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Brief article

Orienting of attention via observed eye gaze is head-centred

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Abstract

Observing averted eye gaze results in the automatic allocation of attention to the gazed-at location. The role of the orientation of the face that produces the gaze cue was investigated. The eyes in the face could look left or right in a head-centred frame, but the face itself could be oriented 90 degrees clockwise or anticlockwise such that the eyes were gazing up or down. Significant cueing effects to targets presented to the left or right of the screen were found in these head orientation conditions. This suggests that attention was directed to the side to which the eyes would have been looking towards, had the face been presented upright. This finding provides evidence that head orientation can affect gaze following, even when the head orientation alone is not a social cue. It also shows that the mechanism responsible for the allocation of attention following a gaze cue can be influenced by intrinsic object-based (i.e. head-centred) properties of the task-irrelevant cue.

Keywords: Object-centred attention; Eye gaze

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1. Orienting of attention via observed eye gaze is head-centred

The orienting of attention to the same feature of the environment to which another person is oriented is known as 'joint attention' (Emery, 2000; Moore & Dunham, 1995). Several recent investigations into the effect of observing nonpredictive averted gaze cues have shown consistent advantages for reaction time to targets presented in the cued (i.e. gazed-at) location (Driver et al., 1999; Friesen & Kingstone, 1998; Hietanen, 1999). This tendency to orient to the direction of another's attention has been posited as vital to

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the development of effective social interactions, language, and theory of mind (Baron-Cohen, 1995; Charman et al., 2001; Moore & Dunham, 1995).

The way that the perception of eye gaze and faces is integrated in such cueing paradigms is of great interest. In the human brain, the superior temporal sulcus seems to be involved in the perception of gaze (Wicker, Michel, Henaff, & Decety, 1998), while separable areas of the inferior occipital lobe and fusiform gyrus are involved in the processing of face identity (Hoffman & Haxby, 2000). The manner in which the face of an agent may be integrated with eye gaze perception has been investigated by studying how the perception of eye gaze is modulated by perceived head orientation in behavioural (Gibson & Pick, 1963; Hietanen, 1999, 2002; Langton, 2000), and in neurophysiological studies (Perrett, Hietanen, Oram, & Benson, 1992; Perrett, Smith, Potter et al., 1985).

Perrett et al. (1992) showed that cells in macaque superior temporal sulcus, coding for gaze direction and head orientation were involved in the perception of social attention, and found that gaze direction was the dominant factor in determining neural response. That is, head orientation was only important when the eyes were obscured, and cells responding to head orientation were actively inhibited when the eyes were visible. However, Langton, Watt, and Bruce (2000) suggest that head and gaze interact as more “equal partners” (p. 56). For example, Langton (2000) presented behavioural evidence that suggested that perceived head orientation influenced the perception of eye gaze. When reporting the direction of gaze (left or right), participants’ RTs were slower when head orientation was incongruently oriented with the direction of gaze, compared with when the head and eyes pointed in the same direction. Furthermore, direction of gaze interfered with the perception of head orientation in the same way. These studies have looked at the influence of head orientation on the perception of social attention, or the effect of head and eye gaze on attention. However, these studies did not present the head in orientations that do not directly act as a cue to social attention, and thus they do not investigate pure object-centred interactions between eye direction and head orientation, since both are cues to attention. However, the use of isomorphically rotated faces (90 or 180 degrees of rotation in the picture plane) has the potential to investigate the role of head orientation on eye gaze perception, without the orientation of the head serving as an additional attentional cue, but as the context for object-centred representations.

The influence of object-centred representations on attention is well demonstrated by studies on visual neglect. Driver and Halligan (1991) studied a patient with right temporo-parietal damage, leading to neglect of left space. Same–different judgements about objects were impaired in this patient if the distinguishing feature of the objects appeared in the left side of space. However, if the objects were rotated 45 degrees about their principal axis, such that the distinguishing feature was now on the right side of space (hence in the ‘good’ visual field), performance was still poor, because the distinguishing feature was still on the left side of the object (see Tipper & Behrmann, 1996, who showed similar object-centred effects). These studies demonstrate that attention can operate in multiple frames of reference.

There is also behavioural evidence for object-centred representations of faces presented in unusual orientations affecting the processing of targets appearing on faces. Hommel and Lippa (1995) showed that responses to targets presented on a face, were influenced by whether the face was presented rotated 90 degrees clockwise or 90 degrees anticlockwise.

That is, when judging whether a visual target appeared in the upper, or lower part of the display, with left and right key presses, response facilitation was found when the targets appeared in locations congruent with required response, in a head-centred frame of reference. For example, if a target appearing in the upper part of the display required a left keypress, then the response would be facilitated to a target appearing over the left eye in a face appearing rotated clockwise. A target appearing in the upper part of the display would result in a slow left key response if the face appeared rotated anticlockwise, since the target would appear over the right eye, and would thus be incongruent in head-centred terms. These head-centred effects were small, in comparison to standard stimulus–response compatibility effects (7 ms, Hommel & Lippa, 1995), however, they were successfully replicated by Proctor and Pick (1999). These effects suggest that the intrinsic head-centred representations of faces can affect the coding of stimuli on the face. That is, the left side of the face is encoded, at least in part, as the left side however it is oriented in space (see also, Young, Hellawell, & Welch, 1992). Indeed, some STS cells do code faces in object-centred coordinates (Hasselmo, Rolls, Baylis, & Nalwa, 1989; Perrett, Smith, Mistlin et al., 1985).

The notion that the processing of unusually oriented faces is less fluent than that of upright faces is well established (Bartlett & Searcy, 1993; Yin, 1969). This may explain why studies have shown disrupted social cueing of attention by faces presented upside-down (Kingstone, Friesen, & Gazzaniga, 2000; Langton & Bruce, 1999). This could be because two simultaneously active reference frames are in direct opposition: a spatial frame could cue attention to the direction of gaze based on simple spatial coordinates, while a competing object-centred frame could bias attention to the opposite side of space. This study aimed to test this hypothesis not by opposing these two frames, but by separating them, by presenting faces oriented 90 degrees from upright, rather than 180 degrees (see Fig. 1). This meant that the object-centred frame would act on the horizontal axis, perpendicular to the spatial frame acting on the vertical axis.

Hence, might a face presented rotated 90 degrees anticlockwise still cue attention to the left, even though the eyes are actually looking *down* (see Fig. 1, upper panel b)? Faces presented in this way are unlikely to be cues to attention themselves (Moore, Angelopoulos, & Bennett, 1997), only providing the object-centred context for the gaze cue. Two tasks were used to test the hypothesis: in one group, participants were required to make a keypress response when the target appeared, and another group was required to make a saccadic eye movement to the target location. Both response types have previously shown strong effects of gaze cueing (Friesen & Kingstone, 2003). If ‘head-centred’ cueing effects are indeed found, then as well as providing further support for object-centred encoding of faces, it would suggest that the influence of social cues such as gaze can be modulated by object-centred representations of the face that produces that cue.

2. Method

2.1. Participants

A total of sixty-one adults participated in the experiment. Twenty-five adults (mean age: 19.4 years; two males) were assigned to the ‘manual detection’ group. Thirty-six

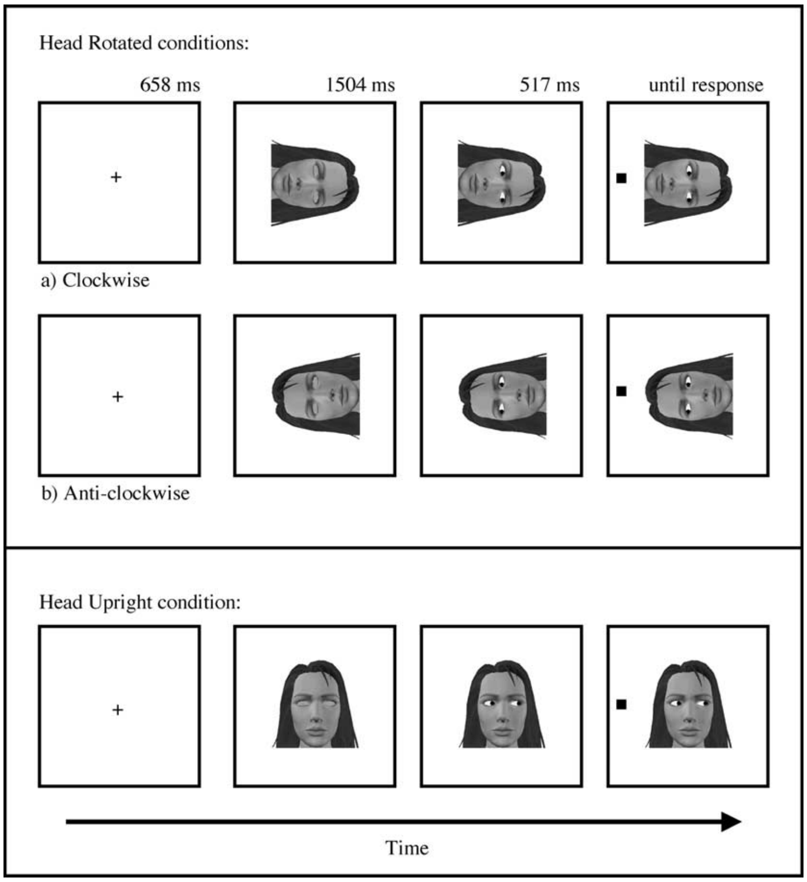

Fig. 1. Upper panel shows (a) an invalid clockwise trial, (b) shows a valid anticlockwise trial (note the true direction of gaze in both (a) and (b) is down, and the target appears on the left). Lower panel illustrates an invalid trial normal 'upright' condition. Targets could also appear on the right.

participated in the 'eye-movement' group, but eleven were excluded due to poor calibration ($n = 6$), high pre-target saccades ($n = 2$), erroneous saccades to targets ($n = 1$), and computer error ($n = 2$). The mean age of the remaining 25 participants (five males) was 19.3 years. Participants received course credit or payment, were naïve to the purpose of the experiment, and had normal or corrected-to-normal vision. Informed consent was gained in accordance with the guidelines of the School of Psychology, Bangor.

2.2. Apparatus

The digitized face measured 13.0 × 13.5 cm and was presented in the centre of the computer screen. The pupils were 0.8 × 0.8 cm in eye regions measuring 2.0 × 1.2 cm. Targets were small black squares, measuring 1.5 × 1.5 cm. Target locations were 12.5 cm from the centre of the screen, in line with the eyes of the stimulus face when presented in the upright orientation. Participants sat with their heads on a chin-rest approximately 60 cm from the screen. In order to record eye position and saccade data for participants in the 'eye movement' group, the EyeLink v.1 eye-tracking system (SensoMotoric Instruments/SR research) was used. The system uses infrared scleral reflectance to measure pupil diameter to determine angle of gaze with two cameras mounted on a headset securely placed on the participants head. Sampling rate was 250 Hz, for vertical and horizontal dimensions.

2.3. Design

The face could appear in one of three orientations (the within-subjects factor 'head orientation') rotated 90 degrees anti-clockwise, rotated 90 degrees clockwise, and also upright. The pupils could then appear in either the left or right of the eye in the upright condition, or upper or lower part of the eye in the face when oriented 90 degrees. The target could appear on the cued or the uncued side of space in head-centred coordinates (left or right of the screen; the within-subjects factor 'validity'). Whether participants responded with a key press or saccade was manipulated between-subjects.

2.4. Procedure

Participants were told that neither the direction of gaze, nor angle of head orientation predicted target location. Participants in the 'manual detection' group were asked to maintain fixation throughout each trial, and to respond to the target as quickly as possible with a press on the spacebar. Participants completing the 'eye movement' task were asked to maintain fixation until onset of the target, then look as quickly as possible to the target. The factors 'validity' (2) and 'head orientation' (3) produced six trial types, each repeated 40 times over the course of the experiment. After a practice block of twelve trials, four experimental blocks of trials were completed. In each block, sixty experimental and eighteen catch trials (no target, no response) were presented in a random order.

On each trial, a fixation cross was presented for 658 ms, followed by the presentation of the face, in the appropriate orientation, for 1504 ms, before the presentation of the gaze cue. The pupils were gazing for 517 ms before the presentation of the target (see Fig. 1). In the 'manual detection' task, after response, or 1974 ms, a blank screen was presented for 1269 ms. In the 'eye-movement' task, the blank screen would appear 600 ms after target onset. Responses on catch trials and misses were followed by an error beep. The 'manual detection' task took approximately 30 min to complete, and the 'eye-movement' task 45 min, due to the apparatus set-up, and drift correction procedures for calibration after every sixth trial.

3. Results

For the 'eye-movement' task group, saccadic RTs were defined as the time between onset of the target and the onset of the first saccade of at least 2.0 degrees of visual angle.

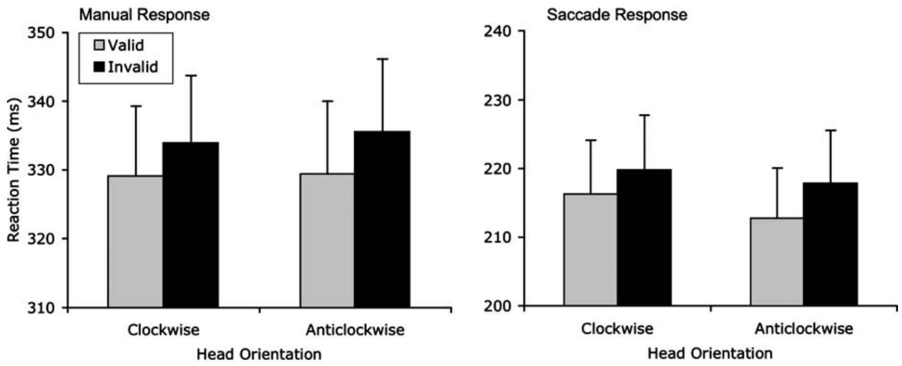

Fig. 2. Reaction times for each rotated head condition, with standard error bars. Each response group are plotted separately.

Trials were excluded if a saccade of more than 5.0 degrees (the approximate size of the stimulus eye-region) occurred during the cue period or if the response was in the incorrect direction (2.2% of trials, $SD = 3.5$). Responses quicker than 50 ms or slower than 600 ms were removed, followed by the removal of trials where RT was more than 2 *SD* outside the participants mean RT (4.2% of trials, $SD = 1.4$). For the ‘manual detection’ group, errors (0.1% of trials, $SD = 0.2$) and outliers (4.8% of trials, $SD = 1.4$) were removed, using the same filtering method, but with 150 and 1000 ms as cut-offs, due to the slower RTs found with manual detection tasks. Remaining trials contributed to each participants mean for each condition type (see Fig. 2).

The critical issue in this study was whether head-centred cueing effects could be observed. Therefore, analysis centred on the head rotated 90 degrees conditions.[1] To analyse the effect of cues presented in a rotated face, a mixed-factor ANOVA, with within-subjects factors of ‘Head Orientation’, ‘Validity’, and the Between-subjects factor of response mode, was undertaken. The main effect of ‘Response’ was significant, due to faster saccades (217 ms) than manual responses (332 ms), $F(1,48) = 82.5$, $p < .001$. Critically, the main effect of ‘Validity’ was highly significant, $F(1,48) = 13.1$ $p < .001$, with quicker RTs to valid (272 ms) than to invalid targets (277 ms). Furthermore, planned contrasts revealed that this effect was significant in both Clockwise face, $F(1,48) = 6.61$ $p = .013$, and Anticlockwise face, $F(1,48) = 7.02$ $p = .011$, conditions. No interactions approached significance, including the ‘Response’ by ‘Validity’ interaction, $F(1,48) < 1$. Furthermore, planned comparisons showed that both the manual detection, $F(1,24) = 7.87$ $p = .010$, and the saccade task, $F(1,24) = 5.28$ $p = .031$, revealed significant cueing effects.

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[1] Analysed separately, the Upright face produced the standard cueing effect, $F(1,48) = 21.6$, $p < .001$. Intriguingly, this cueing effect was weaker in the saccade task (valid = 216 ms, invalid = 221 ms) than in the manual detection task (valid = 321, invalid = 337 ms), $F(1,48) = 7.88$, $p = .007$. However, smaller cueing effects in saccade tasks have been noted previously (Friesen & Kingstone, 2003). Since this was not the focus of the study, and this interaction did not approach significance in the more important rotated head conditions, this will not be discussed further, but is of interest to further study. Saccades were faster than manual responses, $F(1,48) = 75.1$, $p < .001$.

4. Discussion

This study attempted to evaluate the hypothesis that a vertical (up or down) uninformative eye gaze cue, could act as an attentional cue to the left or right, if the cue is placed in the context of a face oriented 90 degrees anticlockwise or clockwise. The experiment reported here shows clear support for this hypothesis. Across two response types, cueing effects were small, but reliable when the face was rotated, even though the eyes never pointed towards the target, only up or down. This suggests that passively viewing a face rotated in this way, involves coding of the object in terms of its normal orientation. Furthermore, if an object contains a cue to attention, the direction of the attention shift can be in the direction of the cue according to the canonical view of the object.

This finding implies, in accordance with Hietanen (1999, 2002) and Langton (2000), that head orientation can influence the interpretation of the direction of eye gaze, and subsequent attention shifts based on signals of social attention. However, the new discovery here is that the head orientation need not itself be a cue to attention (as when the head is turned towards an object of interest). This suggests that head orientation is influential under all circumstances (i.e. when rotated in the picture plane), not just when it implies the direction of social attention. This view may explain findings of disrupted cueing towards the direction of gaze in a face presented upside-down (Kingstone et al., 2000; Langton & Bruce, 1999), since the directions cued in viewer- and head-centred frames are in direct opposition. In the present study, viewer- and head-centred frames are acting independently, allowing us to measure the influence of the head-centred frame in isolation. The face we present, in rotated conditions, is certainly not looking to the left or right, but we find consistent shifts of attention to the left or right in observers. The inhibitory model of Perrett et al. (1992) would also not predict the effects presented here, since, through inhibition, the head position should be rendered irrelevant to the attention system. As such, these findings suggest that object-centred representations can be influential in the perception of social attention.

The data presented here are, as far as we are aware, the first evidence for a gaze cue producing attentional facilitation for targets appearing in locations that are not gazed-at. This finding has a number of important implications for theory and future research. Firstly, it demonstrates that gaze cues can be affected by object-centred properties of the face. This effect may rely on ‘on-line’ mental rotation of the observed face, followed by an updating of the representation at the onset of the gaze cue, or a mechanism acting with reference to stored canonical representations of faces. It is clear that the mechanism that underlies the effect acts before attention is cued by eye gaze. Secondly, since nonpredictive arrows also effectively cue attention (Eimer, 1997; Ristic, Friesen, & Kingstone, 2002; Shepherd, Findlay, & Hockey, 1986; Tipples, 2002), it would be very interesting to investigate whether these effects might generalise to any symbolic cue embedded in any unusually oriented object, or if this effect is a gaze-specific phenomenon. Thirdly, this finding may have implications for the role of theory of mind in gaze cueing effects. Gaze interpretation enables one to access the internal attentional state of another, and thus helps the development of an internal model of the mental state of the observed person (Baron-Cohen, Wheelwright, & Jolliffe, 1997; Calder et al., 2002). In light of this, the orienting behaviour described here seems somewhat maladaptive. An efficient joint attention mechanism should not allow orienting to anywhere other than the absolute direction of gaze. This maladaptivity suggests that this effect emerges automatically[2] through the processing of the face in object-centred frames. It seems that the higher-level representation of 'where a person is (actually) looking', perhaps gleaned from representations of other minds, are not influential enough to prevent some degree of orienting based on object-centred representations. Clearly, gaze perception and the utilization of social cues rely on high- and low-level representations of the visual stimulus and of social context. Determining the relative influence of these representations in a variety of contexts is a central aim in the study of social cognition.

Thus it would seem that the interpretation of gaze cues is always affected by the context in which they are presented. Hence, implicit face processing must occur during the interpretation of eye gaze. This is certainly the case in other work where there is neural evidence for the integration of intentional (Jellema, Baker, Wicker, & Perrett, 2000) and emotional (Wicker, Perrett, Baron-Cohen, & Decety, 2003) states of the observed agent on the coding of eye gaze. The data reported here showing head-centred effects where the eyes are coded in the context of the face implies that the computation may involve an automatic mental rotation, or spatial normalization, of the rotated face to the canonical upright position (Lawson, 1999). Such a discovery has implications for a wide range of issues from object-based models of attention to social interaction driven by social gaze.

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[2] Previous studies have shown that even when gaze looks directly towards a target, the orienting of attention is automatic (e.g. Driver et al., 1999, antipredictive cues). Note that in the critical conditions in the present experiment, the eyes did not look towards a possible target location, but towards an orthogonal non-task related location. Hence, we doubt that subjects would attempt to monitor observed eye gaze direction in a strategic manner. In support of this, no participants reported "working out" the purpose of the rotated head conditions during debriefing. We thank an anonymous reviewer for raising this important point.

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