The Influence of Head Contour and Nose Angle on the Perception of Eye-Gaze Direction

Stephen R. H. Langton, Helen Honeyman and Emma Tessler

University of Stirling, Stirling, U.K

Address correspondence to: Dr. Stephen R. H. Langton, Department of Psychology, University of Stirling, Stirling, FK9 4LA, UK

Email: srhl1@stirling.ac.uk

Phone: (+44) (0)1786 467659

Abstract

We report seven experiments that investigate the influence that head orientation exerts on the perception of eye-gaze direction. In each of these experiments participants were asked to decide whether the eyes in a brief and masked presentation were looking directly at them or were averted. In each case the eyes could be presented alone, in the context of a congruent stimulus, or an incongruent stimulus. In Experiment 1a the congruent and incongruent stimuli were provided by the orientation of face features and head outline. Discrimination of gaze direction was found to be better when face and gaze were congruent than in both of the other conditions, an effect that was not eliminated by inversion of the stimuli (Experiment 1b). In Experiment 2a, the internal face features were removed but the outline of the head profile was found to produce an identical pattern of effects on gaze discrimination, effects that were again insensitive to inversion (Experiment 2b) and which persisted when the lateral displacement of the eyes was controlled (Experiment 2c). Finally, in Experiment 3a nose angle was also found to influence participants' ability to discriminate direct from averted gaze, but here the effect was eliminated by inversion of the stimuli (Experiment 3b). It is concluded that an image-based mechanism is responsible for the influence of head profile on gaze perception whereas the analysis of nose angle involves the configural processing of face features.

Gaze direction represents a biologically significant stimulus that demands rapid and precise discrimination. Indeed, researchers have long been interested in our particular sensitivity to eye direction and the social significance of gaze behaviours. However, there has been rather less interest in the perception of head orientation despite evidence suggesting that head angle can influence the perception of gaze (Anstis, Mayhew & Morley, 1969; Cline, 1967; Gibson & Pick, 1963; Maruyama & Endo, 1983, 1984; Wollaston, 1824). One exception to this is the work of Wilson, Wilkinson and Castillo (2000) who have recently suggested that humans make use of two cues to determine head orientation: deviation of head profile from bilateral symmetry, and the angle of deviation of the nose from vertical. The goal of the present paper was to marry the research on head perception with that of gaze perception to examine whether either, or both of these cues to head orientation are those that influence the perception of eye-gaze direction.

Gaze Perception

Another's eyes provide a rich source of social information concerning, for example, their owner's disposition towards you, their current emotional state, or whether it's your turn to speak in a conversation (for reviews see Baron-Cohen, 1995; Kleinke, 1986). However, the eyes also signal another biologically significant piece of information: the direction in which another's attention is directed. Humans and most other species tend to look at things in their environment which are of immediate importance to them; so you might be rewarded with another's gaze because of a lover's affection or perhaps because you look like a hearty meal. On the other hand, a shift in another's gaze away from you may signal the approach of a predator, prey, or an attractive conspecific (see Byrne & Whiten, 1991). Therefore, an efficient ability to detect a mutual gaze and to compute precisely where another's eyes are directed offers significant adaptive advantages. Indeed, research has shown that we are very efficient at searching for a direct gaze amongst averted gaze distracters – the so called “stare-in-the-crowd” effect (von Grünau & Anston, 1995) – whilst our particular sensitivity to gaze direction has been well established (Anstis, Mayhew & Morely, 1969; Cline, 1967; Gibson and Pick, 1963). Cline (1967), for example, found that humans could detect gaze deviations of just 1.4˚ at a distance of just over 1 m. Similarly, Anstis et al’s research indicated that humans can detect a displacement of the iris by as little as 1.8 mm from the same viewing distance. Moreover, there is some suggestion that this peculiar sensitivity may arise – at least in part – from the operation of functionally specific neural mechanisms (e.g., Perrett et al., 1985; Heywood & Cowey, 1992; Campbell et al., 1990; Hoffman & Haxby, 2000).

In terms of the cues we use to determine another’s gaze direction, researchers have traditionally emphasised the spatial or geometric information present within the eye region (e.g., Anstis et al., 1969). So, for example, the high contrast of the limbus (the junction between the sclera and the iris) could be easily located and compared to a fixed feature such as the corner of the eye (the canthus), or the nose. This would give a measure that is proportional to the angle of rotation of the eyeball in the head. However, there are other plausible non-spatial accounts of gaze perception. Watt (1999; see Langton, Watt & Bruce, 2000), for example, has argued that the cue to gaze direction might be the contrast in luminance between the two parts of the sclera on either side of the iris, making eye direction a simple measurement to perform on the image of the eye. In support of this account, Watt found that sensitivity to gaze direction did not vary with viewing distance up to a cut off point beyond which, presumably, the relevant luminance cues could not be resolved (see also Lord & Haith, 1974). An account based on the geometry of the eye, on the other hand, would predict that performance should deteriorate with increased viewing distance.

The results of a recent study by Ricciardelli, Baylis and Driver (2001) could also be interpreted as offering support for an image-based account. They showed that judgements of gaze direction were highly impaired when the normal contrast polarity of the eyes was reversed so that the sclera appeared to be much darker than the iris. In a similar way, Sinah (2000) contrived the so-called “Bogart Illusion” where contrast negation of a photograph of the eponymous actor’s face caused an apparent reversal of his gaze direction. Finally, in Ando’s “bloodshot illusion” a bias in participants’ gaze judgements was induced by darkening one side of the sclera without shifting the actual location of the iris (e.g., Ando, 2002). Of course, neither contrast negation nor the darkening of the sclera affect the spatial relationships between the “features” of the eye suggesting that a geometrical mechanism cannot be entirely responsible for normal judgements of gaze direction.

The Perception of Head Orientation

Logically, determination of another’s direction of gaze must be based not only on the angle of rotation of the eyeball – however it is computed – but also on the direction in which the head is oriented (Wilson et al., 2000, but see Langton, et al, 2000). For example, if the iris is located close to the left hand corner of a gazer’s eye, this might mean the gazer is looking to your (the viewer’s) right, but if – in addition – their head is rotated to your left, their gaze might then be oriented directly into your eyes.

The importance of head orientation as a cue to attention direction is evident in research in developmental psychology, comparative studies with non-human primates and recent experimental work with human participants. Infants are able to follow a change in their mother's head and eye orientation from 3 – 6 months of age (Scaife & Bruner, 1975; Butterworth & Jarrett, 1991), but it is not until 14 – 18 months that they show any indication of following the eyes alone (Moore & Corkum, 1998). Prior to this, it seems as though children actually ignore the orientation of the eyes and simply use the position of the head as an attention following cue (Corkum & Moore, 1995). By and large, non-human primates – the non-ape species in particular – also use head orientation as the primary cue to another individual's direction of attention (e.g., Emery et al., 1997; Itakura & Anderson, 1996). Experimental studies with human participants have indicated that head cues are able to trigger rapid and reflexive shifts of a viewer's spatial attention (Langton & Bruce, 1999) and are very difficult to ignore, even when attempting to respond to directional information presented auditorily (Langton, 2000; Langton & Bruce, 2000). Finally, single cell recordings of activity in the STS region of the macaque brain have revealed cells that are responsive to certain head orientations and body postures as well as to directions of eye-gaze (e.g., Perrett et al., 1985).

Despite the importance of the head as a cue to the direction of social attention, the perception of its orientation has received relatively little research. Recently, however, Wilson et al (2000) investigated humans' thresholds for discriminating head orientation and examined the cues with which we might make this discrimination. Their participants were able to perceive a change in head rotation from a base angle of 0˚ or 15˚ of as little as 1.9˚ and 2.1˚ respectively, with mean threshold falling off to 4.9˚ for a base head angle of 30˚. Furthermore, they showed that these thresholds were not significantly affected by removal of either the internal features, or the outline head contour suggesting that head orientation can be discriminated using either of these two equal-strength cues. Finally, by using surrogate nose and head shapes Wilson et al. established that, for the internal features, the deviation of nose angle from vertical is the likely source of head orientation information, and that the "external" cue is the deviation of the head contour from bilateral symmetry. To elaborate, when the head is oriented directly at you, its outline contour projects an approximately symmetrical shape about the vertical midline, and a line drawn from the bridge to the tip of the nose will be roughly vertical. As the head rotates, its shape becomes increasingly asymmetrical and the nose angle shifts away from vertical. Wilson et al's evidence suggests that the visual system is able to compute these deviations from bilateral symmetry and vertical angle, respectively, and use them as cues to the orientation of the head.

The Influence of Head Angle on Gaze Perception

Since the pioneering work on gaze perception carried out in the 1960's, it has been known that the perceived direction of eye-gaze can be influenced by the angle of rotation of the head which further attests to the importance of the head as a cue to attention direction. In general there seem to be two kinds of perceptual effects. First, under certain circumstances, the perceived direction of gaze can be "towed" toward the orientation of the head. In this case the direction of gaze is perceived to be somewhere between the angle of the head and the true line of regard of the eyes (Cline, 1967; Maruyama & Endo, 1983, 1984). This kind of effect was first recorded by William Wollaston as long ago as 1824 and is illustrated in his original drawings reproduced here, along with photographic versions, in Figure 1. The second kind of influence of head angle on the perception of gaze is a kind of "overshoot" or "repulsion" effect where an error in gaze perception is introduced in the *opposite* direction to the angle of rotation of the head. For example, imagine someone standing in front of you with their head 30˚ or so to your right and with their eyes either staring straight back at you, or back towards your left shoulder. Apparently, under these conditions, you might perceive their eyes to be gazing a little further to the left than they actually are (Anstis et al., 1969; Gibson & Pick, 1963).

Figure 1. Head orientation influences the perceived direction of gaze. The top two pictures are taken from Wollaston's original paper. Face B seems to be gazing directly at the viewer whereas Face A appears to be looking slightly to the viewer's right. By covering the lower and upper parts of each face you can see that the eye regions of both are, in fact, identical. The lower two faces illustrate a similar effect with greyscale images. The eye region from D has been pasted onto C where the head is rotated slightly to the viewer's left.

As described in the preceding section, Wilson et al's work suggests that humans are able to use head contour and nose angle to judge head orientation. However, it is not clear whether these are the cues which are actually used in practice and which will interact with information extracted from the eye region to yield the direction of gaze. Thus, the question that concerns us here is whether the cues used to judge head orientation are the same as those which influence the perception of gaze direction. In order to study this, we made use of the Wollaston illusion (see Figure 1). In Experiment 1 we first establish an experimental method for quantifying the illusion. Then in Experiments 2 and 3 we investigate whether head contour and nose angle, respectively, can produce a perceived shift of gaze. The basic design of all experiments was the same. Participants viewed brief masked presentations of eyes which were either directed towards them or were angled slightly to their left or to their right and their task was simply to decide whether the gaze was direct or averted. These eyes could be placed in one of several contexts: the head angle – as signalled by either the head and nose (Experiments 1a and 1b), the head outline alone (Experiments 2a, 2b and 2c) or the nose angle (Experiments 3a and 3b) – could be oriented in the same (congruent) or in a different (incongruent) direction to that of the eyes, or the head context could be absent altogether. We were then able to measure how well participants were able to discriminate direct from averted gaze under congruent, incongruent and absent conditions. Using this technique we were also able to examine whether a direct gaze could be "pulled" to one side by a comparison of hit rates (proportion of trials where participants correctly judged that a direct gaze was indeed oriented at them) in congruent and incongruent conditions. By making this same comparison using false alarm rates (proportion of trials where an averted gaze was incorrectly judged as being direct) as the dependent measure, we were also able to determine whether an averted gaze could be made to appear more direct by an incongruently angled head. Finally, we also examined whether each cue could influence the perception of gaze direction when the stimuli were rotated through 180˚, a manipulation considered to disrupt the configural or spatial/relational processing of faces.

Experiment 1a

Experiment 1 was conducted to establish an experimental paradigm for demonstrating that head angle, as signalled by both head contour and nose angle, can influence the perceived direction of gaze. Participants made gaze judgements in the context of greyscale images of heads oriented in congruent or incongruent directions to the eyes. In addition, we examined participants' ability to distinguish direct from averted gaze in the absence of any face context. If head orientation produces a towing effect as in the Wollaston illusion (Figure 1) we would expect performance to be poorer in incongruent compared to congruent conditions. Moreover, this reduction in overall discriminability should be caused by both a reduction in hit rates and an increase in false alarm rates in incongruent versus congruent conditions. We predicted that hit rates would be decreased because incongruent heads should produce an illusory shifting of a direct gaze, and false alarm rates increased as averted gazes will tend to be misjudged as being direct when accompanied by an incongruent, as opposed to a congruent head.

Method

Participants. These were 17 Open University students attending a summer school at the University of Stirling. All had normal or corrected-to-normal vision.

Materials and Apparatus. Digitised images of eyes gazing straight ahead, approximately 16˚ to the left, and 16˚ to the right were obtained from greyscale photographs of the face of a male individual with his head oriented forwards. These images all had the same shape (see Figure 2) and measured 3.8° wide by 1.3° in height. In addition, full face images of the same individual were obtained with his head oriented straight ahead, 16° to the left and 16° degrees to the right. These images subtended 7.1° of horizontal angle and 9.5° of vertical visual angle. The materials to be used in the congruent conditions of the experiment were obtained by pasting the three gaze stimuli onto the appropriately oriented head stimuli using Adobe Photoshop software. Thus, the leftward gaze from the full-face image was pasted onto the image of the head oriented to the left and so forth. A blending tool was then used to eliminate sharp lines so that the resulting face appeared smooth. Incongruent images were obtained by pasting the straight ahead gaze stimuli onto the left and right head images, and by pasting the left and right gaze stimuli onto right and left head images respectively. In this way the same direct and averted gaze stimuli could be presented either alone, in the context of a congruent head orientation, or an incongruent head orientation. Examples of the experimental stimuli are shown in Figure 2.

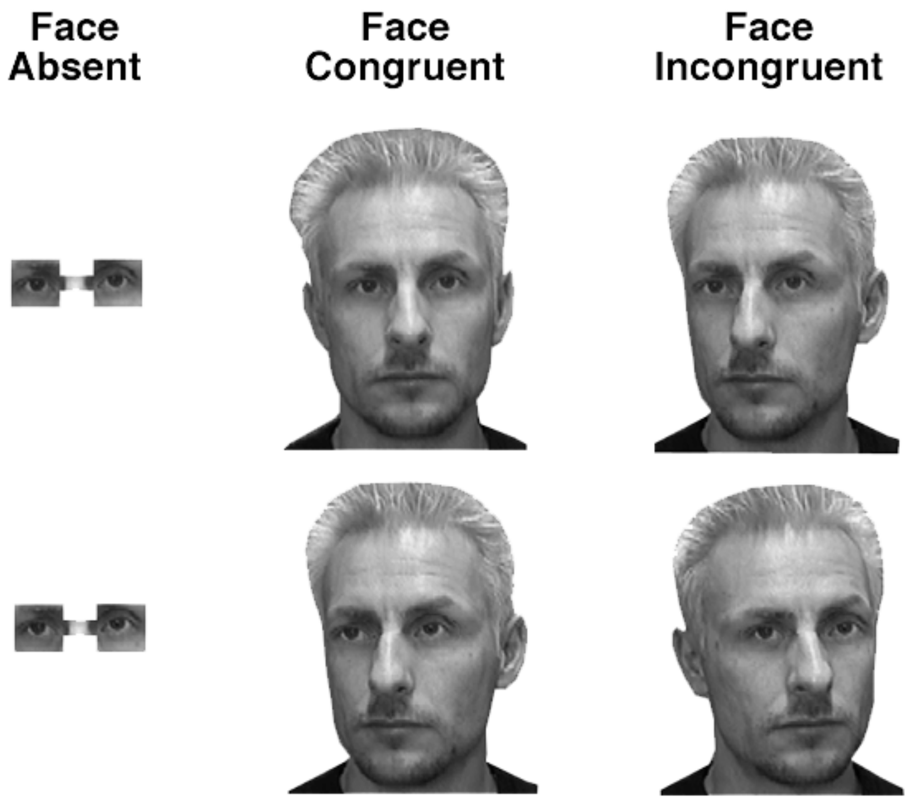

Figure 2. Reproductions of some of the stimuli used in Experiments 1a and 1b. The left column contains stimuli in the face absent condition; the middle column stimuli in the face congruent condition; and in the right hand column, stimuli in the face incongruent condition. The upper row of stimuli have direct gazes and those in the lower row, gazes averted to the left.

The experimental stimuli were presented at fixation on a white background. Each was preceded by a black fixation cross comprising vertical and horizontal lines measuring 0.6˚, and followed by the presentation of a pattern mask. This measured 7.6˚ by 9.5˚ and was created by pixelating the full face image using Photoshop's pointillize tool with cell size set to 16. All stimuli in this and subsequent experiments were presented using SuperLab software (Cedrus Corp.) on a Macintosh G3 computer. Participants were seated 0.6 m from a 15 inch colour monitor set to greyscale.

Design. The direct and averted gaze stimuli were presented in a within subjects design with one factor: head context. The head was either absent, congruent or incongruent with the gaze direction. On each trial participants were asked to decide whether the eyes were averted or were looking at them and their proportions of hits and false positives under each condition were recorded. From these an A' score – a measure of participant's ability to discriminate direct from averted gaze – was computed for each of the three conditions and served as the main dependent variable in the experiment.

Procedure. Trials began with the presentation of the fixation cross which remained on the screen for 1000 ms. This was then replaced by a 140 ms presentation of one of the gaze stimuli followed by the pattern mask which remained on the screen for 200 ms. The screen then went blank and remained so until the participant had made their response. Participants were asked to judge whether the eyes were averted or were looking directly at them by pressing, respectively, either the "m" or "z" keys on a standard keyboard. They were asked to respond as accurately as possible and to take as long as they needed to make their response as only their accuracy was being recorded. Following a response, a 1000 ms delay preceded the beginning of the next trial.

Each participant saw 64 trials in each of the three experimental conditions. These comprised 32 direct gaze stimuli and 16 stimuli with gaze averted to the left and 16 with gaze averted to the right. These were divided into two identical blocks of 96 trials, in which trial presentations were randomised. Prior to the two experimental blocks, participants completed a sequence of 48 practice trials: 16 in each condition with an equal number of direct and averted stimuli.

Results

In this, and all subsequent experiments, hit rates (proportion of direct gaze trials in which participants made a correct response) and false alarm rates (proportion of averted gaze trials in which participants indicated gaze was direct) were first computed for each participant under each of the three experimental conditions. As some participants recorded no misses or false alarms in some conditions, corrected hit and false alarm rates were computed by first adding 0.5 to the number of hits and false alarms, respectively, in each condition and then incrementing the number of trials in each condition by 1 in order to calculate the probabilities. From each single pair of corrected hit and false alarm rates in each condition, A' and B'' scores were then obtained following the procedure outlined by Snodgrass and Corwin (1988). A' is a non-parametric measure of discriminability; in other words, a measure of how well participants were able to distinguish direct from averted gaze. B'' is the equivalent non-parametric measure of response bias which indexes whether participants tended to prefer one response over the other. A B'' score of zero represents a neutral bias, and - in our experiments - a negative value of B'' represents a conservative bias (i.e. the participant tends to respond “averted”) and a positive score, a liberal bias (i.e. a tendency to make more “direct” responses).

Table 1. Mean A' values, hit rates, false alarm rates and B'' values(standard deviations in parentheses) in each condition of Experiment 1a.

	Face Context		
	Absent	Congruent	Incongruent
Discriminability (A')	0.68 (0.18)	0.95 (0.06)	0.21 (0.13)
Hit Rate	0.93 (0.06)	0.93 (0.08)	0.22 (0.18)
False Alarm Rate	0.71 (0.25)	0.11 (0.16)	0.65 (0.16)
Response Bias (B'')	0.39 (0.33)	0.07 (0.45)	-0.18 (0.36)

Mean values of A', hit rates, false alarms and B'' in each condition of Experiment 1a appear in Table 1. Examination of the A' data indicates that participants were well able to discriminate direct from averted gaze in the congruent condition (mean A' = 0.95) but their performance deteriorated when the face context was removed (mean A' = 0.68) and deteriorated still further when head angle and gaze direction were incongruent (mean A' = 0.21).

An ANOVA comparing mean A' values in the three conditions yielded a significant effect of head context ($F(2, 32) = 112.34$, $p < 0.001$). Post-hoc Newman-Keuls tests ($\alpha = .05$) confirmed the above observations; participants' ability to discriminate direct from averted gaze was significantly superior in congruent than in both incongruent and absent conditions. Moreover, performance in the incongruent condition was significantly poorer than in the absent condition.

Clearly, head context influenced participants' performance. However, this overall effect on discriminability could have originated from one – or both – of two sources: first, when eyes directed straight ahead were placed in the context of a head that was oriented to either the left or right, participants might have perceived the direction of gaze as being "pulled" in the direction of the head turn; second, an averted gaze directed to a viewer's left, say, may have been perceived as directed straight ahead when in the context of a head rotated to the right (see Figure 1). The first type of effect (direct gaze being "pulled" to the left or right) will cause participants to "hit" a smaller proportion of direct gazes in incongruent compared to congruent conditions. The second type of effect (an averted gaze being pulled towards the centre by a head rotated in the opposite direction) will produce a higher proportion of false alarms (mistakenly responding "direct" to an averted gaze) in incongruent compared to congruent conditions. Either, or both, of these effects could have produced the observed decrease in discriminability when head and gaze were oriented in incongruent directions. In order to examine these two possibilities, separate analyses of hit and false alarm rates were undertaken.

From Table 1, it is clear that mean hit rates were much lower in the incongruent (mean = 0.22) compared to the congruent condition (mean = 0.93) which would suggest that a turn of the head produces an illusory shift of a direct gaze. A repeated measures ANOVA comparing mean hit rates across the three context conditions yielded a significant effect ($F(2, 32) = 211.93$, $p < 0.001$) Furthermore, a planned comparison revealed that the mean hit rate was significantly lower in the incongruent condition than when head and gaze were congruent ($t(32) = 17.84$, $p < 0.001$), confirming the above observation.

False alarm rates also differed across the three context conditions. In particular, participants made a higher proportion of false alarm responses in the incongruent condition (mean = 0.65) than in congruent condition (mean = 0.11) suggesting that a head turn was able to make an averted gaze appear to be directed toward the observer. In support of these observations, a repeated measures ANOVA yielded a significant effect of condition ($F(2, 32) = 49.48$, $p < 0.001$) and a planned comparison confirmed that participants made significantly more false alarms in the incongruent than in the congruent condition ($t(32) = 7.83$, $p < 0.001$).

In order to determine whether any of the face context conditions produced a systematic response bias, B'' scores in each condition were compared with a score of zero - the B'' value corresponding to a neutral bias. The B'' values presented in Table 1 indicate that participants' responses were only slightly biased in congruent and incongruent conditions but that when the face was absent, they tended to set a rather more liberal criteria, resulting in a bias toward responding that gaze was "direct". A series of one-sample t-tests comparing the mean B'' values with zero confirmed these observations. There were no significant biases in congruent or incongruent conditions (p's > 0.05) but a significant positive bias when the face was absent ($t(16) = 4.88$, $p < 0.001$).

Discussion

The results of this experiment clearly confirm that head context, and its orientation in particular, has an effect on gaze perception. Participants' ability to discriminate direct from averted gaze was significantly poorer when head and gaze were incongruent than when both were oriented in a congruent direction. Moreover, the results suggest that this effect on discriminability can be attributed to illusory shifts of both direct and averted gazes. When the eyes were paired with an incongruent as compared to a congruent head, participants were less likely to respond that a direct gaze was actually looking at them. Similarly, a gaze directed to either the viewer's left or right was more likely to be misjudged as a direct gaze when paired with a head oriented in the opposite direction than when paired with a congruent head cue. Thus, as with the Wollaston illusion (see Figure 1) and in line with findings of Cline (1967) and Maruyama and Endo (1983, 1984), it seems that head orientation produces a "towing" effect on the perceived direction of gaze so that it falls somewhere between the true line of regard of the eyes and the angle of rotation of the head.

However, before concluding that the effect arises as the result of some kind of perceptual illusion we should perhaps consider some alternative explanations. First of all, the influence of head angle on gaze discriminability found in this experiment cannot simply be attributed to participants adopting a strategy of responding, when uncertain, on the basis of the most visually salient cue: head orientation. Although this strategy would indeed produce a reduced rate of "direct" responses (hits) in the congruent condition and a corresponding reduction in overall discriminability (A') as found in Experiment 1a, it would *not* produce the observed increase in false alarms observed in the incongruent condition where neither head nor gaze were actually oriented towards the observer.

It is also difficult to attribute the results of Experiment 1a to some kind of response competition effect where information from head and gaze compete more in incongruent than in congruent conditions. First, these kinds of effects are only usually apparent when a speeded response is required. In contrast to this, participants in Experiment 1a were asked to respond as accurately as possible and were explicitly told that their response speed was not being recorded. Second, if there were some kind of response competition effect operating here, we might expect that in incongruent conditions participants would respond on the basis of the actual gaze direction on roughly half of the trials and the orientation of the head on the other half of the trials. The data do not, however, support such an interpretation. Under this account, the mean hit rate for direct gazes in the incongruent condition would be expected to be roughly 0.5 as participants respond on the basis of gaze (direct) and head orientation (averted) in half of the trials. However, the recorded figure was a significantly lower 0.22 (one sample t-test, $t(16) = 6.41$, $p < 0.001$). Participants in Experiment 1a also made a substantial number of false alarm responses to averted gazes in incongruent trials (Mean = 0.65). Under a response competition account this figure would actually be expected to be closer to zero as in the incongruent condition both head and gaze direction are averted in opposite directions. Participants responding randomly on the basis of either cue would therefore rarely ever make a “direct” (false alarm) response. Of course, the recorded mean false alarm rate of 0.65 was found to be significantly higher than zero ($t(16) = 16.85$, $p < 0.001$) which again argues against a response competition account.

Thus it seems unlikely that the findings of this experiment can be attributed to some kind response bias (respond to the most salient cue) or a response competition effect. Instead, it is argued that the pattern of results obtained here is consistent with observers’ perceived direction of gaze being "towed" towards the angle of the head making averted gazes appear to be direct and direct gazes appear to be averted.

As noted in the introduction, other researchers have obtained a rather different effect when head and gaze are placed into conflict in photographic images of faces. Rather than the perceived direction of gaze being towed toward the orientation of the head, both Anstis et al (1969) and Gibson and Pick (1963) noted that gaze direction is perceived to be shifted in the *opposite* direction to the orientation of the head. This "repulsion" or "overshoot" effect might occur when, say, leftward gazing eyes in a rightward oriented head are perceived as more leftward gazing than they appear to be in a frontward oriented head. As this kind of combination of eye and head orientation occurs in certain conditions of Experiment 1a (see, for example the lower right image in Figure 2), we might ask why a similar repulsion effect was not observed in this study. One possibility is that the repulsion effect occurs, not as a direct result of some interaction between head orientation and gaze direction, but because the effect of a head turn is to expose more visible sclera on one or other side of the eye. As the relative proportion of sclera on either side of the iris can be used as a cue to gaze direction (Ando, 2002; Watt, 1999), changing this ratio by exposing more sclera might result in an illusory shift in gaze. For example, imagine someone facing you with their eyes gazing directly into yours; roughly the same amount of sclera will be visible on either side of each iris. The contrast in luminance between these parts of the sclera will therefore be roughly zero yielding the percept of a direct gaze. If that person then turns their head to your left whilst maintaining eye-contact, proportionately more of their sclera will now be visible on the left side of their eyes – from your point of view – compared to the right. As this luminance configuration ordinarily signals a rightward directed gaze you will therefore erroneously judge the eyes to be oriented slightly to the right. Indeed, the scleral contrast account of gaze perception predicts just this kind of repulsion effect for certain viewing angles of the face (see Langton, Watt & Bruce, 2000).

The absence of a repulsion effect in the present experiment can therefore be explained by the fact that the relative proportion of sclera visible on either side of the iris was held constant across all changes of head orientation. This was achieved by cutting leftward and rightward facing eyes from images of frontward oriented head and pasting them onto heads with congruent and incongruent angles of rotation. In view of this, we argue that the Wollaston illusion and the towing effects obtained here and elsewhere index some kind of integration between information coding the orientation of the head and the direction of eye gaze rather than an error introduced as a consequence of the way in which a turn of the head alters one of the cues used to determine gaze direction.

Another notable finding of this experiment was the significant decrease in A' when the congruent head context was removed so that gazes were presented in isolation from the head. This is in line with the results of a study by Vecera and Johnson (1995) who showed that disruption of the face context by scrambling the features of a schematic face significantly reduced participants' ability to distinguish between direct and averted gazes. In our own work, (Jenkins and Langton, in press) we have also reported that thresholds for gaze judgements were higher when greyscale images of eyes were presented in isolation than when in the context of an upright face. We suggest there at least two possible reasons for this effect, related to the two components necessary for accurate gaze judgements: locating the position of the eye in relation to the head and combining this with the angle of orientation of the head. First, removal of the face context also removes a good deal of information that might be used in the spatial computation of the location of the eye in relation to the head. However, it would seem that sufficient information remains to make this relational computation even after removal of the face context. The location of the iris need only be computed in relation to some fixed part of the head, and the canthus (the corner of the eye) or bridge of the nose would suffice (See Langton, Watt & Bruce, 2000). Inspection of Figure 2 reveals that these "features" remain intact in the face absent stimuli. Thus, it is more likely that removal of the face context disrupts the second component necessary for accurate gaze judgements: perception of the angle of rotation of the head. With no information available from the head contour or from the angle of deviation of the nose, perception of head angle might well be impaired.

Removal of the face context also had an effect on participants' response bias. More specifically, in the absence of a face context participants tended to lower their criterion for making a "direct" response. This seems to be a reasonable strategy; with less information with which to make a decision, defaulting to assuming gaze is directed at you is, adaptively speaking, a "safe" strategy. In other words, it's better to run the risk of making a few false alarms than to miss one occasion when a predator is eyeing you for its next meal.

To summarise, Experiment 1a was successful in inducing a Wollaston-type illusion in our participants. Moreover, the design is such that it allows the size of the effect to be quantified so that we can go on to manipulate the available cues to head orientation and examine the impact of these manipulations on the magnitude of the effect. Before embarking on this, however, we first assess whether or not the effect of head context on gaze discriminability is sensitive to inversion of the stimuli (i.e. rotation through 180˚).

Experiment 1b

In this experiment we ask whether the influence of head rotation on gaze perception noted in Experiment 1a might be caused by a low-level image-based mechanism or a higher-level process perhaps specific to faces. In order to examine this, the gaze and masking stimuli used in the previous experiment were each rotated about 180˚ to produce a set of inverted images.

Numerous studies have demonstrated that inversion severely disrupts various aspects of face processing (e.g., Bruce & Langton, 1994; Diamond & Carey, 1986; Valentine & Bruce, 1986; Yin, 1969). For instance, Yin (1969) showed that recognition memory for upright faces was better than that for pictures of houses, aeroplanes, or schematic men-in-motion, but when all these materials were inverted, performance on the faces became worse than that on the other pictures. At present, it is unclear exactly what causes the inversion effect, but it is generally agreed that it disrupts a mode of processing variously described as configural (e.g., Sergent, 1984), holistic (e.g., Tanaka & Farah, 1993), relational (e.g., Goldstone, Medin & Gentner, 1991) or non-componential (e.g., Barton, Keenan & Bass, 2001). The basic idea is that the encoding of an upright face involves not only processing of information about individual face features (mouth, nose, eyes etc.) but also processing about the spatial arrangement or configuration of these features (e.g., Leder & Bruce, 2000; for a recent review of configural processing see Maurer, Le Grand & Mondloch, 2001). It is thought that inversion selectively disrupts – or at least has a greater effect on – the encoding of this configural information. Some direct evidence for this comes from work by Leder and Bruce (1998) and Searcy and Bartlett (1996). In these studies, faces were made to look more grotesque (Searcy & Bartlett, 1996) or distinctive (Leder & Bruce, 1998) by either manipulating individual face features (e.g., blurring the pupils or darkening the lips) or distorting the relationships between these features (e.g., narrowing the interocular distance). When inverted, faces made distinctive or grotesque by feature changes still appeared to be distinctive or grotesque, whereas faces changed by manipulating the relationship between features looked more like the original, unaltered versions. In other words, these studies suggest that feature information is still encoded in inverted faces, but the encoding of the relationship between these features is disrupted. Furthermore, the idea that inversion has its effect at the perceptual encoding stage of face perception is consistent with studies using event-related brain potentials which have established that inversion exerts consistent effects as early as 170 ms after stimulus presentation. (Bentin, Allison, Puce, Perez & McCarthy, 1996; Eimer, 2000; Rossion, Delvenne, Debatisse, Goffaux, Bruyer, Crommelinck & Guérit, 1999).

There is also evidence that extensive experience with faces may be required to produce the inversion effect as face recognition by children below the age of 10 is less affected by inversion (Carey & Diamond, 1977). Indeed, extensive experience with other categories of object normally encountered in a particular orientation may also make these objects susceptible to the inversion effect. So, for example, Diamond and Carey (1986) showed that dog-show judges' ability to recognise dogs was also disrupted by inversion. The implication is that we have to learn to encode the relevant configural information in order to make within category discriminations. Encoding this information becomes difficult with stimuli with which we are not familiar, such as upside-down faces.

Regardless of the precise mechanism behind the inversion effect, this manipulation provides a way of discriminating between a low-level image based account, and a higher level mechanism based perhaps on face-specific (or expertise-specific) configural processing. If the influence of head orientation on the processing of gaze direction is caused by a higher-level mechanism concerned with encoding the configural arrangement of face features we would expect it to be eliminated by inversion of the stimuli. If, on the other hand, the effect emerges much earlier in processing as the result of an interaction of image-based features it should persist when the stimuli are inverted.

Method

Participants. These were seventeen volunteers attending an Open University residential Summer school at the University of Stirling. All had normal or corrected-to-normal vision.

Materials, Design and Procedure. These were identical to Experiment 1a; however, the gaze stimuli and pattern mask were all rotated through 180˚.

Results

Mean A' and B'' values, along with mean hit and false alarm rates in each condition of Experiment 1b are presented in Table 2. The pattern of results was very similar to that of Experiment 1a. Participants were less able to discriminate direct from averted gaze in the incongruent condition (Mean A' = 0.22) compared to the congruent condition (Mean A' = 0.96). Moreover, incongruently angled heads reduced hit rates and increased false alarm rates compared to heads oriented in congruent directions to the angle of gaze.

Table 2. Mean A′ values, hit rates, false alarm rates and B″ values(standard deviations in parentheses) in each condition of Experiment 1b.

	Face Context		
	Absent	Congruent	Incongruent
Discriminability (*A′*)	0.74 (0.24)	0.96 (0.02)	0.22 (0.10)
Hit Rate	0.91 (0.06)	0.93 (0.07)	0.24 (0.14)
False Alarm Rate	0.54 (0.29)	0.08 (0.08)	0.62 (0.25)
Response Bias (*B″*)	0.37 (0.38)	0.03 (0.62)	-0.05 (0.44)

A series of repeated measures ANOVAs and follow-up comparisons conducted on the *A′* scores, hit rates and false alarm rates confirmed the above observations. Head context exerted a significant effect on discriminability scores ($F(2, 32) = 103.56$, $p < 0.001$) and post hoc Newman-Keuls tests ($\alpha = 0.05$) indicated that the differences between all pairs of means were significant. The effect of context was also significant for hit rates ($F(2, 32) = 346.96$, $p < 0.001$) and false alarm rates ($F(2, 32) = 24.46$, $p < 0.001$). Separate planned comparisons comparing hit rates and false alarms in congruent and incongruent conditions revealed significant differences in both cases (for hit rates, $t(32) = 23.08$, $p < 0.001$; and for false alarms, $t(32) = 6.51$, $p < 0.01$).

As with the upright stimuli, participants operated with a positive bias in judging gaze (i.e. they made more “direct” responses) when the head context was absent, but showed little bias in the other conditions. One sample t-tests confirmed that the mean bias score in the absent condition was significantly greater than zero ($t(16) = 4.03$, $p < 0.01$) but that participants displayed no significant bias in congruent or incongruent conditions (p’s > 0.6).

Discussion

The results of Experiment 1b were almost identical to those of Experiment 1a. Even with inverted stimuli, head context produced an effect on gaze discriminability; participants showed reduced A' scores with incongruent compared to congruent stimuli. Moreover, as in Experiment 1a, hit rates were lower and false alarms higher when head and gaze were incongruent than when they were congruent. The influence of head angle on the perception of gaze therefore persisted when the face stimuli were inverted licensing a conclusion that the root of the effect is a low-level image-based mechanism, and not a process that is necessarily specific to faces, nor one based on the relational aspects of the gaze/head stimuli.

The findings of this experiment are, however, at odds with those of Maruyama and Endo (1984) whose Wollaston-like illusion was markedly reduced by the inversion of their face stimuli. They concluded that inversion disrupted the configural integration of face features which they took to underpin the effect. However, their studies differed from ours in at least two important respects, both of which might explain the discrepant findings.

First, Maruyama and Endo used a finer-grained measure of perceived gaze direction: participants were asked to indicate where they perceived the gaze to be directed by marking a point on a Perspex arc positioned in front of the schematic face. Thus, it is possible that their measure of the Wollaston-like illusion was more sensitive to any effects of inversion than the measure used in our experiments. However, we believe that, given the strength of the illusion found with our stimuli, a finer grained measure would – at best – simply reveal a slightly weaker effect in inverted compared to upright faces (readers might like to satisfy themselves of the robustness of the illusion by viewing Figures 1 and 2 with the pages turned upside down). Even if the illusion is actually slightly weakened in inverted faces it still begs the question as to why it persists at all under conditions where the encoding of relations between face features is known to be severely disrupted, and probably particularly so in the brief, masked displays we have used. The likely explanation is that the effect emerges as the result of an interaction between image-based features, rather than face-specific representations.

Having said this, the discrepancy between our findings and those of Maruyama and Endo is perhaps more likely to rest on a second major difference between the two studies: their use of schematic as opposed to greyscale images of faces. Maruyama and Endo used a circle to represent the outline contour of their schematic faces, even in conditions where the head was rotated. Their participants were therefore unable to use the overall shape of the head as a cue to head orientation. Instead, they had to rely on two other potential cues: the shape of a line denoting the profile of a nose, mouth and chin drawn within the circular face frame; and the horizontal displacement of the eyes and the profile shape, again within the circular face outline. These cues were evidently successful in producing the illusion of a rotated head and, in turn, an illusory shift of eye-gaze in upright faces. Although these cues were also potentially present in the greyscale stimuli used in Experiments 1a and b, these images also include what Wilson et al (2000) regard as being one of the strongest cues to head orientation: the shape of the head profile or, more specifically, its degree of deviation from bilateral symmetry. The discrepant findings between our experiments and those of Maruyama and Endo might therefore be due to the fact that different cues to head orientation were available in these studies, and that these cues might well influence the perception of gaze in rather different ways. The occluding contour formed by the shape of the head, for example, might be sufficient on its own to exert an effect on the processing of eye gaze direction, but it may do so at an early stage in processing which is insensitive to inversion. Cues such as nose angle and eye-displacement, on the other hand, might also be capable of influencing the extraction of gaze, but they do so later in processing as the result of some kind of configural mechanism that *is* disrupted by inversion. The remainder of the experiments reported here explore some of these issues. Experiments 3a and 3b examine whether a Wollaston type illusion can be induced by deviations in the angle of the nose. Meanwhile, in Experiments 2a-c we examine whether the outline contour of the head is sufficient to influence the perception of gaze direction.

Experiment 2a

In order to test whether head shape alone is able to influence gaze perception the face images used in Experiments 1a and 1b were first subjected to a high-pass filter and then the internal features, apart from the eyes, were removed from the resulting images, leaving only the outline contour of the head. As before, we then examined how well participants were able to discriminate direct from averted gaze under conditions where the head outline alone was congruent, incongruent or absent. If head outline is indeed used to perceive head orientation, and this information then used to influence gaze perception, we would expect the context provided by the head contour to exert an effect on gaze discrimination.

Method

Participants. These were 17 Open University students drawn from the same population as in Experiment 1. Again, all had normal or corrected-to-normal vision.

Materials, Design and Procedure. In order to create stimuli where only the outline contour of the head could provide information as to head angle, the internal features were removed from the original greyscale images of the head directed straight ahead, angled to the left and to the right. This was accomplished in the following way. First, Adobe Photoshop was used to subject each of these three images to a high-pass filter. Following filtering, a paintbrush tool was used to replace the internal region of each face with the same grey level as that of the background leaving only the outline contour of the head visible. This resulted in three separate images of head outline shapes: one angled to the left, one to the right and a third straight ahead. Next, the stimuli used in the head absent context condition in Experiment 1a were also subjected to the same high-pass filter, and the paintbrush tool used to remove any information from the areas surrounding the eyes. The resulting eyes-only images served as stimuli in the head absent condition of Experiment 2a. Copies of these stimuli were then pasted onto the appropriate head outline images to create the congruent and incongruent stimuli analogous to those used in Experiment 1. Care was taken to ensure that the eyes were pasted onto the identical position, relative to the head outline, as in the original digitised greyscale images. Examples of the stimuli used in each condition of Experiment 2a are shown in Figure 3.

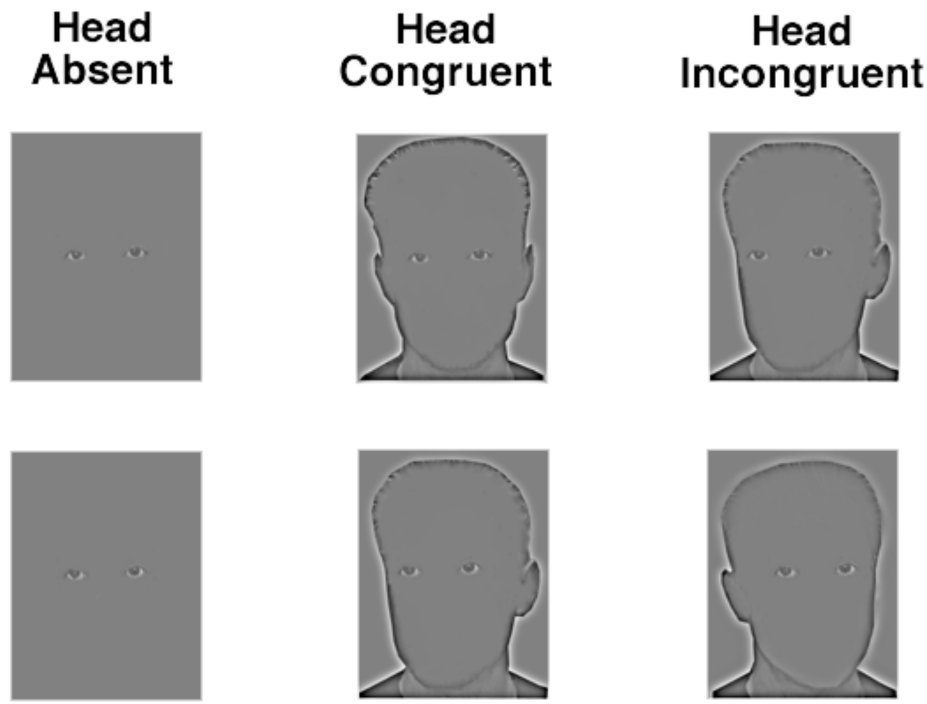

Figure 3. Reproductions of some of the stimuli used in Experiments 2a and 2b. The left column contains stimuli in the head absent condition; the middle column stimuli in the head congruent condition; and in the right hand column, stimuli in the head incongruent condition. The upper row of stimuli have direct gazes and those in the lower row, gazes averted to the left.

The pattern mask used in Experiment 1a was also high-pass filtered and used as the mask in this experiment. Stimuli were presented on a background with the same grey level as the median level of that of the experimental stimuli. All other aspects of the design and procedure remained the same as in Experiment 1a.

Results

Measures of discriminability (A') and bias (B'') were calculated as in Experiments 1a and 1b and the means of these values in each experimental condition are reported in Table 3, along with mean hit and false positive rates. From this table it is clear that the effect of head outline context on gaze perception was strikingly similar to that of the full face in Experiment 1a. Participants were well able to discriminate direct from averted gaze in the congruent condition, rather less so when the face was absent and their performance was poor in incongruent conditions.

Table 3. Mean A′ values, hit rates, false alarm rates and B″ values(standard deviations in parentheses) in each condition of Experiment 2a.

	Head Outline Context		
	Absent	Congruent	Incongruent
Discriminability (*A′*)	0.86 (0.01)	0.98 (0.01)	0.50 (0.20)
Hit Rate	0.90 (0.11)	0.96 (0.03)	0.53 (0.06)
False Alarm Rate	0.36 (0.26)	0.04 (0.03)	0.54 (0.25)
Response Bias (*B″*)	0.41 (0.44)	- 0.02 (0.40)	0.04 (0.24)

A one way repeated measures ANOVA conducted on the *A′* data confirmed that head context produced a significant effect on participants' performance ($F(2, 32) = 65.75$, $p < 0.001$). Post-hoc Newman-Keuls tests ($\alpha = .05$) confirmed that sensitivity scores were higher in the congruent condition (Mean *A′* = 0.98) compared to both the absent (Mean *A′* = 0.86) and incongruent (Mean *A′* = 0.50) conditions, and that discriminability in incongruent conditions was poorer than when the face was absent.

The mean hit rates in the congruent (0.96) and in the absent condition (0.90) were also higher than in the incongruent condition (0.53) indicating that a gaze stimulus which participants judged to be looking at them when presented alone or in the context of a centrally oriented face, was more likely to be judged as averted when in the context of a head angled to the left or right. A repeated measures ANOVA comparing hit rates in the three conditions confirmed that context influenced performance ($F(2, 32) = 183.62$, $p < 0.001$). Furthermore, a planned comparison comparing hit rates in congruent and incongruent conditions was also significant ($t(32) = 17.62$, $p < 0.001$) suggesting that participants were indeed experiencing an illusory shift of direct gaze in this experiment.

The context manipulation also influenced false alarm rates as can be seen in Table 3. Specifically, participants made a higher proportion of false alarms in the absent and incongruent conditions (means = 0.36 and 0.54 respectively) compared to the congruent condition (Mean = 0.04). A repeated measures ANOVA confirmed that context produced a significant effect on false alarm rates ($F(2, 32) = 27.08$, $p < 0.001$). A planned comparison also confirmed that the false alarm rate was significantly higher in the incongruent than in the congruent condition ($t(32) = 7.26$, $p < 0.001$), suggesting that averted gazes were also subject to an illusory shift caused by an incongruently rotated head outline.

The mean bias index values were also very similar to those obtained in Experiment 1a. These indicate that participants were using a neutral criteria in congruent and incongruent conditions but operating with a liberal bias when the face context was absent. One sample t-tests comparing these scores with a bias score of zero provided support for these observations. Bias scores in congruent and incongruent conditions were not significantly different from zero (p's > 0.5) but participants were operating with a significantly negative bias when the eyes were presented with no face context ($t(16) = 3.82$, $p < 0.01$).

Discussion

The results of this experiment were very similar to those obtained with full-face images in Experiment 1a. Again, participants were less able to discriminate direct from averted gaze in incongruent than in congruent images. Moreover, this reduction in discriminability could be attributed to both an increase in the false alarm rate and a decrease in hit rate when the head outline was incongruent with the gaze direction. These findings suggest that head contour alone is sufficient to induce a Wollaston-like effect and hence exerts an effect on the perception of gaze direction.

Experiment 2b

In order to examine whether or not an image-based process is responsible for the effects obtained in Experiment 2a, we repeated this experiment but with the stimuli rotated through 180˚. Given that the full face images used in Experiments 1a also produced an effect on gaze perception when inverted (Experiment 1b), we expected that the effects of head contour would also persist in inverted images in this experiment.

Method

Participants. These were again 17 Open University students attending a summer school at the University of Stirling all of whom had normal or corrected-to-normal vision.

Materials, Design and Procedure. These were identical to Experiment 2a save for one detail: the full face, eyes-only and masking stimuli were each rotated through 180˚.

Results

Mean discriminability and bias values, hit rates and false positive rates are presented in Table 4. A comparison of the sensitivity data in this table with those from Experiment 2a (Table 3) indicates that inversion seems to have had little influence on the pattern of effects. Once again, participants' discriminability scores were high in the congruent condition (Mean A' = 0.94), but reduced when the head context was removed (Mean A' = 0.81) and reduced still further when the head was incongruent with the direction of gaze (Mean *A′* = 0.25). A repeated measures ANOVA conducted on the *A′* data confirmed that participants' ability to discriminate direct from averted gaze was influenced by head context ($F(2, 32) = 218.81$, $p < 0.001$). Furthermore, Newman-Keuls tests ($\alpha = .05$) revealed that all comparisons between pairs of mean *A′* scores were significant.

Table 4. Mean A′ values, hit rates, false alarm rates and B″ values(standard deviations in parentheses) in each condition of Experiment 2b.

	Head Outline Context		
	Absent	Congruent	Incongruent
Discriminability (*A′*)	0.81 (0.12)	0.94 (0.04)	0.25 (0.12)
Hit Rate	0.89 (0.09)	0.91 (0.06)	0.24 (0.21)
False Alarm Rate	0.48 (0.28)	0.12 (0.10)	0.57 (0.22)
Response Bias (*B″*)	0.35 (0.44)	0.15 (0.33)	-0.20 (0.29)

An analysis of hit rates was also conducted to examine whether participants were likely to have experienced an illusory shift of direct gaze caused by the rotation of an inverted head outline stimuli. Mean hit rates in both congruent (0.91) and absent (0.89) conditions were higher than when head and gaze were incongruent (0.24). A repeated measures ANOVA confirmed that context did indeed affect hit rates ($F(2, 32) = 143.07$, $p < 0.001$). A planned comparison indicated that mean hit rate in the congruent condition was significantly higher than in the incongruent condition ($t(32) = 14.82$, $p < 0.001$) suggesting that participants were once again experiencing an illusory shift of a direct gaze when paired with a rotated, and inverted, head outline.

The false alarm rates presented in Table 5 were also influenced by the context manipulation. In particular it is clear that participants made markedly more false alarms when the head context was either incongruent (Mean = 0.57) or absent (Mean = 0.48) compared to when head and gaze were congruent (Mean = 0.12). This would suggest that participants were experiencing an illusory shift of averted gaze towards themselves. A repeated measures ANOVA conducted on the false alarm data yielded a significant effect of context ($F(2, 32) = 27.69$, $p < 0.001$) and a planned comparison confirmed that false positive rates under the incongruent condition were significantly higher than in the congruent condition ($t(32) = 7.17$, $p < 0.001$).

The pattern of bias scores across the three conditions with inverted heads was rather different from that with upright faces. As before, there was a bias towards responding that gaze was direct when the face context was absent. However, inversion seems to have introduced a similar - but smaller - bias with congruent stimuli, and an opposite bias (i.e. towards responding that gaze is averted) when head and gaze were incongruent. One sample t-tests largely confirmed these observations. The mean bias score in the absent condition was significantly smaller than zero ($t(16) = 3.26$, $p < 0.01$) but the bias in the congruent condition was only marginally positive ($t(16) = 1.93$, $p = 0.072$). Participants were significantly biased towards responding that gaze was averted when head and gaze were incongruent ($t(16) = 2.75$, $p < 0.05$).

Discussion

The main finding of this experiment was that, as in all the previous experiments, the context manipulation – this time of the inverted head contour – produced a significant effect on participants' ability to distinguish direct from averted gaze. In particular, as with the upright head contour stimuli, A' scores were significantly lower when head contour and gaze were incongruent than when they were congruent with one another. Again, this reduction in discriminability could be attributed to both an increase in the false alarm rate, as participants mistakenly judged an averted gaze to be directed at them when it was accompanied by a head oriented in the opposite direction, and a decrease in hit rate, as an incongruent head contour "towed" a direct gaze to one side or the other. Inversion therefore had no influence on the Wollaston-type effect we have observed with either the full face contexts (Experiment 1a) or head contour alone (Experiment 2a). These findings suggest that the effect arises as a result of low-level image-based processes.

The inversion manipulation did, however, introduce some bias in participants' responses. As in previous experiments, in the absence of any face context, participants tended to make more "direct" than "averted" responses whilst no particular bias existed in either of the other two conditions. However, here inversion of the head contour introduced a bias towards responding that gaze was averted in the incongruent condition. It seems that, with conflicting head and gaze information, participants bias their responses towards the more salient stimulus (the head contour).

Experiment 2c

The findings of experiments 2a and 2b suggest that the shape of the head contour is sufficient to influence the perception of gaze. However, it is possible that participants in these experiments were using another cue to head orientation that was present in the images used. When head and gaze are directed straight ahead, the outline shape of the head is bilaterally symmetrical and the eyes are located in the horizontal centre of this shape. Now, as the head rotates, not only does the shape of the head contour deviate from bilateral symmetry but the eyes are displaced laterally from the centre of the shape bounded by the occluding contour of the head. Since the eyes are also displaced in this way in conditions with rotated heads in Experiments 1a and 2a (see Figures 2 and 3) it is possible that participants were using the horizontal displacement the eyes within the face surround to compute head angle and it is this cue, rather than the shape of the head contour, that influences the perceived direction of gaze. Indeed, Maruyama and Endo (1983, 1984) showed that a Wollaston-like effect could be induced in schematic faces by simply displacing the eyes alone to the left or right within a circular head outline.

In Experiment 3, therefore, the stimuli used in Experiment 2a were manipulated so that the eyes always appeared in the centre of the shape bounded by the face contour. If the displacement of the eye region was responsible for the effects obtained in the previous experiments we would expect no effect of head context in this experiment. On the other hand, we would expect the effect to persist if the shape of the head outline is used as a cue to head orientation which, in turn, influences the perception of eye gaze.

Method

Participants. Once again 17 Open University students acted as participants in this experiment. All had normal or corrected-to-normal vision.

Materials, Design and Procedure. The design and procedure remained identical to those used in the previous experiment. However, the materials used in this study differed from those used in Experiment 2a in the following respect. For all those stimuli where the heads were oriented to the left or right the eye region was shifted horizontally so as to offset the displacement caused by the rotation of the head. In heads rotated to the viewer's left, for example, Adobe Photoshop software was used to shift the eye-region 6 mm (0.6˚) to the viewer's right. The eyes were shifted by the same distance to the left in heads rotated to the viewer's right. Examples of the stimuli used in this experiment are illustrated in Figure 4.

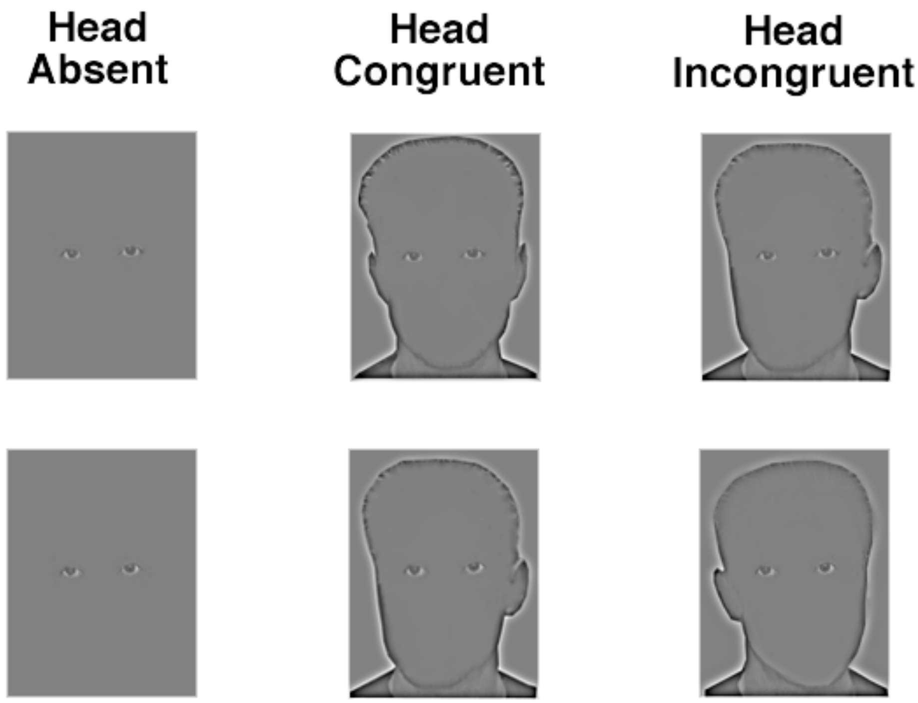

Figure 4. Reproductions of some of the stimuli used in Experiment 2c. The left column contains stimuli in the nose absent condition; the middle column stimuli in the nose congruent condition; and in the right hand column, stimuli in the nose incongruent condition. The upper row of stimuli have direct gazes and those in the lower row, gazes averted to the left.

Results

Mean discriminability and bias values, hit rates and false positive rates are presented in Table 5. The pattern of data displayed in this table is clearly very similar to that of Experiment 2a. Participants were well able to discriminate direct from averted gaze in the congruent condition (mean A' = 0.93) but their performance was slightly poorer when the head was absent (mean A' = 0.88) and poorer still when head angle and gaze were incongruent (mean A' = 0.80). Furthermore, in the incongruent condition participants' hit rates were lower compared to those in the congruent condition (means = 0.53 and 0.96 respectively) and their false alarm rate was higher (means = 0.54 and 0.04 respectively). Again, the pattern here is similar to that in the previous experiments.

Table 5. Mean A′ values, hit rates, false alarm rates and B″ values(standard deviations in parentheses) in each condition of Experiment 2c.

	Head Outline Context		
	Absent	Congruent	Incongruent
Discriminability (*A′*)	0.88 (0.07)	0.93 (0.07)	0.80 (0.12)
Hit Rate	0.87 (0.14)	0.92 (0.06)	0.67 (0.20)
False Alarm Rate	0.31 (0.15)	0.13 (0.16)	0.23 (0.16)
Response Bias (*B″*)	0.42 (0.42)	- 0.03 (0.40)	- 0.12 (0.31)

A series of one way repeated measures ANOVA conducted on the *A′*, hit rate and false alarm rates confirmed these observations. First, head context produced a significant effect on participants’ ability to discriminate direct from averted gaze ($F(2, 32) = 17.31$, $p < 0.001$). Post-hoc Newman-Keuls tests ($\alpha = .05$) confirmed that *A′* scores were significantly higher in the congruent condition than in both the absent and incongruent conditions and that performance was significantly poorer when head and gaze were incongruent than when the head outline was absent. Second, hit rate scores were also significantly affected by the head context manipulation ($F(2, 32) = 17.31$, $p < 0.001$) and a planned comparison indicated that scores in the congruent condition were significantly higher than in the incongruent condition ($t(32) = 5.47$, $p < 0.01$). Head context also produced a significant effect on false alarm rates ($F(2, 32) = 9.50$, $p < 0.01$) and a planned comparison confirmed that participants made significantly more false alarms in the incongruent condition than in the congruent condition ($t(32) = 2.46$, $p < 0.05$).

Finally an inspection of Table 4 reveals the pattern of bias index scores was also very similar to that obtained in Experiment 2a. Once again, participants seemed to operate with neutral criteria in congruent and incongruent conditions (means = -0.02 and -0.12 respectively), but adopted a more liberal criterion (mean = 0.42) when the gaze stimuli were presented in the absence of the head context. A series of one-sample t-tests comparing the mean B'' scores with a neutral criterion of zero confirmed these observations. There were no significant biases in congruent or incongruent conditions (p's > 0.1) but a significant positive bias when the head context was absent ($t(16) = 4.09$, $p < 0.01$).

Discussion

The results of this experiment confirm that head outline is sufficient to induce a Wollaston-like effect on the perception of gaze direction. Even when the horizontal displacement of the eyes in rotated heads is controlled, A' scores were significantly lower when head contour and gaze direction were incongruent than when they were oriented in the same direction. As in Experiments 1 and 2, this reduction in participants' ability to discriminate direct from averted gaze could be attributed to both a higher false alarm rate and a lower hit rate in incongruent compared to congruent conditions.

Although the effect most certainly persisted in the absence of any displacement of the eyes, its magnitude was reduced compared to that obtained in Experiments 1a and 2a. Thus, it may well be that the horizontal displacement of the eyes within the overall face frame is used as another cue to head orientation and does indeed contribute to the perception of gaze direction as shown in the work of Maruyama and Endo (1983, 1984) with their schematic faces. However, the results of Experiment 2c confirm that the shape of the head profile *is* sufficient to influence the perception of gaze direction when eye displacement is controlled.

So far we have established that the context provided by the angle of rotation of both a full face, and the head contour isolated from the internal features, exerts an influence on the perception of gaze. Furthermore, they do so by virtue of some low-level image-based processes. What of nose angle, the other major cue that Wilson et al (2000) argue is important in head perception? Is a deviation in nose angle from vertical sufficient to influence the perception of gaze? This question was addressed in the final pair of experiments.

Experiment 3a

In this experiment, the shape of the head contour in congruent and incongruent conditions remained symmetrical (i.e. directed straight at the viewer) but the relationship between the nose angle and gaze direction was manipulated. We therefore investigated whether participants' ability to distinguish direct from averted gaze was influenced by the context provided by the angle of the nose. Wilson et al (2000) maintain that head contour and nose angle provide cues of equivalent strength for discriminating head angle. If, in order to compute gaze angle, the visual system integrates information from these same cues with information extracted from the eyes we would also expect nose angle to influence gaze perception. Two lines of evidence hint that this might actually be the case. First, some more of Wollaston's (1824) original drawings seem to indicate that a change in the angle of the nose is sufficient to induce a change in the apparent direction of a person's gaze. Second, Maruyama and Endo (1984, Experiment 2). showed that a line denoting the profile shape of the nose, mouth and chin could indeed influence judgements of gaze direction in schematic faces. Thus, although cues other than nose angle were available in these stimuli, participants may well have been using the deviation of nose angle from vertical as a cue to head orientation and this cue may, in turn, have influenced the perception of gaze direction. In view of these studies, we predicted that nose angle would indeed produce similar effects on gaze perception to those observed in Experiments 1 and 2.

Method

Participants. Seventeen Open University students acted as participants in this experiment. Again, all had normal or corrected-to-normal vision.

Materials, Design and Procedure. In this experiment, the head outline context was held constant, directed toward the observer in all conditions. In order to achieve this, the eyes-only stimuli used in Experiment 1a were pasted onto copies of the original greyscale image of the head directed toward the observer. In this way, eyes-only stimuli and full-face stimuli were created with gaze directed straight ahead, to the left and to the right. In order to vary the nose context, the nose regions were cut from the full grayscale images of the left and rightward angled heads used in Experiment 1a. These left- and right-angled noses were then pasted onto full-face stimuli to create stimuli where nose and gaze were congruent and incongruent. The incongruent images were created by pasting copies of the left- and right-angled noses onto the full-face images with gaze directed to the right and left respectively, as well as onto images where the gaze was directed straight ahead. Similarly, congruent stimuli were created by pasting the left- and right-angled noses onto faces with gaze oriented to the left and right respectively. Examples of the stimuli used in this experiment are illustrated in Figure 5, all were identical in size to those used in Experiment 1a.

All other aspects of the materials, design and procedure remained identical to those in Experiment 1a.

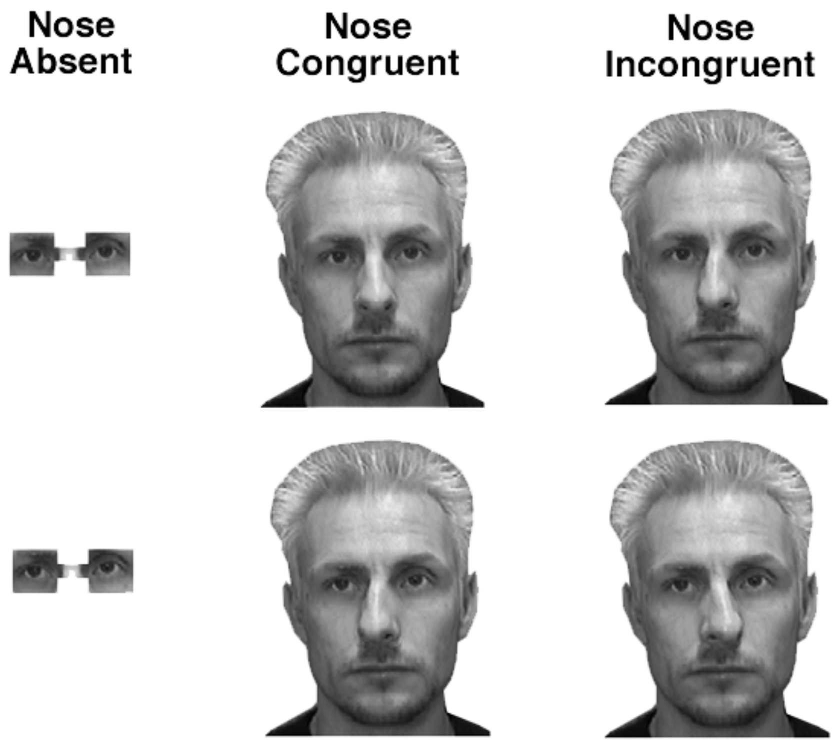

Figure 5. Reproductions of some of the stimuli used in Experiments 3a and 3b. The left column contains stimuli in the nose absent condition; the middle column stimuli in the nose congruent condition; and in the right hand column, stimuli in the nose incongruent condition. The upper row of stimuli have direct gazes and those in the lower row, gazes averted to the left.

Results

The means of participants' A' and B'' scores are summarised in Table 6. An inspection of the discriminability data in this table reveals that the context manipulation - this time of the nose - produced similar, but smaller, effects on participants' performance as did the full face and head outline manipulations in Experiments 1a and 2a. Participants' discriminability was greatest when gaze and nose were congruent (Mean A' = 0.90), but fell off when the face context was removed (Mean A' = 0.83) but was reduced only slightly further when the nose was oriented in an incongruent direction to the eyes (Mean *A′* =0.80). In support of these observations, a repeated measures ANOVA conducted on the *A′* data yielded a significant effect of nose context ($F(2, 32) = 5.33$, $p < 0.05$). Post hoc Newman-Keuls tests ($\alpha = .05$) indicated that discriminability was significantly greater in congruent compared to both absent and incongruent conditions, but performance in these latter two conditions did not differ.

Table 6. Mean A′ values, hit rates, false alarm rates and B″ values(standard deviations in parentheses) in each condition of Experiment 3a.

	Nose Context		
	Absent	Congruent	Incongruent
Discriminability (*A′*)	0.83 (0.12)	0.90 (0.09)	0.80 (0.17)
Hit Rate	0.89 (0.12)	0.85 (0.12)	0.74 (0.17)
False Alarm Rate	0.41 (0.26)	0.18 (0.16)	0.27 (0.21)
Response Bias (*B″*)	0.41 (0.33)	0.33 (0.47)	0.04 (0.47)

The hit rate scores also suggest that the nose manipulation affected participants' perception of direct gaze. Mean hit rates in absent (Mean = 0.89) and congruent (Mean = 0.85) conditions were higher than in the incongruent condition (Mean = 0.74). A repeated measures ANOVA confirmed that these means differ ($F(2, 32) = 6.85$, $p < 0.01$) and a planned comparison indicated that participants were less likely to decide that a direct gaze was looking at them when the nose was angled to one side than when directed straight ahead ($t(32) = 2.63$, $p < 0.05$).

Context also had a small effect on participants' false alarm rates. Of particular relevance is the observation that more false alarms were made when nose and gaze were incongruent (Mean = 0.27) than when congruent (Mean = 0.18). This suggests that nose orientation can influence the perception of an averted, as well as a direct gaze. Indeed, a repeated measures ANOVA confirmed that nose context had a significant effect on false alarm rates ($F(2, 32) = 17.80$, $p < 0.001$) and a planned comparison revealed that participants were significantly more likely to misjudge that an averted gaze was actually looking directly at them when the nose was incongruent than when congruent with the true direction of gaze.

Turning to the bias data, Table 6 shows that participants set neutral criteria in the congruent and incongruent conditions, but that - as in previous experiments - they showed a bias toward responding “direct” when the face context was removed. One sample t-tests indicated that this bias was indeed significantly different from zero ($t(16) = 5.23$, $p < 0.001$) and that bias was neutral in the other two conditions (p’s > 0.5).

Discussion

The results of Experiments 1a – 2c have suggested that the full face and head outline contour exert an influence on gaze perception. Similarly, the findings of this experiment suggest that the deviation of the nose angle alone can influence the perception of gaze direction, as suggested by Wollaston’s (1824) drawings and by Maruyama and Endo’s (1984) study. When the nose angle was incongruent with the true line of regard of the eyes, participants were less able to distinguish direct from averted gaze than when nose and gaze were congruent. As in previous experiments, the poorer discriminability with incongruent stimuli could be attributed to both a decrease in hit rate and an increase in the rate of false alarms. Participants made fewer hits as a deviated nose “towed” the line of regard of a direct gaze toward the direction indicated by the nose angle. Conversely, the increased rate of false alarms could be attributed to a leftward gaze being "pulled" toward a nose deviated to the right - and vice-versa - so participants perceived the gaze as being less averted; in other words, more likely to be direct.

Another point to note is that the effect of nose context is very much smaller than that of the full face, or the head contour manipulation in previous experiments. So, although nose deviation might, in principal, provide a cue to head direction of equal strength to the shape of the head contour (Wilson et al., 2000), the latter exerts a greater influence on gaze perception. However, we should be somewhat cautious in drawing this conclusion because – in effect – nose angle was actually in competition with head orientation in this experiment (head contour remained fixed in the "direct" orientation in both congruent and incongruent trials) whereas no equivalent competition existed for the head contour in Experiment 2a. Nevertheless, regardless of the size of influence of the nose cue, the fact that nose angle has exerted an effect on gaze perception, in spite of the presence of the head outline context, is good evidence that this cue is used in the perception of gaze direction.

Inversion of both the full face and head contour stimuli failed to eliminate the influence that these signals exert of gaze perception. In Experiment 3b, we ask whether the same is true of the nose angle cue.

Experiment 3b

In this experiment, the stimuli used in Experiment 3a were rotated through 180˚ and participants' ability to distinguish direct from averted gaze was again assessed. Again, if a higher-level configural process is responsible for producing the effect of nose angle on gaze perception, we would expect it to be eliminated when the faces are inverted. Persistence of the effect under inverted conditions, on the other hand, would implicate a lower-level image-based account. As mentioned in the discussion of Experiment 1b, Maruyama and Endo's (1984) Wollaston-like illusion *was* influenced by inversion of their schematic face stimuli leading them to conclude that a configurational integration was responsible for the illusory shift in gaze. To the extent that their Wollaston effect was induced by the angle of the nose (see above) we might also expect the influence of nose angle on gaze perception to be similarly sensitive to inversion of the face stimuli.

Method

Participants. Seventeen individuals from the same population as tested in previous experiments served as participants in this experiment.

Materials, Design and Procedure. The face, gaze and masking stimuli used in Experiment 3a were all rotated through 180˚, otherwise all aspects of the design and procedure remained the same as in Experiment 3a.

Results

Means of participants' discriminability and bias scores in the three experimental conditions are presented in Table 7. From this table it is clear that with inverted stimuli, nose context did not greatly influence participants' ability to discriminate direct from averted gaze. Indeed, a repeated measures ANOVA comparing A' scores across the three conditions failed to yield an effect of context ($F(2, 32) = 0.43$, $p = 0.66$).

Table 7. Mean A′ values, hit rates, false alarm rates and B″ values(standard deviations in parentheses) in each condition of Experiment 3b.

	Nose Context		
	Absent	Congruent	Incongruent
Discriminability (*A′*)	0.78 (0.12)	0.76 (0.13)	0.78 (0.09)
Hit Rate	0.75 (0.15)	0.70 (0.17)	0.70 (0.13)
False Alarm Rate	0.36 (0.23)	0.34 (0.17)	0.32 (0.16)
Response Bias (*B″*)	0.05 (0.32)	0.03 (0.30)	0.01 (0.29)

Nose context also appears to have exerted little effect on hit rates or false alarm rates, observations confirmed by separate repeated measures ANOVAs conducted on these data neither of which approached statistical significance (p's > 0.2).

Although, once again, participants' operated with a rather more liberal bias in the absent condition compared to congruent and incongruent conditions, the bias scores were very close to zero throughout. One-sample t-tests confirmed that none of the bias scores differed significantly from zero (p's > 0.4).

In order to compare the effects of nose context on gaze discriminability with upright and inverted stimuli an omnibus ANOVA was conducted on the *A′* data from this and the previous experiment. Context (absent, congruent and incongruent) was entered as a repeated measures factor and orientation (upright and inverted) as a between-subjects factor. This analysis yielded a marginally significant effect of orientation with better discrimination of upright as opposed to inverted gaze stimuli ($F(1, 32) = 3.99$, $p = 0.054$), and a significant interaction between orientation and context ($F(2, 64) = 4.82$, $p < 0.05$). Simple main effects analysis confirmed that context exerted an effect on discriminability scores for upright ($p < 0.05$), but not for inverted stimuli ($p = 0.56$).

Discussion

In Experiments 1b and 2b, the influence of head context on gaze perception was found to persist when the head/gaze stimuli were inverted. In contrast, the results of this experiment indicate that the influence of nose angle is eliminated under inverted conditions. Whilst some kind of image-based process seems to be responsible for the effects exerted by head contour, a rather different account – perhaps based on the encoding of spatial relations between face "features" – is implicated for the influence that nose-angle exerts on gaze perception.

General Discussion

The aim of the experiments reported here was to investigate whether the cues that are thought to be used in the perception of head orientation – the deviation of the head profile from bilateral symmetry and the deviation of nose angle from vertical – are also those which influence the perception of eye-gaze. In Experiment 1a we confirmed that the orientation of the head and internal face features can indeed influence the perception of gaze. Participants' perception of both direct and indirect gazes were "towed" in the direction of an incongruently oriented head so that a direct gaze was judged to be averted, and an averted gaze more likely to be judged as direct. Moreover, the effect on gaze discriminability was found to be uninfluenced by inversion of the stimuli (Experiment 1b), suggesting that the locus of the effect was at an early stage of processing, prior to categorisation of the stimuli as faces. The remaining experiments attempted to isolate the cues responsible for the effect. In Experiment 2a, stimuli consisting of only the outline head contour gave rise to a near identical pattern of effects on gaze perception as the full face images. This pattern was maintained when the stimuli were inverted (Experiment 2b) and, though reduced in magnitude, persisted when the eyes were always located in the centre of the surrounding face pattern (Experiment 2c). As for the second cue to head orientation – the deviation of nose angle from vertical – Experiment 3a showed that this cue also influenced participants' ability to distinguish between direct and averted gazes. Although the magnitude of the effect was much smaller than that exerted by the head contour images in the previous experiments, the pattern was identical. Finally, at odds with previous experiments, the influence of nose angle on gaze judgements was eliminated when the stimuli were inverted (Experiment 3b) implicating the operation of a higher-level mechanism perhaps based on the configural/relational encoding of the face stimuli.

So, our results suggest that those cues deemed important by Wilson et al (2000) for judging another's head angle are also capable of influencing the perception of gaze, although they seem to do so in rather different ways: head contour via a low-level process, and nose angle at a later stage in processing. In the remainder of this section, we discuss each of these mechanisms before turning to more general issues concerning the role of head orientation in social interactions.

Image-based processing of head orientation and gaze direction

Wilson et al's (2000) work together with findings by Watt (1999), Ricciardelli et al (2000) and Sinha (2000) suggest that both head orientation and gaze direction can be coded very early in processing by mechanisms that are insensitive to inversion. For example, Wilson et al. (2000) show how head shape can be coded from the visual image by V4 units that are sensitive to concentric and radial structures. When the head is oriented at 0˚ (i.e. looking directly towards an observer), the outputs from each of a number of these units arranged in an hexagonal array encode the overall head shape and the vertical axis of face elongation. Moreover, Wilson et al showed how the responses of these units are bilaterally symmetric about this axis. As the face turns, the relative pooled responses of the units to the right of the axis of elongation will differ from those to the left so that a ratio describing the degree of asymmetry can be computed. Wilson et al. showed that such a ratio has a linear relationship with the angle of deviation of the head from 0˚ up to 23˚. Thus, the symmetry axis and angles of deviations of the head outline can be extracted early in processing from the image of the face[1], a procedure that does not require the categorisation of the face as such, nor the localisation or explicit categorisation of any face features. As these V4 units essentially operate as asymmetry detectors, inversion would not be expected to affect judgements of head orientation based on this cue since the symmetry, or otherwise, is maintained in inverted images. Indeed, Wilson et al's data indicate that perception of head orientation, as signalled by a combination of head contour and internal face features, was unaffected by the inversion manipulation. Our data go one step further in indicating that the *influence* that head contour exerts on gaze perception is unaffected by inversion.

There is a suggestion that the cues to eye-gaze direction can also be extracted very early in processing. The fact that contrast negation has an effect on judgements of gaze direction (Ricciardelli et al, 2000, Sinah, 2000) points towards an image-based, rather than a purely spatially-based, representation of eye-gaze. As described earlier, Watt (1999, see Langton, Watt & Bruce, 2000) also favours an image-based account. He has argued that the contrast in luminance between the areas of sclera on either side of the iris provides a reliable cue that the visual system might use to determine gaze direction. Furthermore, he showed how this information could be extracted from the image of the eye by vertically oriented simple cells in striate cortex. As with the computation of head angle, this method of determining gaze direction would proceed equally well with inverted as with upright stimuli.

Thus, both head and gaze direction can, in principle, be computed early in processing by mechanisms that would be insensitive to inversion of the stimuli. Having extracted the relevant information concerning gaze direction and head angle respectively, presumably some kind of additive (e.g., Cutting, Bruno, Brady and Moore, 1992) or multiplicative (e.g., Massaro & Friedman, 1990) interaction takes place combining information from the two cues. An important point to note is that with these kinds of integrative interactions, the integrity of the component signals is lost; that is, a new representation of gaze direction is created from the combination of eye and head angle. This seems appropriate in the case of head contour and eye-gaze direction given that the same eye stimuli can give rise to two different percepts of gaze direction depending on the congruity or otherwise of the head contour. Whatever the precise nature of this interaction, as with the extraction of information from the component cues, it is also presumably insensitive to face inversion.

Configural Processing and Nose Angle

What of the influence of nose angle on the perception of gaze? The effect we noted in Experiment 3a was very much smaller than that exerted by the head shape in Experiment 2a and was actually eliminated when the stimuli were inverted. As suggested earlier, the reduced magnitude of the effect could have been caused by the fact that head orientation and nose angle were effectively in competition in this experiment. It is therefore difficult for us to draw any firm conclusions about the relative ability of nose angle and head-shape cues to influence the perception of gaze and it also makes our interpretation of the inversion effect a little more circumspect. However, in view of the fact that Maruyama and Endo's (1984) illusion – also probably triggered by a nose angle cue – was similarly sensitive to inversion, we suggest that the influence of nose angle on gaze judgements is unlikely to be the result of some early integration of information extracted from the image of the face, simply because the relevant image features will still be present in the inverted stimuli. The implication is that the effect arises at a later stage in processing. Another possibility, consistent with this suggestion, is that the sensitivity of the nose-effect to inversion could be caused by a difficulty in actually encoding the relevant face feature – in this case the nose – because of our unfamiliarity with upside-down faces. However, as discussed earlier, the evidence suggests that face features (nose, eyes, mouth etc.) are, in fact, encoded in inverted faces whereas the relationship between these features is not (e.g., Leder & Bruce, 1998, 2000; Searcy & Bartlett, 1996). In view of this, a more likely explanation for the inversion effect is that the nose contributes to the perception of gaze direction as part of a *configuration* of face features.

The term "configuration" is somewhat vague and has been used in rather different ways by different researchers. Holistic processing of gaze direction – an extreme version of the configural processing view (e.g., Tanaka & Farah, 1993) – would imply that neither the nose angle nor eye direction are represented separately, but that some kind of gestalt involving the internal face features signals the direction of attention. Alternatively, a somewhat less extreme "relational" processing view (e.g., Diamond & Carey, 1986) would imply that nose, eyes etc. *are* represented but that the processing of, say, the nose provides some kind of contextual modulation of the processing of gaze direction (e.g., Phillips & Singer, 1997). This form of interaction can be contrasted with the additive or multiplicative interactions suggested to operate to combine head outline and gaze direction. In the latter types of interaction, information from the two sources is actually integrated to create a new representation. Contextual modulation, on the other hand, does not involve an actual integration of signals but rather a facilitation of the processing of one variable (e.g., eye direction) by information in another processing channel (e.g., nose angle). Thus, it is possible that early in processing some kind of integrative interaction operates to combine head outline and eye-gaze direction to yield a new representation specifying gaze direction. The processing of this information might then be modulated at a later stage by the context provided by the orientation of the nose.

However, it may also be the case that the computation of nose angle itself involves a kind of configural/relational processing, so that face inversion may have disrupted this process as well as - or instead of - the contextual interaction between nose angle and eye-direction. Configural or relational processing may be involved in the extraction of nose angle because, in order to give a reliable indication of head rotation, the deviation of angle of the nose must be computed *in relation to* the vertical axis of elongation of the face, and not simply as the deviation of the nose angle from vertical in space (Wilson et al., 2000). In order to see that this must be so, consider a deviation in the angle of nose to the viewer's left. This could signal that the head is turned to the left (rotation in the horizontal plane), or that the head is tilted to the viewer's right (rotation in the coronal plane). The estimation of head angle using the nose as a cue thus involves location of the nose region[2], a computation of the vertical axis of elongation of the face and, of course, a computation of the nose angle itself. It seems as though this process is not as simple as the coding of head angle and involves a good deal of relational processing: the kind of activity thought to be disrupted by face inversion.

To summarise, we speculate that head outline operates to influence eye-direction at a very early stage in processing, possibly through some kind of integrative combination of information extracted from the visual image concerning head outline asymmetry and scleral contrast. Nose angle, on the other hand, seems to influence the processing of gaze direction through a configural interaction at a later stage in processing after the integration of head and gaze information. However, the precise nature of these interactions awaits further research.

We have shown that head angle, as signalled by whole face, head outline and nose angle, can influence the perception of eye-gaze direction. The choice of head and gaze angles in the present experiments were deliberately chosen to best produce the Wollaston illusion with the full face images; however, further work should explore whether an interaction exists over a range of head and gaze angles. Wilson et al. speculate that as head angles approach 30˚, deviations of the head profile from bilateral symmetry might be ineffective in coding head angle and that nose angle might be the principal cue under these conditions. Thus, it may be that with greater incongruities between head and eye-gaze angle, that the nose angle will exert a larger effect on gaze perception.

Although this paper has focussed on the relationship between the perception of head orientation and that of eye gaze, we should be mindful of the importance of the former as an independent social signal in its own right, and not simply as a vehicle for the eyes. We have already mentioned how the head acts as the primary cue to attention direction in infants and many non-human primates. However, perhaps it also serves as a "special" cue in adults. When engaging in a conversation research has shown how a speaker's gaze will often be averted from their partner only to return when, for example, they have finished their conversational turn (Kendon, 1967). However, during this aversion of gaze, it may be critical for the listener to maintain their attention on the speaker's face in order to process more efficiently their facial expressions and gestures or changes in face and mouth shape that can help disambiguate speech sounds (e.g., McGurk & MacDonald, 1976). Perhaps a speaker holds a listener's attention by ensuring that the orientation of their head does not stray too far from the line of regard of the listener, even though their actual eye gaze might. If this is true, the implication is that the angle of the head might actually be the more powerful cue to the direction of another's "social" as opposed to their "visual" attention direction.

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Footnotes

[1] Hancock, Bruce and Burton (1998) have serendipitously shown that Principle Components Analysis (PCA) of image pixel values can encode the angle of the head. PCA is a technique that extracts statistical regularities in a set of images and can encode various facial dimensions such as identity, expression and gender with, it is claimed, some psychological plausibility (e.g., Hancock, Burton & Bruce, 1996; Turk & Pentland, 1991; O'Toole, Deffenbacher, Valentin & Abdi, 1994).

[2] The location of face features is, itself, a far from trivial problem. However, Wilson et al (2000) suggest that location of the bridge of the nose region could, in principle, be achieved by V4 units before the sampling of orientation specific cells below this point could code its angle of deviation from vertical.