orientation, while the previous behavioural studies of orienting (e.g., Hietanen, 1999) were concerned with how averted gaze may cue peripheral locations, not with the response to direct gaze. Moreover, our result is consistent with previous imaging work showing generalisations across different views of faces (e.g., Tong *et al.*, 2000), and also with McCarthy *et al.*'s (1999) observation, in their recordings from implanted electrodes in epileptic patients, that the amplitude of the face-selective N200 is similar for full-face and three-quarter views of faces. In the present study, we found a difference between frontal and deviated views of faces only in early posterior visual cortex, presumably caused by the substantial differences in low-level visual properties of the stimulus for these very different views. Note, however, that there were no such early, posterior occipital activations for the comparisons of faces with direct versus averted gaze. Such stimuli differ only subtly in terms of their low-level physical properties, around just the eye regions; moreover, any such differences vary across frontal and deviated head angles. By contrast, the biological significance of direct gaze holds regardless of head angle.

No previous study has reported that the response in fusiform regions can be modulated by the gaze direction of seen faces, being stronger for direct than

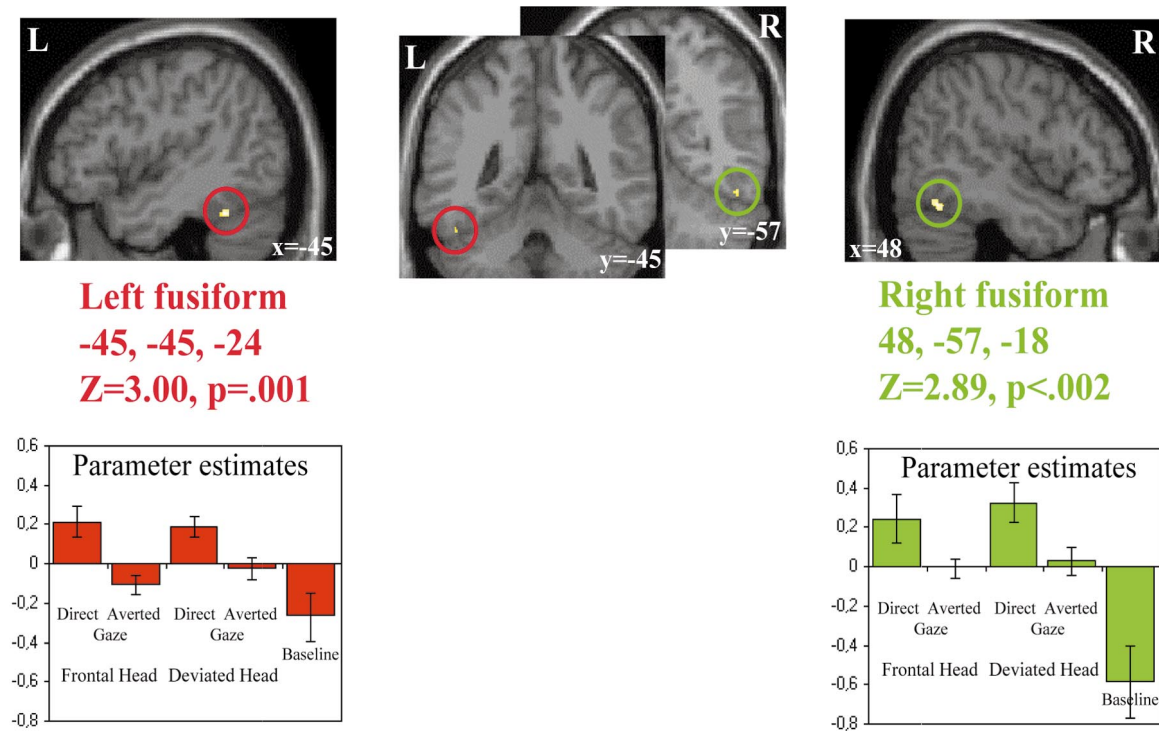


FIG. 3. Fusiform gyrus responses to direct versus averted gaze in face stimuli. Upper part: Responses in the left and right fusiform are shown on coronal and sagittal sections of a T1-weighted template through the maxima of activation, circled in red and green, respectively, together with the Talairach coordinates of these maxima and the corresponding Z and P values. Lower part: Parameter estimates of the activity in the maxima, showing estimates of mean-corrected percent signal change (relative to the overall mean activity at each voxel), averaged across repetitions and subjects, for the 4 conditions: direct or averted gaze, each in frontal or deviated face views. Bars indicate standard errors across the seven subjects for each condition and hemisphere. Left and right graphs are for the left and right hemisphere, respectively.

averted gaze as we observe. The methodological details of previous studies may explain this. Several previous studies of brain responses to gaze stimuli used recursively moving stimuli, which may be more likely to recruit areas specialized in movement processing, rather than the ventral pathway encompassing the fusiform gyrus. Moreover, many previous studies used only limited numbers of faces. For example, one PET study examining neural responses to eye-contact used just a single videoed face repeatedly (Kawashima *et al.*, 1999). If, as we suggest, the enhanced fusiform response found here is caused by deeper encoding of faces in situations of direct gaze, then this may not arise when exactly the same face is presented on every single trial, leading to habituation. In the present study, 34 different male and female faces were used and there was no repetition of any face within each block. Only Hoffman and Haxby's (2000) second experiment presents some similarities with ours in this respect. However, they used a passive viewing task, while we used a gender discrimination task that may have highlighted the deeper encoding and/or increased attention devoted to faces with direct versus averted gaze. Furthermore, their analysis of fusiform responses averaged together the responses of all regions of the fusi-

form showing greater activations to faces than control (scrambled nonsense) stimuli. This may have obscured modulations of fusiform responses by gaze within specific subregions of the fusiform. Finally, and importantly, Hoffman and Haxby (2000) concentrated on responses to averted (relative to direct) gaze, rather than the converse.

Some previous studies (e.g., Hoffman and Haxby, 2000; Puce *et al.*, 1998; Wicker *et al.*, 1998) suggested that the STS region may be particularly involved in extracting seen gaze direction. While this region showed some activity in the comparison of all our face conditions against the low-level baseline, it was not activated by our critical comparisons of different face conditions. This may have arisen for several possible reasons. We used static stimuli while Puce *et al.* (1998) and Wicker *et al.* (1998) used moving stimuli, and STS may be part of a network involved in processing biological motion (see Bonda *et al.*, 1996; Puce *et al.*, 1998). All our displays included gaze stimuli, with either of two possible head orientations, and STS may include neurones tuned not only to many different gaze directions but also to different head views (Perrett *et al.*, 1994, 1992, 1985). If so, it is possible that individual neurones within the STS did respond to the gaze

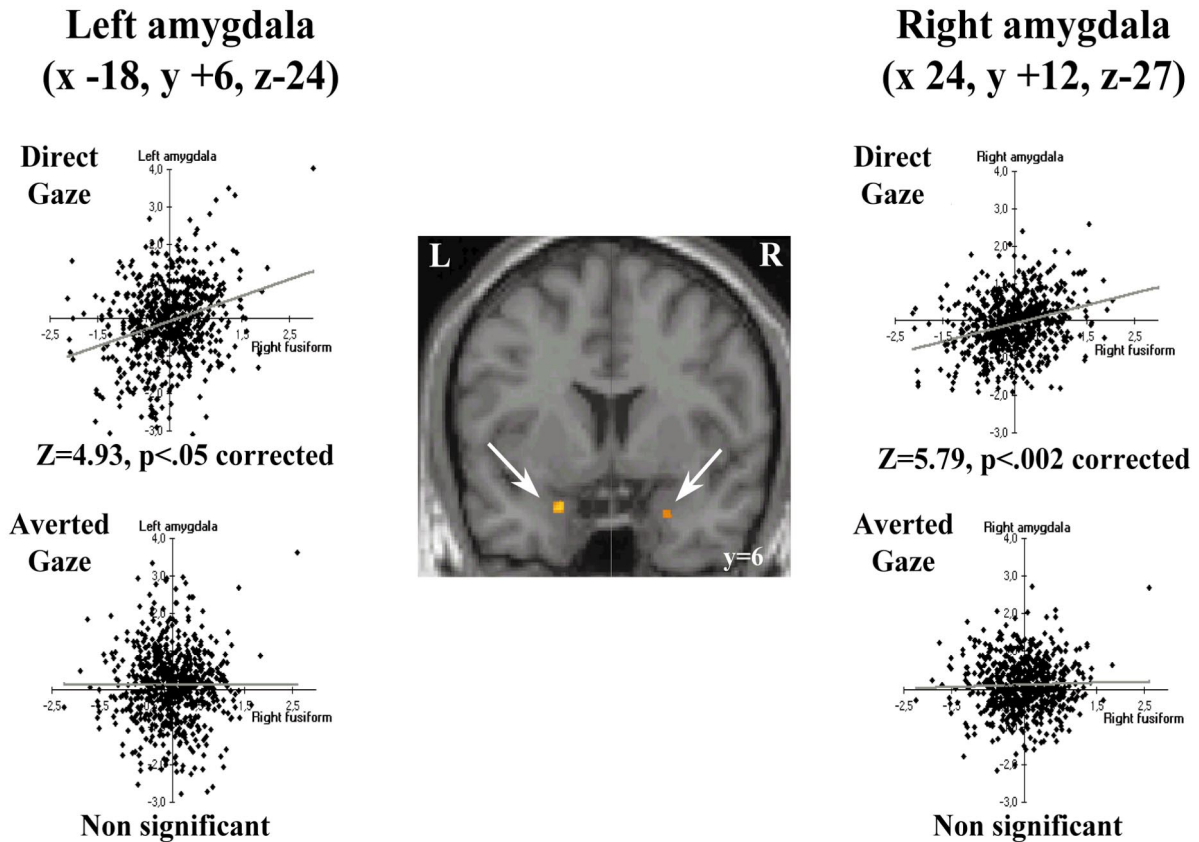


FIG. 4. Display of the increased coupling between the fusiform and the amygdala activity under the direct relative to the averted gaze condition. Bilateral amygdala activity is presented on a coronal section of a T1-weighted template and arrowed. Note that a low threshold for display was used in order to visualise the left as well as the right amygdala activation in this section. On the left and right of the figure, graphical displays illustrate the condition-dependent coupling between the amygdala and fusiform. The upper graphs present the correlation between fusiform and bilateral amygdala activity under the direct gaze conditions. The correlation coefficients are 0.32 and 0.45 for the right and left amygdala, respectively; corresponding Z and corrected P values are given. The lower graphs present the correlation between fusiform and bilateral amygdala activity under the averted gaze conditions. The correlation coefficients are 0.04 and -0.004 for the right and left amygdala, respectively; corresponding Z values were nonsignificant even at a lower threshold of 0.01 uncorrected.

stimuli in our study, but that the population response of the STS, as indexed by fMRI, might not have differed for the different conditions we compared. Finally, unlike most previous studies, we focused on the effect of direct (versus averted) gaze. STS activation has never been reported for direct gaze, minus averted gaze, so its absence here may be unsurprising (see also Kawashima *et al.*, 1999).

In addition to the overall comparison of direct versus averted gaze, regardless of head orientation, a further aim of our experiment was to investigate how gaze direction may influence the functional connectivity (Friston *et al.*, 1997) between the activated fusiform regions, and other brain areas. That is, we anticipated that gaze direction might not only modulate the response to faces within the fusiform, but also modulate how activity within the fusiform covaried with activity elsewhere. Interestingly, although there was no simple effect of seen gaze direction in the amygdala region, our results revealed functionally specific coupling be-

tween the fusiform gyrus and the amygdala, for direct relative to averted gaze conditions.

The amygdala is known to be involved in processing stimulus salience, and associated rewards and emotion (especially for the case of fear; e.g., Adolphs *et al.*, 1995, 1994; Hamann *et al.*, 1999; Morris *et al.*, 1997, 1996; Schoenbaum *et al.*, 1998; Zalla *et al.*, 2000). It has been shown to be involved in processing facial expressions (Adolphs *et al.*, 1995, 1994; Breiter *et al.*, 1996; Hariri *et al.*, 2000; Morris *et al.*, 1996, 1998a; Young *et al.*, 1996), and more generally in social evaluation of faces (Adolphs, 1999; Adolphs *et al.*, 1998) and inferences about mental state from seen eyes (Baron-Cohen *et al.*, 1999). The increased coupling between the fusiform and amygdala observed here, for the case of direct gaze, extends such findings. It suggests links between brain regions processing a face as a visual object (the fusiform), and those extracting the affective significance of that face (the amygdala). These links evidently become particularly important in cases of direct gaze,

presumably because such gaze is a frequent precursor to social interaction and thus the assessment of possible threat (see Introduction; and also Argyle, 1982; Emery, 2000). Note that reciprocal anatomical connections are known to exist (Amaral *et al.*, 1992) between the ventral visual pathway, including the fusiform, and the amygdala, which could subserve this coupling. As in the study of Kawashima *et al.* (1999), our results also provided some evidence for a stronger role of the right than left amygdala in situations of direct gaze (see Morris *et al.*, 1998b, for further evidence on possible laterality of amygdala function in relation to “covert” effects of stimulus valence, as for the task-irrelevant gaze direction here).

Finally, our analysis of functional connectivity showed stronger coupling between right fusiform and intraparietal sulcus, for the case of averted rather than direct gaze. The intraparietal sulcus is associated with spatial perception and spatially directed attention to peripheral locations (Corbetta, 1998; Corbetta *et al.*, 2000, 1998, 1993; Mishkin *et al.*, 1983; Nobre *et al.*, 1997; Van Essen *et al.*, 1992; Wojciulik and Kanwisher, 1999). Gaze deviation by another person is a potent cue for shifting one’s own spatial attention towards where they are looking (e.g., Driver *et al.*, 1999). In agreement with Hoffman and Haxby (2000) proposals, parietal activity may be related to such shifts. Our analysis further suggests that such gaze-driven shifts of attention may involve a coupling between ventral regions that process the face as a visual object (e.g., the fusiform) and more dorsal regions that control the direction of spatial attention (e.g., the intraparietal sulcus).

In conclusion, our results show that seen gaze direction can modulate activity in the fusiform gyrus, with stronger activation for faces with direct gaze, regardless of seen head orientation. We attribute this to increased deployment of face-processing resources in the ventral occipitotemporal cortices when gaze-contact indicates the likelihood of imminent social interaction. Furthermore, analyses of condition-dependent functional connectivity suggest that the network engaged in face processing can dynamically change its coupling between brain areas as a function of seen gaze direction, with greater fusiform–amygdala coupling for direct gaze, and greater fusiform–parietal coupling for averted gaze.

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