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RESEARCH ARTICLE

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The inversion effect on gaze perception reflects processing of component information

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Abstract When faces are turned upside-down they are much more difficult to recognize than other objects. This "*face* inversion effect" has often been explained in terms of configural processing, which is impaired when faces are rotated away from the upright. Here we report a "*gaze* inversion effect" and discuss whether it is related to configural face processing of the whole face. Observers reported the gaze locations of photographed upright or inverted faces. When whole faces were presented, we found an inversion effect both for constant errors and observer sensitivity. These results were closely replicated when only the eyes were visible. Together, our findings suggest that gaze processing is largely based on component-based information from the eye region. Processing this information is orientation-sensitive and does not seem to rely on configural processing of the whole face.

Keywords Features · Featural information · Configural information · Gaze perception · Face perception · Inversion effect

Introduction

Our ability to identify the direction of another person's gaze is important for our social interactions. For example, being looked at can have various meanings, which must be interpreted and understood by an observer. In a seminal study, Gibson and Pick (1962) examined spatial perception of the line of gaze. Observers decided whether or not a "looker" who was sitting directly in front was looking into the observer's eye or at a peripheral target. The authors reported an exquisite ability to distinguish between direct eye contact and gaze directed to peripheral targets when they were a few degrees off to the observer's side. Taking the standard deviation of the distribution of all "yes" answers as a measure of threshold, Gibson and Pick (1962) found that an angular deviation of the eye by only 2.8° was readily detected. This remarkable result has been replicated and extended in several further studies (e.g. Anstis et al. 1969; Cline 1967; Gale and Monk 2000; Masame 1990). For example, Cline (1967) used a half-silvered mirror to provide the looker with a view of a variety of targets and the observer with a full view of the looker's face. Target points were aligned with the bridge of the observer's nose or deviated either vertically or horizontally, requiring an angular rotation of 2, 8, or 12° of the looker's eye. Cline reported even greater sensitivity for gaze-direction processing than Gibson and Pick (1962), estimating that an angular deviation of the looker's eyes of 0.75° was readily detected by an observer. Accuracy of peripheral gaze discrimination was significantly smaller and dropped further when the looker's head was turned 30° to the right. This latter result could indicate that eye-related information is not the only source of gaze direction interpretation. Instead, configural cues from a looker's face might be taken into consideration when gaze locations are computed by the observer. By turning the looker's head away from the observer, however, the manipulation of eye and face information had been confounded in Cline's (1967) study.

Anstis et al. (1969) avoided this confound by presenting faces on a television screen and rotating the screen's surface out of the frontal plane. They found that turning the TV screen did not have the same impact as turning the head of the looker. Turning the looker's head to one side caused a perceived gaze deviation in the opposite direction, whereas turning the TV screen

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caused a deviation in the same direction. This evidence supports the findings of Cline (1967) and of Gibson and Pick (1962) who also reported that the looker's head position had an effect on perceived gaze direction. The results do not, however, clarify the relative contributions of face versus eye processing to gaze direction perception, because the video-mediated gaze cues may have introduced additional factors that do not contribute to real life gaze perception. Gale and Monk (2000) recently addressed this concern. They presented lookers to their observers both face-to-face and on a TV screen and found that video-mediated stimuli were just as effective for gaze localization as face-to-face stimuli. These observations indicate that an investigation of gaze perception with two-dimensional gaze information is ecologically valid (see also Symons et al. 2004).

Gale and Monk (2000, p. 586) distinguished three types of gaze awareness—full, partial, and mutual gaze awareness. They defined full-gaze awareness as "the knowledge of what object in the environment someone is looking at" and partial gaze awareness as "the knowledge of only the general direction someone is looking in". Finally, mutual gaze awareness refers to the knowledge of being directly looked at. Most of the previous work on gaze perception has focused on our ability to distinguish mutual from partial gaze awareness. The cognitive mechanisms relevant for full-gaze awareness are less well understood than those for the other two types of gaze awareness. This is surprising, given the importance of identifying peripheral gaze-lines for allocating one's own attention or for the attribution of mental states (Baron-Cohen 1995a, b; Lee et al. 1998).

What visual information from a looker's face is used to compute gaze direction and, eventually, to acquire full-gaze awareness? Several studies suggest that the anatomy of the human eye must be (at least partly) responsible for gaze interpretation. As the pupil and the iris are embedded in the white sclera, the proportion of the contrasting colors yields reliable information about the angular deviation of the eyeball (Anstis et al. 1969; Cline 1967; Gibson and Pick 1962; see also Ando 2002; Langton et al. 2000). Comparison of the external eye morphology of a large number of primates shows that eyeballs with contrasting iris and sclera are unique to humans (Kobayashi and Kohshima 1997, 2001a, b). This suggests that local features such as the iris/sclera ratio are influential components of gaze perception (Ando 2002), although more global cues, for example head orientation, are also taken into account (Anstis et al. 1969; Cline 1967; Gibson and Pick 1962, Langton et al. 2000). A recent study by Symons et al. (2004) clarified that full-gaze awareness depends on target eccentricity, is unaffected by whether or not the preceding eye movement is observed, and utilizes information from both of the looker's eyes.

To further evaluate the relative contributions of different types of facial information to gaze perception, a clear definition of what we mean by configural, holistic, component, and featural information is necessary. According to Bruce (1988, p. 38) the term "configural information" refers to the "spatial interrelationship of facial features". Diamond and Carey (1986) distinguished between two types of configural information: First-order relational information refers to the basic arrangement of the parts whereas second-order relational information means specific metric relations between features such as the inter-eye distance or the eye-mouth distance. The term "holistic" has sometimes been used to describe configural information as defined above. But according to Farah et al. (1995) and Tanaka and Farah (1993), the term "holistic" refers to representations that store a face as an unparsed perceptual whole without specifying its parts explicitly. Thus, there is no broad consensus in the literature on face processing regarding the terms "configural information" or "configural processing" (for a similar view see Maurer et al. 2002). In this study we will use the term "global configural information" for the interaction between facial features and their spatial relationship. This term entails the concept of holistic information and second-order relational information without distinguishing between them. In contrast with such global configural information we will use the term "component information" for local elements, which are perceived as distinct parts of the face, such as the eyes, mouth, nose, cheeks, forehead, chin, etc. (Carey and Diamond 1977; Sergent 1984). The term "featural information" has been used for describing the same type of information (for recent reviews see Rakover 2002; Schwaninger et al. 2003a).

Face processing is very orientation-sensitive: upside-down faces are disproportionately more difficult to recognize than inverted versions of other object classes. This has been referred to as the "face inversion effect" (Yin 1969; for a review see Valentine 1988). Many studies have provided converging evidence that turning faces upside down results in an impairment of global configural information (as defined above) whereas the processing of component information is much less—if at all—affected by orientation (Leder et al. 2001; Nachson and Shechory 2002; Searcy and Bartlett 1996; Sergent 1984; for reviews see Maurer et al. 2002; Rakover 2002; Schwaninger et al. 2003a; Valentine 1988). At least for processing of configural information there are substantial differences in perception versus recognition. Schwaninger et al. (2003b) found large overestimations of the inter-eye and the eye–mouth distance in upright faces. These overestimations remained unaffected when faces were presented upside-down. Because, in face *recognition*, configural processing is strongly impaired in inverted faces, the results of Schwaninger et al. (2003b) indicate that configural information is processed differently in perception and recognition of faces.

In this study, we examined whether there is a "gaze-inversion effect" and how it relates to component information contained in the eyes and global configural information from the face context. If gaze processing relies on the same system used for face recognition we would expect a gaze-inversion effect for whole faces but not when eyes are presented in isolation. Alternatively, it could be argued that gaze perception relies on a separate system that processes component information contained in the eyes. If such a system is dependent on perceptual learning, an inversion effect would also be expected, because faces are usually seen upright. If the gaze localization system relies mainly on component information, the gaze-inversion effect would be comparable for whole faces and eyes presented in isolation. In other words, there would be a gaze-inversion effect that is due to processing component information but independent of global configural information from the face context.

Method

Participants

Eighteen observers (13 females, five males), ranging in age from 20 to 34 years participated in this experiment. All reported normal or corrected to normal vision. After the experiment, participants were paid £5. They were naïve with regard to the hypotheses under investigation.

Apparatus

The experiment was run on a Pentium PIII 500E computer using custom-made software running on Windows 98. Participants were seated on a height-adjustable chair at a distance of 50 cm from the screen and were required to keep their head still by using a headrest. They used a standard QWERTY extended keyboard and a serial mouse.

Stimuli

The faces of four models (two females, two males) were used to ensure the results were not stimulus-specific and would generalize across faces. A specially designed box consisting of two horizontal, parallel boards, 400 mm apart, was used to manipulate gaze direction. On each of the boards two fixation targets were marked (top left, top right, bottom left, and bottom right). These fixation points were 220 mm apart at a distance of 350 mm from a headrest which ensured that the lookers kept their head absolutely still while fixating the four different target points with their eyes. Eye level corresponded to the optical axis of the camera and was exactly half way between the two boards (200 mm above the bottom board). The actual viewing distance between the eye and each target was therefore 418 mm. Five photographs were taken frontally of each model: one with eyes closed and one gazing at each of the four targets. The gaze line deviated from a straight gaze (into the camera) by 29.74° either up or down, and 32.15° left or right.

For the whole-face condition these images were then modified in two steps. First the closed eyes were superimposed on each of the directed gazes to create neutral images. Then all targets were erased from the stimuli. The final pictures measured 317×260 mm (899×737 pixels), the face being between 59 and 65 mm wide. The resolution of the image was 28.35 pixels cm^{-1}. Because observers were tested at a viewing distance of 50 cm the faces subtended between 6.75 and 7.44° horizontally. Sample stimuli are shown in Fig. 1. The stimuli for the eyes-only condition were generated from the same photographs used in the whole-face condition (Fig. 2). The eyes were cut out in elliptical shape using slightly blurred boundaries. The rest of the face was

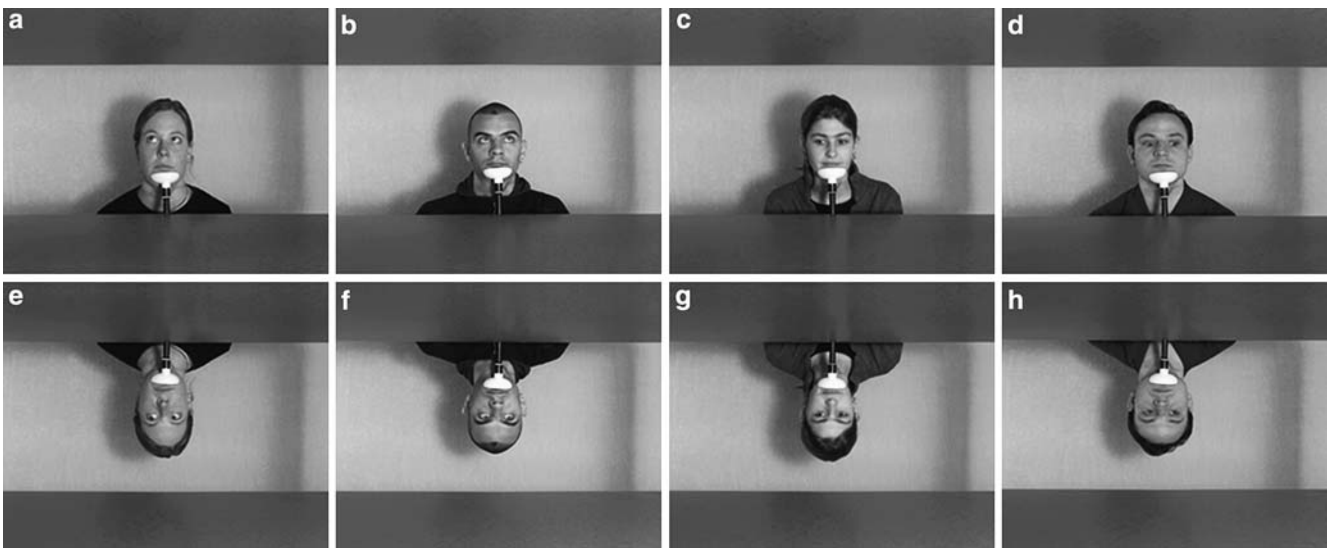

Fig. 1 Examples of stimuli used in the whole-face condition: **a**–**d** upright, **e**–**h** inverted (vertical flip). Original stimuli were in color

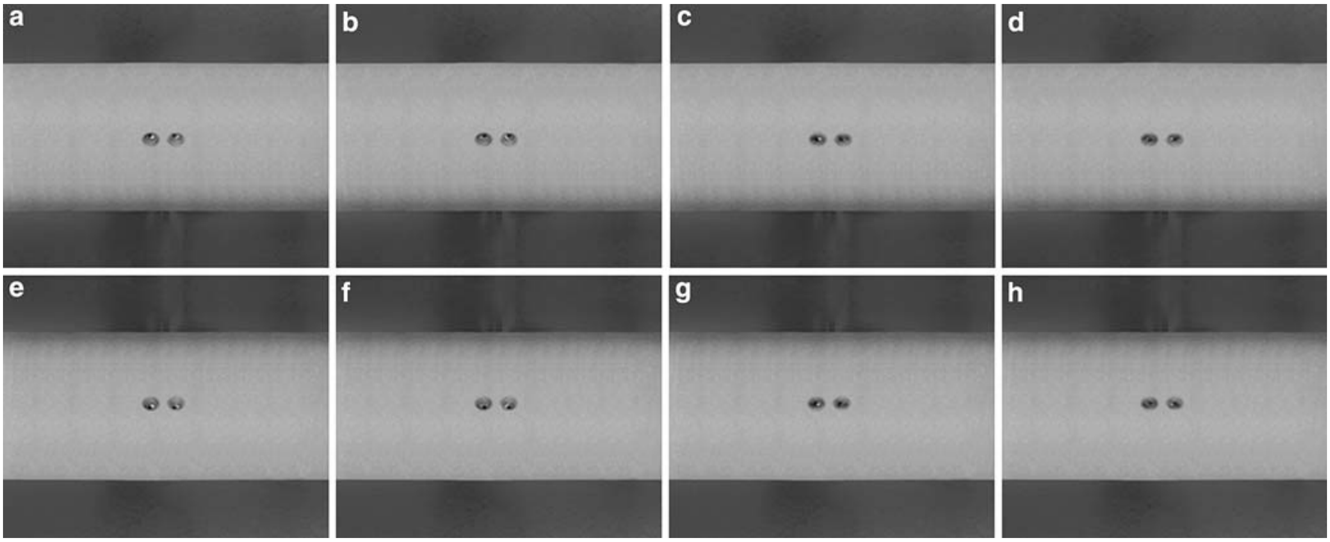

Fig. 2 Examples of stimuli used in the eyes-only condition: **a–d** upright, **e–h** inverted (vertical flip). Original stimuli were in color

hidden by superimposing a gray background corresponding to the rest of the background. All stimuli appeared upright and inverted. Inverted stimuli were created by a vertical flip (i.e. a mirror reversal and not a 180° rotation).

Task and procedure

All observers gave informed consent and information about their gender, age, and preferred hand. They then received written instructions. The experimenter made sure the observers understood the task before they underwent eight practice trials encompassing all experimental conditions. None of the stimuli used in the experiment proper was used in the practice trials. In the whole-face condition each trial began with the appearance of a stimulus face with closed eyes. After 1000 ms this neutral image was replaced by a photograph of the same person looking at one of the targets, which were not visible. At the same time a crosshair cursor appeared at a random location on the screen. Using the mouse with their preferred hand, observers located the cursor precisely at the perceived fixation location on the screen and confirmed their judgments by pressing the space bar with their other hand. This was done to reduce variability in judgments because of mouse button pressing. The computer program recorded the selected location and the next trial started. In the eyes-only condition the procedure was exactly the same but stimuli were presented with the eyes in isolation (Fig. 2). After 32 trials it was possible for the observers to take a short break. The length of the break was self-paced and participants started the next set by pressing the space bar.

Design

Half of the observers were tested in the whole-face condition, the other half in the eyes-only condition. Each observer underwent 10 blocks of 32 trials each (four faces, four gaze locations, and two face orientations). The order of trials was randomized online for each block.

Analyses

For each trial the errors in x and y dimension were computed by subtracting the veridical coordinates and the judged coordinates from each other, so that positive values represent overestimations (i.e. outward errors) and negative values represent underestimations (i.e., errors towards the center). These error values in the x and y dimension were averaged across faces to eliminate item-specific biases in the data. Less than 0.5% of the trials were discarded before analysis because of trial lapses.

Constant errors, i.e. systematic deviations from veridical, were estimated by calculating the mean of all errors in the x and y dimension. Constant errors were first calculated for each face across repetitions and then averaged across faces. The data were subjected to a multivariate analysis of variance (MANOVA) with the between-groups factor face information (whole face, eyes only), and the within-participants factors orientation (upright, inverted), vertical direction (up, down), and horizontal direction (left, right).

As a measure of observer sensitivity, standard deviations of adjustment errors were calculated for each gaze location. For each participant the standard deviations were first calculated for each face across repetitions and

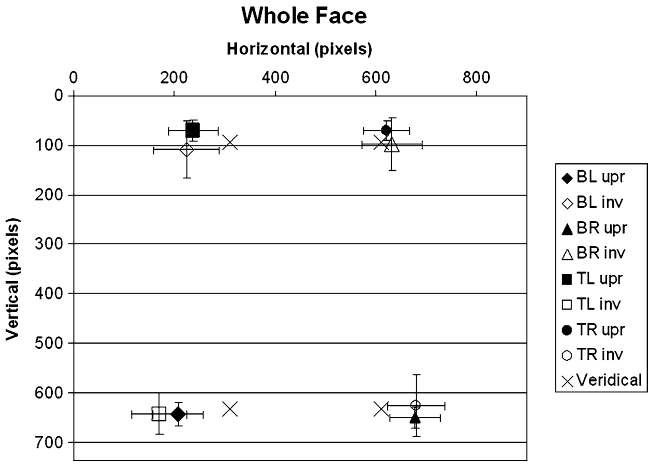

Fig. 3 Mean estimated gaze localizations for whole faces, with standard deviation of means. (*TL upr* top left upright, *BL upr* bottom left upright, *TR upr* top right upright, *BR upr* bottom right upright, *TL inv* top left inverted, *BL inv* bottom left inverted, *TR inv* top right inverted, *BR inv* bottom right inverted; *Veridical* true target location.) The coordinates are stimulus-based. Note that in this study inverted means a mirror reversal and not 180° rotation

then averaged across faces. Again, these data were subjected to a MANOVA with the same design as above.

Results

Means of location judgments and standard deviations are shown in Fig. 3 (whole-face condition) and Fig. 4 (eyes-only condition). Note that stimulus-based coordinates have been adopted to facilitate comparisons between localizations of identical gaze positions for upright and inverted faces. For example, top left location judgments made in the inverted conditions appear next to the bottom left location judgments in the upright conditions, both of which appear in the bottom left corner of our figures.

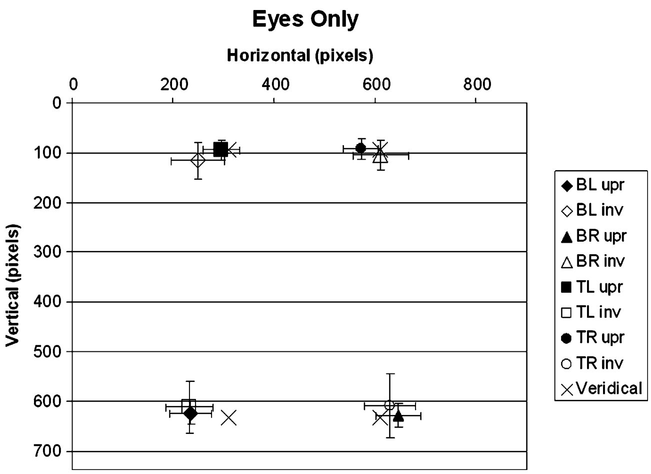

Fig. 4 Mean estimated gaze localizations for eyes only with standard deviation of means. (*TL upr* top left upright, *BL upr* bottom left upright, *TR upr* top right upright, *BR upr* bottom right upright, *TL inv* top left inverted, *BL inv* bottom left inverted, *TR inv* top right inverted, *BR inv* bottom right inverted; *Veridical* true target location.) The coordinates are stimulus-based. Note that in this study inverted means a mirror reversal and not 180° rotation

Constant errors

The MANOVA revealed a significant inversion effect as reflected by the main effect of orientation, $F_{(2,15)}=7.72$, $P<0.01$. This effect was similar for the whole-face and eyes-only conditions, because there was no effect of group, $F_{(2,15)}=2.67$, $P=0.10$ and there were no interactions involving this factor (whole-face versus eyes-only).[1] The main effect of horizontal direction (left versus right) was significant $F_{(2,15)}=25.05$, $P<0.001$. The main effect of vertical direction (up versus down) was not significant $F_{(2,15)}=1.22$, $P=0.23$. From the six two-way interactions only two were significant: vertical direction×orientation, $F_{(2,15)}=13.99$, $P<0.001$, and horizontal direction×orientation, F $(2,15)=4.52$, $P<0.05$.

Standard deviations (sensitivity)

Again, a significant inversion effect was found as revealed by the main effect of orientation, $F_{(2,15)}=14.11$, $P<0.001$. This effect was again similar for the whole-face and eyes-only conditions, because there was no effect of group, $F_{(2,15)}=1.64$, $P=0.23$. Replicating the pattern obtained for constant errors, no interaction involving information type (whole face versus eyes only) achieved statistical significance for standard deviations (sensitivity). [2] The main effect of vertical direction was significant $F_{(2,15)}=4.02$, $P<0.05$. The main effect of horizontal direction was not significant $F_{(2,15)}=0.31$, $P=0.74$. No interactions of the within-participants factors reached statistical significance.

[1] *Constant errors*: Vertical direction×group: $F_{(2,15)}=2.484$, $P=0.117$, horizontal direction×group: $F_{(2,15)}=0.506$, $P=0.613$, orientation×group: $F_{(2,15)}=.219$, $P=0.806$, vertical direction×horizontal direction×group: $F_{(2,15)}=0.568$, $P=0.579$, vertical direction×orientation×group: $F_{(2,15)}=0.291$, $P=0.752$, horizontal direction×orientation×group: $F_{(2,15)}=0.468$, $P=0.635$, vertical direction×horizontal direction×orientation×group: $F_{(2,15)}=0.089$, $P=0.916$.

[2] *Standard deviations*: Vertical direction×group: $F_{(2,15)}=0.698$, $P=0.513$, horizontal direction×group: $F_{(2,15)}=0.987$, $P=0.396$, orientation×group: $F_{(2,15)}=0.721$, $P=0.502$, vertical direction×horizontal direction×group: $F_{(2,15)}=0.692$, $P=0.516$, vertical direction×orientation×group: $F_{(2,15)}=0.335$, $P=0.721$, horizontal direction×orientation×group: $F_{(2,15)}=0.985$, $P=0.396$, vertical direction×horizontal direction×orientation×group: $F_{(2,15)}=0.451$, $P=0.645$.

Discussion

This study investigated the visual information required for full-gaze awareness. Observers indicated the perceived gaze locations of upright and inverted faces. Very similar effects of inversion were found for whole faces and for eyes presented in isolation. This result was obtained for constant errors and for observer sensitivity, as measured by individual standard deviations. These results clearly show that full-gaze perception is orientation-sensitive. Such orientation sensitivity in face perception signals the processing of component information while being largely independent of global configural information originating from the face context. Thus, we conclude that gaze perception relies heavily on component information.

At first sight, the results of our study seem to be incompatible with recent findings by Jenkins and Langton (2003). Using the method of constant stimuli they compared perceived gaze location for a single face that was either upright or inverted, while the orientation of its eye region was independently manipulated. They found that sensitivity for gaze direction was severely affected when the eyes were inverted, and that this effect was independent of the orientation of the face context. The authors suggested that inversion disrupts configural processing that is involved in computing the eye-gaze direction.

There are, however, several important methodological differences between our study and that of Jenkins and Langton (2003). They investigated eye-gaze direction discrimination whereas we measured eye-gaze location judgments. They worked with the method of constant stimuli whereas we adopted the method of adjustments. We tested the effects of orientation within participants using four faces whereas they tested it between participants and using only a single face. However, the most important difference between the two studies is in the definition of configural processing. Note that the Jenkins and Langton (2003) concept of configural processing in the perception of eye-gaze direction differs from our definition of global configural processing. The configural mechanism proposed by Jenkins and Langton (2003) is restricted to analyzing relational information in the eye region and computes the rotation angle of the eye. The authors take no position on whether "this configural mechanism relies on abstract representations of the relative location of various eye features, or non-componential holistic representations" (p. 1187). In short, our own results and the study by Jenkins and Langton (2003) show: (1) that there is a gaze-inversion effect, and (2) that this effect is because of orientation-sensitive processing of the eye region.

Whereas we used the term component information for the eye region they suggest that the eye region is processed by some kind of configural process, which is different from global configural information provided by the face context. Although both studies used different methods and measured different aspects of full-gaze awareness, they come to very similar conclusions and thus provide converging evidence for the view that full-gaze awareness relies on an orientation-sensitive mechanism to analyze the information contained in the eye region.

This study differs in two important aspects from previous work on face recognition. First, the inversion effect in face recognition is usually explained by the processing of global configural information, which is strongly impaired or disrupted when faces are turned upside down (Farah et al. 1995; Leder et al. 2001; Searcy and Bartlett 1996; for recent reviews see Maurer et al. 2002; Schwaninger et al. 2003a). In contrast, both our study and Jenkins and Langton (2003) showed that global configural information provided by the face context is not relevant for the gaze-inversion effect. Second, many face-recognition studies showed that component information processing is much less—if at all—affected by inversion (Leder and Bruce 2000; Leder et al. 2001; Searcy and Bartlett 1996; for recent reviews see Rakover 2002; Schwaninger et al. 2003a). This contrasts with results from Jenkins and Langton (2003) and our study which provide converging evidence for the view that the gaze-inversion effect results from processing information from the eye, i.e., component information.

These differences are consistent with the assumption of a separate system for processing gaze. Single-cell recording studies have revealed that cells responsive to facial identity are found in inferior temporal cortex whereas selectivity to facial expressions, viewing angle, and gaze direction can be found in the superior temporal sulcus (Hasselmo et al. 1989; Perret et al. 1992). On the basis of results from neurophysiology and neuroimaging, Haxby et al. (2000, 2002) proposed a distinction between the representation of invariant and changeable aspects of faces. Processing invariant aspects forms the basis for recognizing individuals and is mediated by face-selective regions in the lateral fusiform gyrus. The processing of changeable aspects entails information that facilitates social communication, i.e. the processing of gaze, emotional expression, and lip movement. This latter system is mediated by a face responsive region in the superior temporal sulcus.

An interesting question for future research will be whether these systems rely on component or configural information. The inversion effect in face recognition seems to result from orientation-sensitive processing of global configural information. In contrast, the gaze-inversion effect seems to be based on processing the eye region itself (component information). Because both face recognition and eye gaze processing require complicated computations it seems reasonable to assume that they have to be learnt through perceptual experience. Because faces are usually seen upright an inversion effect would result if the processed information is orientation-sensitive. This explains both inversion effects even though they result from processing different types of information.

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