Gaze Perception and Social Attention

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Abstract

Orienting our own attention in the same direction as another person is a common example of social attention. Gaze direction and its perception offer an effective way to signal or perceive someone's current interest. Past accounts of gaze perception emphasised just geometrical cues from the seen eye. But human eyes have a unique morphology, with a large white surround (sclera) to the dark iris that may have evolved to enhance gaze processing. A series of new experiments show that the contrast polarity of seen eyes has a powerful influence on gaze perception. Adult observers are highly inaccurate in judging gaze direction for images of human eyes with negative contrast polarity, regardless of whether the surrounding face is shown in positive or negative polarity. The detrimental effect of negative contrast polarity is much larger for gaze perception than for other directional judgements (e.g. seen head direction). Cueing effects from seen gaze on the direction of the observer's own attention is also reduced for negative polarity eye stimuli. These results suggest an "expert" system for gaze perception, invariably treating the darker region of a seen eye as the part that does the looking.

Further experiments show that gaze cues can interact with cues to head angle in determining gaze perception, in a manner that depends on time pressure. New evidence is also brought for possible right-hemisphere specialisation in gaze perception, as observers are more influenced by the left visual field eye than the right eye in a seen image.

Finally, studies of gaze perception in a right-parietal patient with neglect suggest that some aspects of gaze perception can be relatively preserved even when awareness of the left eye is impaired.

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To Mum, all my family and Tim

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Chapter 1

A REVIEW OF RESEARCH ON SOCIAL ATTENTION AND GAZE PERCEPTION

Summary: "Social attention" refers to people's ability to direct the attention of others, and to have their own attention deviated by those they interact with, during social exchanges. Orienting our own attention towards the same direction or object as another person is a common example of social attention in every-day life. Gaze direction and its perception offers one of the most effective ways to signal or perceive someone's current interest. Infants and adults are exceptionally sensitive to other people's gaze direction, but this sensitivity can be lost after brain injury (to the temporal lobe). Different geometrical shape cues (e.g. the relative position of the pupil within the visible part of one eye; or a comparison of the relative positions of the pupils and irises across the two eyes) have been proposed as the basis of gaze perception. However, the role of head angle, and of the contrast polarity between the darker part of the eyes (i.e. the iris) and the lighter part (the sclera) has not been fully assessed yet, nor the relationship between attentional processes and face or gaze perception. This chapter reviews the existing evidence, while seeking a new perspective that may bring together two fruitful, yet previously disparate areas of research (i.e. on visual attention, and on face/gaze perception). From such a perspective, new questions arise about gaze perception, and about how gaze perception may direct our attention.

1.1 Selective attention

Most real-world situations bombard our senses with stimulation, but only a small fraction of this gets fully processed. For instance, if you consider looking for a friend at a railway station, you have probably experienced how hard it can be to find a face in a crowd when you do not have any clue about which platform he/she comes from. You look around searching for the "target" face, but it is likely that your attention may be distracted by other surrounding faces, so that you might even miss the person you are looking for. On the other hand, if you know roughly where he/she might come from, and keep your attention steadily in that direction, ignoring the other things that are going on around you, you are more likely to find him/her. Selective visual attention can improve your performance by filtering out all the irrelevant stimulation, narrowing your focus to prioritise the processing of relevant information.

In cognitive psychology, one way in which selective attention is classically studied is to ask a person to detect the onset of a target (for example, a light) which may appear at different locations in the visual field; reaction times are typically recorded (e.g. Posner, 1980). If, prior to the target onset, the possible target location is cued (giving an indication of where the target may appear), the subject is usually faster to perform the detection task. This advantage in processing provides one example of the facilitatory effects that spatially-selective attention can have on performance.

1.2 Social functions of selective attention

In real life, people interact with each other, talking and exchanging information, feelings and ideas. They share experience and thoughts. We make an effort to get people to listen to us and understand us. We try to draw their attention to ourselves, or to relevant objects in our environment (e.g. those we are currently talking about). In the same manner, our social partners may try to attract our attention towards their current focus of attention. The term "Social Attention" refers to these attempts to "... co-ordinate attention and actions on objects in our environment with attention and actions of our social partner" (Moore & Dunham, 1995). One example of social attention is the so-called joint-or-shared attention behaviour. When an infant draws his or her mother's attention toward a wanted object, such as a toy by gazing or pointing at it, he or she makes the mother attend to it. As a consequence, the mother and the infant's visual attention are both directed jointly to the object. This phenomenon is known as joint-attention behaviour and involves two people jointly attending to the same external object or in the same direction.

Eyes have a particular role in this ability. Gaze direction and eye contact are used by many species as a means to signal or perceive the current interest of others. For instance, looking towards a particular direction might (sometimes unwittingly) inform peers about the location of food, or some possible danger, or even about an attractive conspecific (see Byrne & Whiten, 1991; Menzel & Halperin, 1975). Staring and direct gaze have been shown to be treated by many species as signalling an imminent attack, or being threatening. Fear responses are often associated with direct gaze (Mendelsohn, Haith &

Goldman-Rakic, 1982; Perrett & Mistlin, 1990), even among humans (e.g. Argyle & Cook, 1976), although gaze contact can also signal attraction or a desire to communicate (e.g. Argyle & Cook, 1976).

Moreover, moving our own eyes provides one prominent mechanism of selective attention in vision. Moving the eyes towards a specific object or location causes that stimulus to fall on high acuity regions of the retina and thus can make it easier to recognise. Therefore for an observer, the direction of someone else's eyes can be a useful cue as to where that person is directing their high acuity vision, and thus to where they are attending in this sense. Butterworth (1991) described how babies of different ages become sensitive to where somebody else is looking, and may ultimately themselves come to look where another person is looking. This behaviour is an example of joint-attention behaviour (see earlier in this section) and it emerges fairly early in infancy, as described below. Negative emotional reactions to averted gaze have also been reported in babies, as evidence that they can discriminate gaze direction on the basis of seen eye position (Ehrlich, 1993). Developmentally, gaze-following behaviour is often thought to underlie the development of referential communication, as well as the ability to share the experiences of others. Bruner (1983) argued in particular that gaze interaction between adults and preverbal infants forms an essential precursor to initial language acquisition.

In every-day life for adults, monitoring the attentional signals provided by other individuals is essential for perceiving social relationships and social actions, which can have obvious adaptive value. Gaze perception has been described as a fundamental component of various social skills. For instance, gaze direction is normally used to regulate social interactions and conversation. Baron-Cohen (1994, 1995) has argued that gaze perception and joint-attention form essential components of our ability to understand other people's mental states: what somebody else is thinking, or feeling, and what they may be planning. Are they potentially dangerous for me, or instead, are they potential allies? Do they agree or disagree with me, etc.? On this account, while joint-attention behaviour initially starts from simple gaze-following behaviour, whereby infants usually turn their eyes and heads in the same direction as their mother or caregiver, this role in early social interactions is thought to lead ultimately to the infant's attribution of intentions to others (Baron-Cohen, 1994, 1995).

1.3 The "social brain"

From a neuroscience perspective, recent work has revealed that special-purpose neural systems exist which are dedicated to processing particular classes of social stimuli, such as faces, hands and eyes. In particular, single-cell recording in the superior temporal sulcus (STS) in nonhuman primates has shown pools of neurones which seem particularly responsive to faces and facial features. Perrett and colleagues (1990) found that cells in this region of the temporal cortex can also appear sensitive to where other individuals are directing their gaze (Perrett et al., 1990). This was extended in a further study (Perrett & Emery, 1994) which showed that some cells in STS respond to particular combinations of seen gaze, head and body directions, as if coding the perceived direction of attention of an observed animal. Such results have been taken by some authors as evidence for postulating the existence in the brain of "social modules" which are thought to be specialised for processing different aspects of social existence (Brothers, 1990).

One recent account of this kind was put forward by Baron-Cohen (1994, 1995). He argued that several specialised mechanisms in the brain may together constitute the-so called "social brain". These mechanisms were hypothesised to be part of a more general "mindreading" system, in part genetically and biologically determined. One component that Baron-Cohen proposed was termed the Eye-Direction Detector (EDD), which is specific for visual input only. Its proposed functions are to detect both the presence of eyes, and the direction in which they gaze; and ultimately to interpret this gaze in terms of what an agent sees, to provide a representational link between the looker and the object. Another component was called the Shared Attention Mechanism, which receives input from the EDD mechanism and would be responsible in humans or higher primates for shared/joint-attention behaviour, in which the self and another agent both come to attend to the same object or event (Baron-Cohen, 1995). Preliminary evidence for the distinction between these proposed mechanisms comes from studies on autism (Baron-Cohen, 1989; Baron-Cohen et al., 1992). Autism is a neuropsychiatric condition with a complex symptomology (Frith, 1989), but in which the characteristic development of shared attention behaviour can be impaired. Children with autism may show abnormal gaze-following behaviour and fail to orient their attention according to seen gaze or other social cues (e.g. Baron-Cohen, 1992). Many further social skills, including understanding what other people are thinking or desiring, are often very poor (e.g. Baron-Cohen et al., 1995). Language and communicative skills may be severely affected too (e.g. Happe', 1993). Nevertheless, if asked to indicate where somebody else is gazing, people with autism may correctly point towards the right direction (Baron-Cohen, 1995). This has been interpreted as evidence for the existence of a specialised module for joint-attention which seems to be impaired in autism, while the EDD may remain intact. Although the evidence for the proposed mechanisms is somewhat indirect when based on autism alone, it is also known that normal humans have a very high sensitivity to the direction of others' gaze, particularly to being looked at (Gibson and Pick, 1963; Cline, 1967; Anstis et al, 1969). A sceptic might suggest that Baron-Cohen's (1995) proposed components of the "social brain" seem more like descriptions of problems to be solved, rather than detailed accounts of exactly how the mind/brain does in fact solve them. However, his discussion does illustrate the widely acknowledged importance of gaze perception, and its association with social attention.

In the next sections, I review what is currently known about Shared Attention and Gaze Perception in more detail, and will eventually suggest the potential usefulness of further experimental and neuroscience studies on these topics.

1.4 Current issues in shared-attention research

1.4.1 Developmental studies of joint-attention in infants

Earlier I described social attention as the mutual tendency of an agent and his/her social partner to direct each other's selective attention towards a common object, by looking behaviour in the prototypical case. I have also stressed how perceiving the gaze direction of someone else's eyes play a critical role in these skills. Scaife and Bruner (1975) carried out one of the first developmental studies on such joint visual attention. They showed that young infants, aged from 2 to 14 months-old, would turn in the direction of an adult's (i.e. the experimenter seated in front of them) suddenly deviated gaze and head. The experimenter interacted with the baby so as to make eye contact with the baby, and then turned away from the baby to look to a target object. The baby's behaviour was video recorded. The authors used the baby's head movement towards the same direction that the experimenter was looking as an index of joint-attention behaviour, accepting the direction as correct even if the baby did not fixate exactly the same point that the experimenter was gazing towards. The percentage of infants following the experimenter's line of regard increased with age from 2 to 14 months-old .The authors described such results as an example of the development of joint-attention behaviour in early infancy.

Butterworth & Jarrett (1991) showed that while at 6 months infants could correctly look in the same left versus right direction as an adult, they did not precisely fixate the target of the adult's fixation, unless it was the first object they encountered in their visual path. They interpreted this result as the inability of young infants to exhibit correct joint-attention behaviour outside the immediate visual field. 12 and 18 month-old infants were not only able to move their eyes in the same general direction as the adult, but also to correctly locate the target even if it was the second object in their scan path. In addition, 18 month-olds infants could even search for a target behind them when the adult fixated it, but only when the visual field in front was empty of potential targets. Thus, one constraint on infants appears to be the absence of competitor objects in the visual field, if the infant is to correctly fixate the exact object of the adult's attention. Presumably, the young infant's failure with distracting objects might either be due to attentional capture by these distractors, or alternatively to relatively poor direction discrimination for the seen adult's gaze. The latter possibility could be tested in habituation studies of gaze perception.

To summarise, from all the studies reviewed so far it emerges that the utilisation of another's gaze direction seems to be a very basic process, which emerges very early in infancy, around 3-6 months. However, Scaife & Bruner (1975) and Butterworth & Jarrett (1991) studies do not prove that infants can exhibit joint-attention behaviour determined solely by the direction of adult's eyes. In fact, in all of the studies described above, the baby and the care giver were interacting with each other in a natural manner, and so the change in gaze direction was usually accompanied with head turning in the same direction by the adult (Scaife & Bruner, 1975; Butterworth & Jarrett, 1991). More recent studies with a similar method (Corkum & Moore, 1995) have suggested that only at the age of 18 months can infants follow an adult's eyes direction alone, when the adult does not make any corresponding head turn. Habituation studies show that young babies can indeed discriminate gaze direction (Maurer, 1985; Ehrlich, 1993), but it has remained unclear whether they can orient their own gaze in the same direction as others are looking without deviated-head cues. It may be that the adult's gaze alone might be too weak a signal to direct young infant's attention, when exhibited in an interactive context. Babies might find it difficult to disengage their attention from the salient central stimulus of the mother's or care giver's face, and hence would not show any gaze-following behaviour if the adult's head does not turn. Moreover, it is known that at 3 months infants cannot make large voluntary saccades (Hood, 1995). In naturalistic studies, these eye-movement restrictions might be one of the reasons why young infants do not always follow adults' gaze alone, when the adult's head does not turn. A recent study (Hood et al., 1998) tested whether these limitations may have led to an underestimation of young babies' ability to shift attention in the direction of seen gaze alone (i.e. without any adult head-turn).

Hood et al. (1998) used a computerised version of previous joint-attention paradigms to investigate whether adult's eyes alone can trigger shifts of young infants' visual attention, when the possible limitations described above are circumvented. They manipulated the direction of gaze for a digitised adult face which appeared centrally on a computer screen in front of the infant. The eyes of the face (but not the head) looked to one side, and a peripheral probe (i.e. a contrast phase-reversing stimulus) subsequently appeared either on the same side or on the opposite side (see Fig. 1.1, which illustrates the latter case). Note that the sudden onset of the peripheral probe should attract eye-movements towards it in its own right, which may simplify the task for young infants. The latency (reaction times) for the infants' eyes movement was now recorded, rather than merely whether any movement occurred or not.

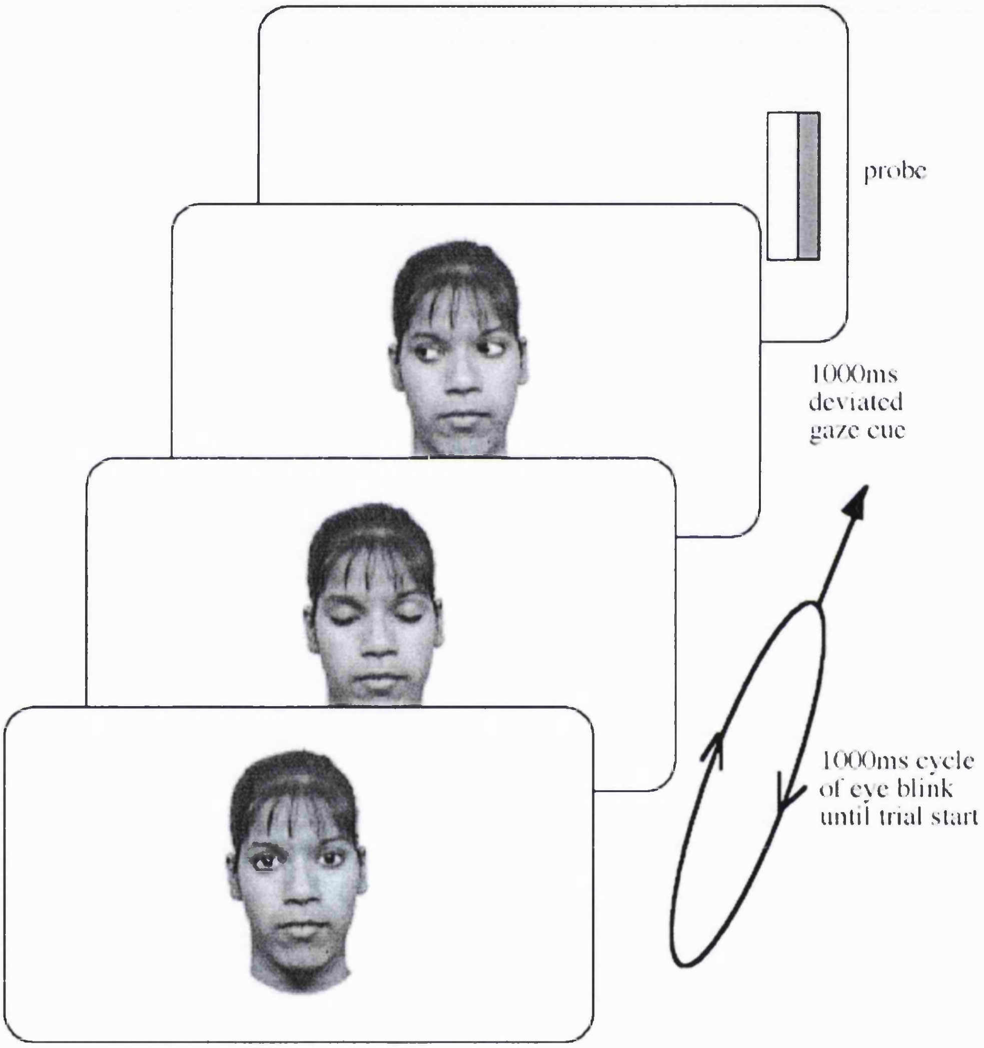


Fig. 1.1. Above an example of a stimulus sequence from Hood et al. (1998), with the face looking away from the subsequent probe in this case.

Hood et al. reported that even infants as young as 3 months were faster to direct their eyes to the peripheral probe if it appeared in the same direction that the face was gazing at (rather than in the other direction, as illustrated in

Fig. 1.1). This suggests that even such young infants reliably shift their attention in the direction that just the eyes of an adult in a picture gaze towards. This effect was stronger and larger when the peripheral probes were presented after the central face had been removed from the screen (see Fig. 1.1). This might explain why, in the previous literature on naturalistic interactions, the same sensitivity to eye-direction alone has not been reported in such young infants. According to Hood et al., the lack of this effect in previous work might be due to the infants' tendency to anchor their attention on the salient central stimulus of the adult's face itself. This possible confounding is difficult to disambiguate for previous interactive joint-attention paradigms. The Hood et al. study (1998) is the first study which showed that even 3 month old infants can in principle use adults' deviated gaze alone (i.e. with no head-turn by the adult), to shift their attention in the corresponding direction.

1.4.2 Studies of gaze perception and joint-attention in adults

The literature on social attention that I have reviewed so far has focused on babies. Within developmental research, joint-attention behaviour has become a well-known phenomenon. However, in the adult literature, very little had been described or reported on the same topic until quite recently. Studying the mechanisms of joint-attention in adults might address issues that would be difficult to approach with babies. For instance, adults' joint-attention behaviour might be more sophisticated, since a person might voluntarily orient his/her visual attention towards where another person is gazing but without moving their eyes (i.e. *covert* orienting of attention; Posner, 1980). On the other hand, an adult's joint-attention behaviour could remain primitive in the sense that their attention might still be automatically deviated by somebody else's gaze, unintentionally and reflexively. While the study of joint-attention in babies can inform us about its developmental time course, studying adults' behaviour might provide further understanding of the attentional and perceptual mechanisms underlying this phenomenon. In addition, more precise measures of performance can be obtained with adults, as tasks different from just the naturalistic gaze-following one (normally employed in developmental studies) may readily be used. Recall that cueing visual attention to a specific location in space improves people's performance there (Posner, 1980). Hence one suitable way to test joint-attention phenomenon in adults might be to look for any analogous cueing effects from seen gaze and/or face cues, on tasks like detection or discrimination of peripheral targets. Several recent studies (Langton & Bruce, 1999; Friesen & Kingstone, 1998; Driver et al., 1999) did exactly this.

Langton & Bruce (1999) used a variation of the standard Posner cueing paradigm to study whether the direction of a seen person's social attention could produce reflexive orienting of an adult observer's own visual attention. Recall that the cueing paradigm had previously been developed by Posner (1980), within the mainstream of "pure" visuospatial orienting research on attention. In a typical Posner situation, subjects were asked to detect the onset of a peripheral visual target, which might appear at any of several locations. Before the target onset, the subjects' attention could be drawn to one of the possible locations by some kind of cue (i.e. a brief peripheral light, or a central arrow) which may or may not predict where the target was going to appear. The typical finding is that target detection is faster at the cued location compared to the uncued ones. This effect, known as spatial cueing, is thought to be due to visual orienting of attention in the cued direction. Langton and Bruce (1999) used a slightly modified version of Posner's paradigm in which the cueing stimuli, presented centrally, were photographed head and eye signals. Adult subjects were asked to detect a target letter at one of four locations on a visual display. One of those locations was previously "cued", by a photographed face that was turned towards it (as seen in Fig. 1.2). This cue could predict that target location, or be spatially nonpredictive, in different conditions.

Fig.1.2. Examples of four different stimuli used as cues in Langton and Bruce's study. (From Langton and Bruce, 1999).

Detection latencies for the peripheral stimuli were used as a measure of subjects' attentional shifts. Faster RTs were found for targets at cued than at uncued locations, even when the face cues did not predict where the target would occur. Langton & Bruce (1999) argue that these findings provide evidence for a reflexive ("exogenous") orienting mechanism driven by social-attention signals in adults.

Driver et al. (1999) adopted a similar behavioural measure to test the automaticity of orienting visual attention in the direction of just a seen gaze (i.e. when the eyes were deviated in the seen face, but the seen head did not itself deviate from a frontal view, unlike Fig. 1.2). A computerised face was presented centrally, with the direction of just its gaze being manipulated. The task was speeded discrimination of a peripheral letter, which could appear on either side. The direction of gaze in the central face could be either uninformative of target location (as in Langton & Bruce's study) or counter-informative (i.e. the target letters were now four times as likely to appear away from where the computerised face looked). Driver et al. (1999) found faster letter discrimination for cued locations when the seen gaze was uninformative. More interestingly, they also found faster RT on the side towards which the face gazed, even when people knew that this gaze direction was counter-informative, thus suggesting a strongly automatic tendency to attend where the seen face looked.

In a similar study, Friesen & Kingstone (1998) used a cueing paradigm in which the cue was a central drawing of a cartoon face, gazing either left or to right, or straight ahead. This cue was first presented with the "eyes" closed, and then after a brief interval, the eyes "opened" to show gaze direction. The direction of the cartoon gaze did not predict which side the peripheral target letter would appear on. Three different tasks (detection, localisation and identification of a target) were used for these peripheral targets, with subjects' reaction times being recorded in each case. Friesen & Kingstone (1998) found faster latencies for targets on the side the cartoon face looked towards in both the detection and localisation tasks.

In all these three studies, a common finding was thus the presence of a cueing effect, which produced faster target latencies for the side to which the computerised face looked and/or faced. However, the cueing effect was present only when the cue appeared at a short interval (100-300 ms) before the onset of the target, suggesting a short-lived effect. Most interestingly, in the Driver et al. study, the effect was found at these early intervals even when the subjects did not have any motivation whatsoever to follow the direction of the seen gaze (i.e. in the counter-informative condition). These studies strongly suggest that social stimuli, such as eyes and faces, can serve as a powerful cue to attract or orient social attention. They illustrate that joint-attention can be studied successfully in adults, as well as in babies.

Moreover as mentioned earlier in this section, by applying more controlled experimental paradigms to adults, new knowledge of the mechanisms underlying joint-attention may be achieved. Recently, different proposals about the nature of those mechanisms have been put forward by several authors: i.e. automatic and gaze-driven mechanisms (e.g. Baron-Cohen, 1995; Driver et al., 1999); mechanisms that depend on spatial cognition, such as the representation of the space behind one own's head (Butterworth & Jarrett, 1991); or even specific neuroanatomical substrates (Perrett & Emery, 1994). However, so far no agreement has been reached. A common belief (e.g. Leslie, 1991; Baron-Cohen, 1994) is that there are specialised modules which are responsible for the emergence of different aspects of joint-attention during the course of development, including gaze perception.

The cueing studies just described (i.e. Langton & Bruce, 1999; Driver et al., 1999; Friesen & Kingstone, 1998) suggest that the perception of somebody else's gaze can automatically trigger attention shifts in corresponding direction. But how is the direction of gaze perceived by the observer? Are people accurate at perceiving this? What cues does the human visual system use in perceiving gaze direction? In the next section, I will review several studies on these issues.

1.5 The gaze perception literature

Evidence for gaze sensitivity in babies has been reported quite extensively in the previous sections. What emerges is that infants can use eye position as indicator of gaze direction, but how they do so is still not clear-cut. In the adult literature, gaze perception has been studied more systematically, by a few classic studies (Gibson & Pick, 1963; Cline, 1967; Anstis et al., 1969; Ehrlich & Field, 1993). In the present section I will focus on gaze perception in adults and brain-damaged adult patients, with an emphasis on what cues from seen eyes the human visual system may use to perceive gaze direction.

1.5.1 Gaze perception in adults

There have been many claims that people are exceptionally good at perceiving the direction of somebody else's gaze, but only a few formal studies have examined this in detail. In these studies, gaze perception was examined through psychophysical techniques for measuring people's sensitivity to gaze direction. The pioneering study on the perception of looking behaviour was carried out by Gibson & Pick (1963). For the first time, eyes and gaze were studied as spatially informative regarding the direction of someone's attention, rather than solely as expressions of emotion. Gibson & Pick (1963) were particularly interested in studying the acuity with which a shift from direct to indirect gaze could be detected by an observer (see Fig. 1.3). They hypothesised that it is the position of the pupil/iris within the sclera which informs an observer of someone's gaze.

Fig. 1.3. Schematic example of centring or off-centring of the pupil/iris in the sclera, for direct versus indirect gaze, (adapted from Gibson & Pick, 1963).

In particular, the authors argued that the position of the pupil/iris within the sclera, plus the orientation of the head in the space, can act as combined cues for the observer as to the direction of the observed person's gaze (see Fig.1.4 on the next page). In their experiments a real person (i.e. the looker) was employed as a source of controlled social stimulation. The subject (i.e. the observer) sat opposite the looker at a distance of 2 m.

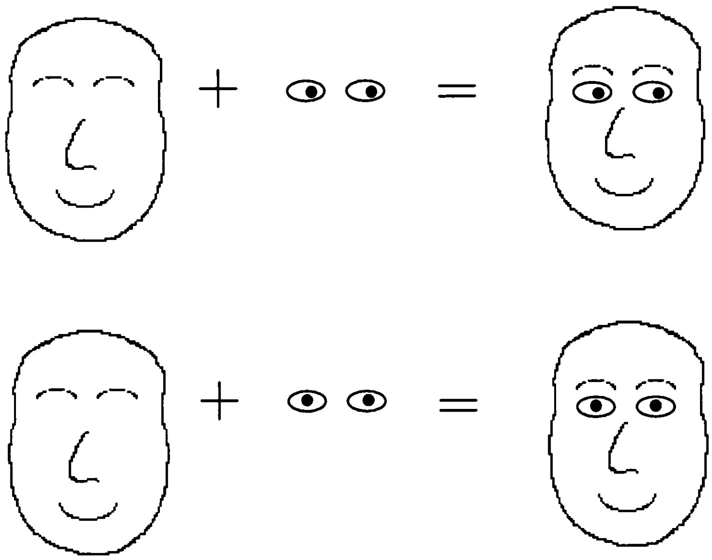
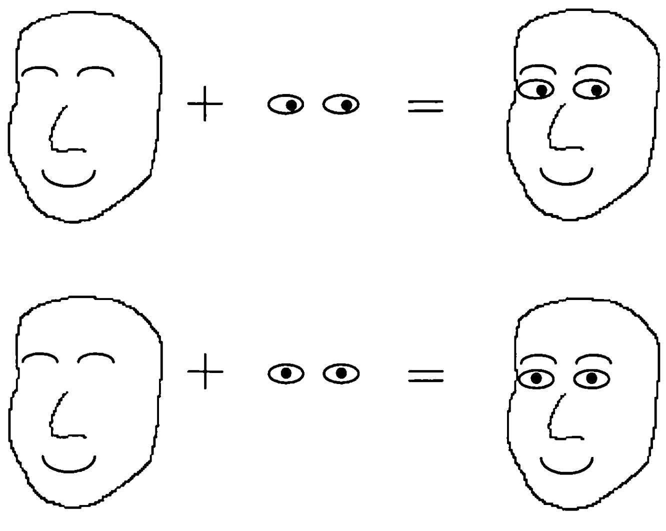


Fig. 1.4. The above two rows show the same eye-shapes as in Fig. 1.3 , but now surrounded by a quasi-frontal view of a face. The two rows beneath this caption show the same eye-shapes but now surrounded by a face turned further to the viewer's left (from Gibson & Pick, 1963). If you compare these figures, you should see the apparent shift in gaze direction when the head is turned further. For instance, eyes gazing to the right in the straight head seem to be gazing straight at you in the turned head, while those which look straight ahead in the frontal view of the face seem to look to the left in the deviated head.



The looker gazed at one of seven eye-positions (marked on the wall behind the observer's head, as shown in Fig. 1.5), in one of three head-postures relative to the observer (i.e. facing the observer, turned 30^0 right, or turned 30^0 left).

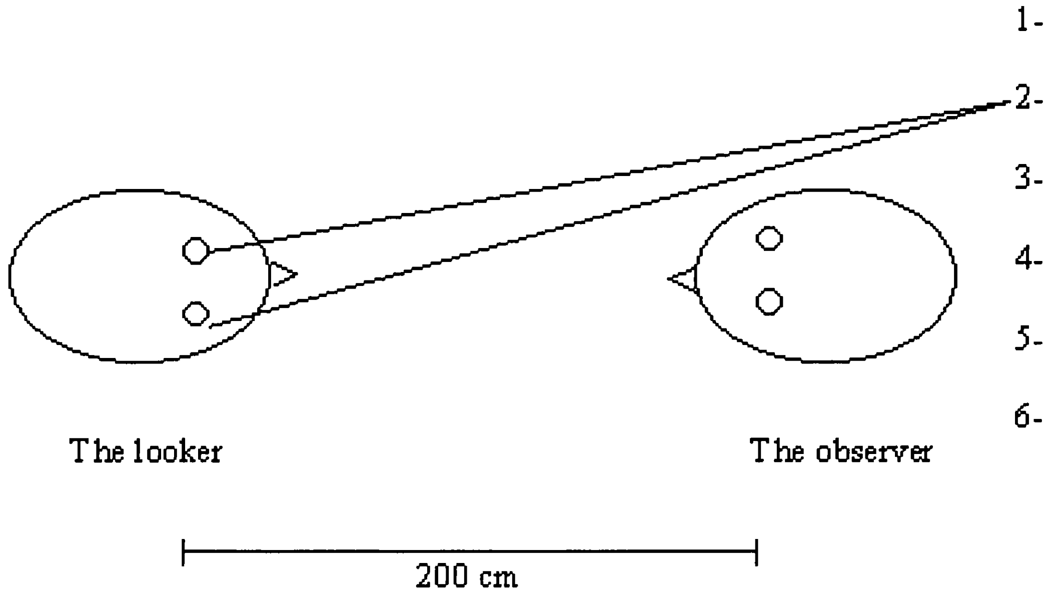


Fig. 1.5. Schematic example of the experimental setting, from above, in Gibson & Pick, (1963), with the looker's head facing the observer.

The middle eye-position (marked 4 in Fig. 1.5) was actually the bridge of the observer's nose, and the others were to his right or left. The observer was asked to judge whether he was or was not being looked at, by making a "yes or no" judgement. Gibson and Pick were interested in measuring, in particular, the smallest (just noticeable) deviation of the looker's line of regard that could be detected from the bridge of the observer's nose. They plotted the mean frequency distributions of "yes" responses for each head-position (see Fig 1.6 below) and calculated the standard deviation (SD) for each of them. The SDs were assumed to be a measure of the precision of judgements (that is, the greater the SD the less accurate was the judgement).

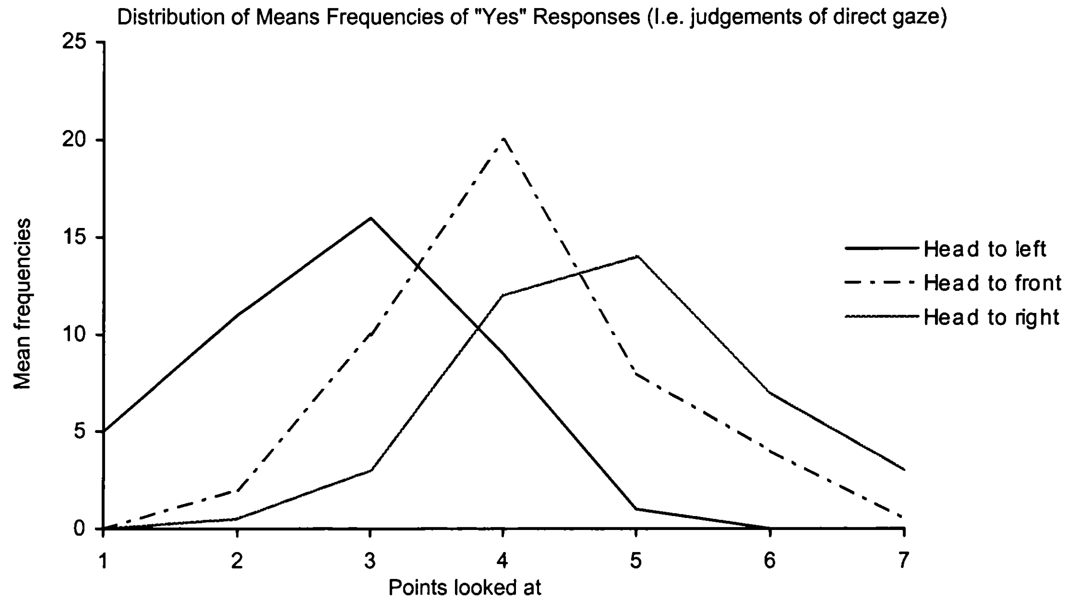


Fig. 1.6. Distributions of the "Yes" judgement means at seven different eye-positions for each of three head-positions (From Gibson & Pick, 1963).

They obtained two main results. First of all, they found small SDs (less than one step on the scale of fixation points) for each head-position while the latter were not significantly different from each other in this respect. Second, for the deviated head positions, they found a systematic constant error in the judgement means (i.e. mistakes tended to misallocate eye direction away from the direction the deviated head, from the observer's viewpoint), as seen in the shift of the distributions (Fig. 1.6). We will later refer to this second result as the "reverse congruency effect"; as the eyes seem less deviated when deviated in the same direction as the head (see also Fig. 1.4). Although the first finding was essentially a null result, Gibson & Pick concluded from it that what is detectable from the observer is "... the absolute orientation of the eyes in space..". According to their proposal, the actual stimulus used for the perception of the direction of gaze is the shape projected by the eyes relative to the shape projected by the face (see Fig. 1.4). On the other hand, the significant constant error found for the head-turned situations (see Fig.1.6) led them to argue that the position of the head biases the discrimination of gaze, interfering with the judgement of the direction of the eyes to some extent. It seems plausible that the visual system takes into account the position of the head and, thus, tries to compensate for it. However, the constant error found in Gibson and Pick's study suggests that the visual system does not compensate enough for the deviated head. In particular, when the head is deviated towards one direction, the eyes themselves do not need to deviate as much in their sockets to look in that same direction (see Fig. 1.4), and viewers seem to underestimate this influence.

Using the average SDs for all the "yes" judgement responses-distributions as a measure of the just noticeable deviation of the looker's line of regard from the observer's nose, Gibson and Pick inferred the exact threshold for this. It was concluded that people can detect a displacement from direct gaze of about 1 mm at a distance of 200 cm. This is a very sensitive threshold, very close to the one calculated for reading fine print on an acuity-chart. Overall, then, Gibson and Pick's results are important not only because for the first time they formally confirmed a high sensitivity to gaze, but also because they showed that the judgement of eyes can depend on head orientation, as shown by the constant errors (i.e. the "reverse congruency effect"). The null result reported for the difference in variance at different head orientations might have been due to a lack of power in the data, and thus does not provide particularly strong evidence for true independence of gaze perception from head orientation. It is fairly surprising how often this finding has been misdescribed by subsequent authors (e.g. Cline, 1967).

In a later study, Cline (1967) did find worse performance in gaze judgements with deviated head angle, both in constant error, and also in variability (i.e. SDs). Contrary to the usual description of Gibson and Pick, this thus confirms that head angle can indeed have an effect on perceiving the direction of gaze. A better control on the experimental setting was achieved in Cline's study, since no direct interaction between the looker and the observer was allowed, and both horizontal and vertical dimensions were now tested. The experimental apparatus comprised a half-silvered mirror which projected an image of the looker's eyes to the subject. The looker gazed at one of 13 different target positions on a target board in front of him. The subject's task was to indicate on a response board the exact position that the eyes gazed at (the response board comprised 65 dots, including 13 which had the same coordinates as the targets). The response board and the target board were arranged such that the common positions on each board overlapped, and each target fixated by the looker had a corresponding position on the response-board. Unlike Gibson & Pick, acuity for gaze in several directions, not only looking straight at the subject, was now studied. Three different head conditions were also tested (i.e. head straight, and head turned either 30^0 towards the same direction of the eyes (congruent) or 30^0 towards the opposite direction (incongruent)). As in Gibson & Pick (1963), Cline considered both the constant errors and the standard deviations as different measures of subjects' acuity for gaze direction. The findings revealed that the greatest interference from head orientation occurred in the congruent condition (greater SDs, and constant error away from the direction of the turned head on the horizontal axis), while the best performance was found when both the eyes and the head were straight. A more sensitive threshold for gaze directed at a central target (i.e. a displacement of 0.18 mm was detected at 200 cm) was found, suggesting that, compared to Gibson and Pick's study (1963), the changes in methodology introduced in this study contributed to better judgements of gaze perception. However, in line with Gibson and Pick's proposal, Cline (1967) argued that the cue in the eyes used to judge the direction of gaze is purely geometrical; he suggested that the position of the iris (i.e. the dark region around the pupil) relative to the visible sclera (i.e. the "whites of the eyes") is crucial for gaze perception.

Anstis et al. (1969) took this proposal a step further. In their experiments they used three different procedures but the task was always the same (i.e. to judge the direction of seen gaze). There were nine target positions on either side of the centre (i.e. -20^0, -15^0, -10^0,-5^0, 0^0, $+5^0$, $+10^0$,$+15^0$,$+20^0$). As in Gibson & Pick's study (1963), in one procedure the looker and the subject were interacting, with the looker gazing directly at the subject's head, or close to it. In the second procedure, similarly to Cline's study (1967), the subject did not interact directly with the looker but saw the looker's face on a TV. Finally in the last procedure, the looker was replaced by an artificial eye (made from a table-tennis ball, surrounded with an artificial socket and no face-like context!). The subject still had to judge the direction of "gaze" for this artificial eye. The looker (or ball!) gazed at one of nine possible points marked on a horizontal scale. As in the previous studies three different head positions were considered: head facing straight towards the subject, head turned 30^0 clockwise to the subject's left and head turned 30^0 anti-clockwise to the subject's right (the artificial eye-socket was rotated through these same angles in the experiment on artificial eyes). The subject's response was made by marking on the horizontal scale the point at which the looker (or artificial eye) seemed to be gazing.

For each condition, Anstis et al. (1969) summarised the data by means of a regression equation ($y=mx+c$) where y represented the actual subject's judgement, c any constant directional error made by the subject, and m the systematic error made in judging the gaze (i.e. particular over- or under-estimation of the angle of looker's gaze). The authors found a consistent <u>overe</u>stimation of the angle by which the looker's gaze was turned away from the observer. They explained this by arguing that the cue that the human visual system uses to judge the direction of gaze is a "pure" geometrical fact, consisting of the angular displacement of the pupil and/or iris from the centre of the eye. However, since the visual system can "calculate" the angle of this displacement only by relying on the visible part of the eye (and only a small portion of the eye-ball is visible at any one time), the perceived angle turns out to be bigger than the actual one. In fact, if you consider a sphere which represents the eye ball, and the angle subtended between two points at a particular separation on its surface, that angle will be larger for the same separation along the surface of a smaller-sphere (such as that which might represent only the visible part of the eye ball, rather than its full extent). Conversely, similar angles lead to different distances along the surface for spheres of different sizes (see Fig. 1.7).

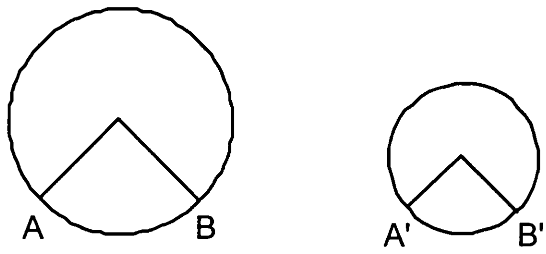
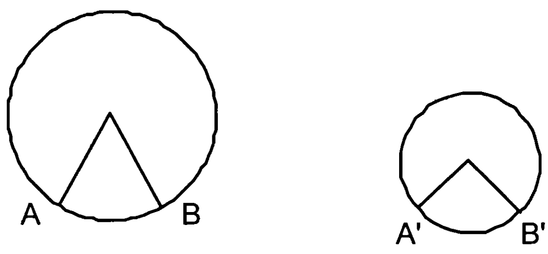


Fig. 1.7. In the example above, AB and A'B' subtend the same angle but the distance between A and B on the left sphere is larger than that between A' and B'. Conversely, in the figure below, the distance between A and B and between A' and B' is the same, but the angle subtended by AB is smaller than the one subtended by A'B'.



The error which would derive from estimating the size of the eye-ball from only its visible extent is constant (as Anstis et al., 1969, found), in line with the authors' claim that it is the different amount of exposed white on either side of a stationary pupil which is used to perceive gaze direction. Surprisingly, according to Anstis et al.'s account, the human visual system has apparently never learnt how to correct for the difference between the visible size of the eye, and the actual size of the entire eyeball!

In my view, Antis et al.'s paper is important for two reasons. First of all, they correctly described the "head turned" effect already found by Gibson & Pick (1963) and by Cline (1967) for the first time. As mentioned earlier, a greater constant error in judging the direction of the looker's gaze occurs when the head of the looker is turned. Specifically, turning the looker's head cause an apparent shift of his/her gaze in the opposite direction (the "reverse congruency effect", see Fig. 1.4). For instance, when the looker's head is turned to the observer's left and the looker is gazing to the observer' left, the observer may perceive the looker as gazing straight at him and not to his left. Anstis et al. explain this as being due to the observer basing his/her judgement on the position of the iris relative to the sclera, without taking sufficient account of the fact that with a deviated head, the eye doesn't need to deviate as far in its socket to gaze in the same direction as the head. Secondly, Anstis et al. extended this result by carrying out an experiment where an artificial eye (a table-tennis ball!) was used as the stimulus.

1.5.2 Seeing two eyes together provides a better cue for gaze perception

More recently, a somewhat different account for the high acuity of gaze perception has been put forward by Ehrlich & Field (1993). They argued that the position of the iris relative to the sclera in one eye is not sufficient to perceive gaze direction, since this cue alone does not take into account the different shapes of different people's eyes. Certainly, it may be that shape features from a single eye are inadequate for the accurate perception of gaze direction, since there is a great degree of individual variation in eye shape. Ehrlich & Field showed that a comparison of the relative position of the iris and sclera across the two eyes of one person (specifically, a judgement of symmetry) may account better for subjects' performance. Unlike the studies described so far, Ehrlich & Fields (1993) presented as stimuli either just one eye, or both eyes (as shown in Fig. 1.8 (a) and Fig. 1.8 (b)).

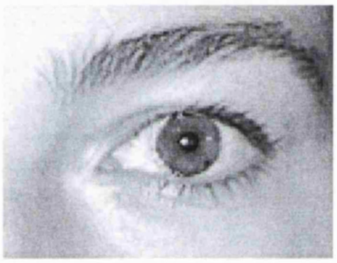


Fig. 1.8 (a). Above shows the one-eye condition similar to that used by Ehrlich &Field (1993).

Fig. 1.8 (b). Above shows an example of the two-eye condition. Adding the left eye enhances the percept of where the person is looking.

They found a loss in accuracy when only one eye was presented. Given that different people have different amounts of white on either side of the iris when gazing ahead (due to individual differences in eye shape), relying only on this cue could lead to confusions. In order to perceive that someone is gazing straight ahead, a comparison of the two eyes may be necessary. In particular, Ehrlich & Fields (1993) argued that symmetry between the two eyes arises only in the case of direct gaze (at least, with a frontal view of the face).

Several new questions arise once it is realised that a comparison of the two eyes may be necessary. First, Ehrlich and Field (1993) proposed that a comparison of symmetry across the two eyes is required for gaze judgements, to take into account the fact that different people have differently shaped eyes. However, while symmetry may indeed be useful when the head is straight, as soon as the looker's head is deviated, there will no longer be any symmetry between the two eyes (in the projected image even when the looker gazes directly at the observer). Ehrlich and Field (1993) did not test this situation. Second, what happens if, following brain damage, subjects lose the ability to deal with both eyes? This could be the case in neglect patients with right parietal damage, for example. In neglect, the processing of contralesional (left-sided) stimuli is severely impaired (as described later). Could any impairments in perceiving the direction of gaze be found in such patients? According to Ehrlich and Field (1993), if comparing the two eyes is crucial in gaze perception, studying this in neglect patients (who usually neglect the left half of the stimuli they are presented with) may reveal a pathological dominance of the right eye when judging the direction of seen gaze, since the leftmost of the two eyes should be neglected. In the following, neuropsychological section I will discuss this issue in more detail.

1.6 Loss of gaze sensitivity after brain damage

The ability to perceive the direction of seen gaze is one of several visual abilities which can be lost after brain injury (e.g. Perrett & Mistlin, 1990). It is well known that in the brain, the primate visual system includes two main cortical pathways subserving different kinds of visual processing (see Humphrey & Weiskrantz, 1967; Trevarthen, 1968; Milner & Goodale, 1995). On the one hand, the ventral stream which runs from occipital areas into the inferotemporal cortex is thought to be implicated in object recognition. On the other hand, the dorsal stream running from the occipital cortex up into the parietal lobe is thought to underlie the representation of space, and possibly spatial attention. Damage to certain visual areas in the temporal lobe (i.e. a ventral lesion) can lead to a deficit in face processing, known as "prosopagnosia" (Bodamer, 1947; De Renzi, 1986). In prosopagnosic patients, the ability to perceive or recognise faces is disrupted. A selective impairment for the identification of faces, but not for other classes of object, can be shown in some cases (Bodamer, 1947; De Renzi, 1986). Gaze perception may be related to face processing, since gaze is one important aspect of faces, but only a few studies have investigated whether gaze perception is disrupted in prosopagnosic patients. Campbell et al. (1990) carried out a study seeking to investigate the sensitivity to seen gaze direction in such patients, and also in monkeys with ablation of the superior temporal sulcus (a region of the temporal lobe thought to be involved in coding information about eyes and gaze; see Perrett & Mistlin, 1990). In a forced-choice detection task, human subjects and monkeys had to detect when a photographed face was looking at them. The authors found impairment in this task both in the prosopagnosics, as compared to two normal humans controls, and also in the lesioned monkeys. In the latter, sensitivity to gaze direction was impaired after the STS ablation. These results are important since they suggest the involvement of specific ventral stream areas (STS) in the ability to judge seen gaze in the monkeys. Moreover, recordings from single-cells in this area have also shown a selective responsiveness of those cells for the direction of gaze in a seen face (Perrett & Mistlin, 1990).

The dichotomy between ventral and dorsal streams, and the apparent separation of these two cortical routes, is not absolute. In fact, in a physiological single-cell recording study where the distribution of cells' projections was also studied with retrogradely transported fluorescent dyes, Harries and Perrett (1991) found a strong temporoparietal projection which originated from the STS and projected to the parietal cortex. The authors argued that "... the temporoparietal projections could provide a route through which temporal lobe analysis of facial signals about the direction of other's attention can be passed to parietal systems...". If so, it would not be surprising if dorsal stream lesions in the parietal lobe could have their own influence on the response to such facial signals. Unilateral neglect, which I briefly introduced in the previous section, is a relatively common and disabling syndrome following dorsal lesions (especially those involving right parietal damage) in which the patient ignores or fails to respond appropriately towards events on the contralesional (usually, left) side of space (e.g. Robertson & Marshall, 1993; Rizzolatti & Berti, 1993). Of particular interest for my argument, the typical lesion in such patients is far away from the ventral areas thought to be involved in face and gaze perception. Nevertheless, face processing can be impaired in neglect patients, as they often seem unaware of information towards the contralesional side of a face (typically, its left side). Young et. al (1992) reported the case of one patient (B.Q.) who following a stroke in the right parietal region showed visuospatial neglect, and marked problems in recognising the left side of seen objects and faces. Furthermore, a more specific form of unilateral neglect has been described that apparently only affected the left side of faces (Young et. al, 1990). That is, patient K.L. only showed left neglect in face-processing tasks.

Studying in more detail how neglect patients perceive and respond to faces should be particularly revealing about how the dorsal attentional processes thought to be impaired in these cases can influence ventral recognition processes for gaze and faces. Earlier, it has been suggested that sharing a common representation of space may be crucial for people to successfully engage in "joint-attention" behaviors (Butterworth & Jarrett, 1991). This might, or might not be preserved in neglect patients. If the neural circuits for social attention are distinct from those involved in general visual attention, then it should be possible to find dissociations between neglect patients' abilities in these two realms. Furthermore, as discussed earlier, it has been shown that in normals both eyes of a face must be seen for highly accurate judgements of where that face is looking (Ehrlich and Field, 1993); how might neglect influence gaze perception, given this? Does the patients' pathological spatial attention modulate their gaze perception? Neglect patients, who are usually unaware of the contralesional side of a face (Young et al., 1992), might either still process this side implicitly, in which case it could be available to influence their perception of the direction of gaze, or they might show an abnormal bias in gaze perception, basing their judgements on only the ipsilesional (right) eye.

1.7 Effect of contrast polarity on face perception; and its possible influence on gaze processing

In the previous section I have stressed how gaze perception could be studied within a neuropsychological context and, in particular, how it might be usefully related to attentional deficits, such as neglect. It has been suggested that eyes and gaze perception could be considered special stimuli, given their particular biological significance, and their important social functions. Furthermore, I have argued for the plausibility of some sort of special neuro-cognitive mechanism underlying their processing. Further evidence for the "special" nature of faces and eyes as visual stimuli (or at least, of our particular expertise in perceiving them) comes from purely behavioural effects with normal adult subjects. Given length constraints, I will not review all of the extensive literature on face perception (e.g. Bruce and Young, 1998 for a review), but I will highlight two potentially relevant effects. The first is the "face inversion" effect. Across several studies it has been shown that the recognition of stimuli which have a conventional upright can be disrupted when they are presented upside-down. This effect, known as the inversion effect, is usually much stronger for face stimuli than for other classes of objects (Yin, 1969; Ellis, 1975; but see also Diamond and Carey, 1986).

A second effect suggesting the possibility of "expert" systems for gaze perception is "the negation effect", which may also be particularly interesting for the further study and understanding of gaze perception (see Chapters 2 and 3). The identification of a face in photographic negatives is extremely difficult (Galper, 1970; Philips, 1972), despite the fact that the geometrical layout of facial features (and all the associated edges and spatial frequencies) remains the same whether faces are shown in positive or negative format. The usual explanation for this effect refers to the extraction of 3D cues by the visual system, based on the correct interpretation of shadows (e.g. Kemp et al., 1996). The visual system appears to follow a simple rule, that shadows have to be darker than the rest. In negation, reversing the direction of contrast polarity disrupts the perception of 3D cues from shading, since shadows now appear as brighter regions and so are misinterpreted. Thus, the 3D percept of shape-from-shading is lost, and that makes the recognition of faces particularly difficult.

Recently, the role of contrast polarity in face recognition has been investigated in two papers. Bruce and Langton (1994) used laser-scanned head volumes (which measured the exact 3D surface layout of human heads) as stimuli, and found a dramatic drop in recognition for famous faces when the same face was presented in photographic negative. The authors suggested that this negation effect might either have been due to reversing the normal pigmentation values, and/or to inverting the apparent patterns of shading produced by self-shadowing. In a subsequent paper, Kemp et al. (1996) carried out three experiments aiming to separate the influences of shape-from-shading, and of the apparent pigmentation of the face. For the first time, the hue and the luminance component of face images were independently manipulated. Kemp et al. (1996) found that although changes to face pigmentation caused some errors in identification, it was the loss of shape-from-shading cues which better accounted for the negation effect. These new findings thus fit with the proposal mentioned earlier, according to which the recognition of individual faces depends on the correct perception of the 3D surface-structure of the face, based on shape-from-shading cues.

The effect of negative contrast polarity on face perception thus now appears to be well understood. In the next two chapters, I will report new experiments aimed at investigating how negation of contrast polarity might affect gaze perception.

1.8 Gaze perception and the unique morphology of the human eye

As mentioned earlier, several authors have noticed (e.g. Anstis et al., 1969) that the usual high contrast in seen eyes between the pupil/iris, and the white surrounding sclera, may help extraction of those geometric form cues to gaze direction that are given by the position of the iris in the sclera (and by the relation of this across the two eyes). More recently, Kobayashi & Kohshima (1997) have shown that human eyes have a unique morphology; only human eyes have a widely exposed white sclera surrounding the darker coloured iris. Other species, including other primates, lack the large extent of contrasting white sclera. This difference in contrast between the lighter part of human eyes (the sclera) and the darker part of the eyes (the iris), has long been thought to be important for detecting the direction of gaze, by highlighting the geometrical cues discussed earlier. However, surprisingly, nobody seems to have commented on the possibility that, analogously to the negation effect for face perception, the polarity of this contrast in seen eyes may be critical for gaze perception. The next two chapters test whether gaze perception is particularly impaired for negative images of eyes.

Conclusions

Four general questions have emerged from this review. First, how does visual attention as characterised in previous work relate to more social situations, involving shared or joint-attention behaviour? Gaze perception now appears to direct visual attention automatically, but the exact mechanisms for this remain unknown. Second, more investigation is needed into the exact cues used by the visual system to perceive gaze direction (and then use it as an attentive cue). Thus, what are the exact cues used by the visual system to judge gaze, and how does this vary when the head is also turned? Third, do the factors known to influence face perception (e.g. negative contrast polarity) have similar effects on gaze perception? Fourth, how might gaze perception be affected by the pathological disorder of attention and spatial representation that is seen in neglect patients? I will address each of these questions in the following experimental chapters.

Chapter 2

EFFECT OF CONTRAST POLARITY ON PERCEIVING THE DIRECTION OF GAZE

As outlined in the previous chapter, there are several reasons to study how the human visual system perceives the gaze direction of other people; some of theoretical importance and others of more practical interest. In every-day life, visual looking is often equivalent to paying attention to an object or event, or orienting toward it. Hence, the direction of someone's gaze can indicate the attentional state of that person to an observer. It is known that observers can judge the direction of someone else's gaze quite well, and experiments show that they are particularly accurate at judging whether another person is looking at them (e.g. Cline, 1967). An interesting question ~~be~~ is which visual cues people use to analyse seen gaze direction. Several cues have been proposed, such as the relative position of the iris within the visible part of the eye (Anstis, Mayhew, and Morely, 1969; Gibson & Pick, 1963), or the configuration produced by this relation across the two eyes, in terms of any symmetry between them (Ehrlich & Field, 1993). In fact, although the specific cues which have been suggested for gaze perception vary somewhat from one author to other, *all* proposals to date have concerned purely geometric cues about the shape or form of the eye region. An important feature of human eyes may have been neglected.

As shown by the comparative studies of Kobayashi & Kohshima (1997), human eyes have a unique morphology. They have a widely exposed white sclera surrounding the darker coloured iris. Other species, including other primates, lack the large extent of contrasting white sclera. This difference in contrast between the lighter part of the eyes (the sclera) and the darker part of the eyes (the iris), might be crucial for the human ability to accurately judge the direction of gaze, in addition to the already proposed geometrical cues. Indeed, several authors have remarked (e.g. Anstis et al, 1969) that this high contrast may help extraction of the geometric form cues to gaze direction that were mentioned above. However, surprisingly, nobody seems to have commented on the possibility that the polarity of this contrast may also be critical. The iris is invariably darker than the surrounding sclera in human eyes. Our visual system may have evolved, or may have learnt, to exploit this, by always coding the darker region of the eye as the iris when extracting form cues concerning its relative position. If so, what would happen if we reverse the eye contrast artificially, making the sclera darker and the iris lighter, while leaving everything else in the eyes unchanged (i.e. the same geometry, so that all form cues such as edges, spatial frequencies, shape and relative position etc. remain intact)? Are people still good at judging the direction of the gaze, or is their performance severely disrupted by this manipulation? If performance were disrupted, this would indicate that gaze judgements are not based on geometrical factors alone, but depend critically on the assignment of darker regions in the eye as the iris.

Overview of the experiments in this chapter

In order to address these questions, three experiments were conducted in this chapter, for which the main manipulation was simply to reverse the contrast polarity of the eyes in a computerised face. Subjects were presented with different monochrome pictures of the same person (the looker) gazing at different positions (left, right, or straight at the camera). Half of the time the pictures had two-tone eyes with normal or *positive* contrast (that is, white sclera and black iris, see Fig.2.1 (a,c,e,g,i) and half of the time the same pictures had *negative* contrast for the eyes (i.e. black sclera and white iris, see Fig.2.1 (b,d,f,h,j). The subject, sitting in front of the computer screen, was told simply to make a forced-choice judgement about the direction in which looker appeared to gaze, by pressing corresponding buttons on the computer key-board.

If the contrast polarity of the eyes is crucial to making a correct judgement of perceived gaze direction, then reversing its polarity should cause a drop in subjects' accuracy. If, on the other hand, only purely geometric cues to gaze direction matter, as several previous authors (Gibson & Pick, 1963; Cline, 1967; Anstis et al. 1969; Ehrlich and Field, 1993) have suggested, then there should be no difference in performance for the two types of polarity, since the geometric cues (edges, shapes and spatial frequencies) from the eyes all remain the same even when contrast polarity is reversed.

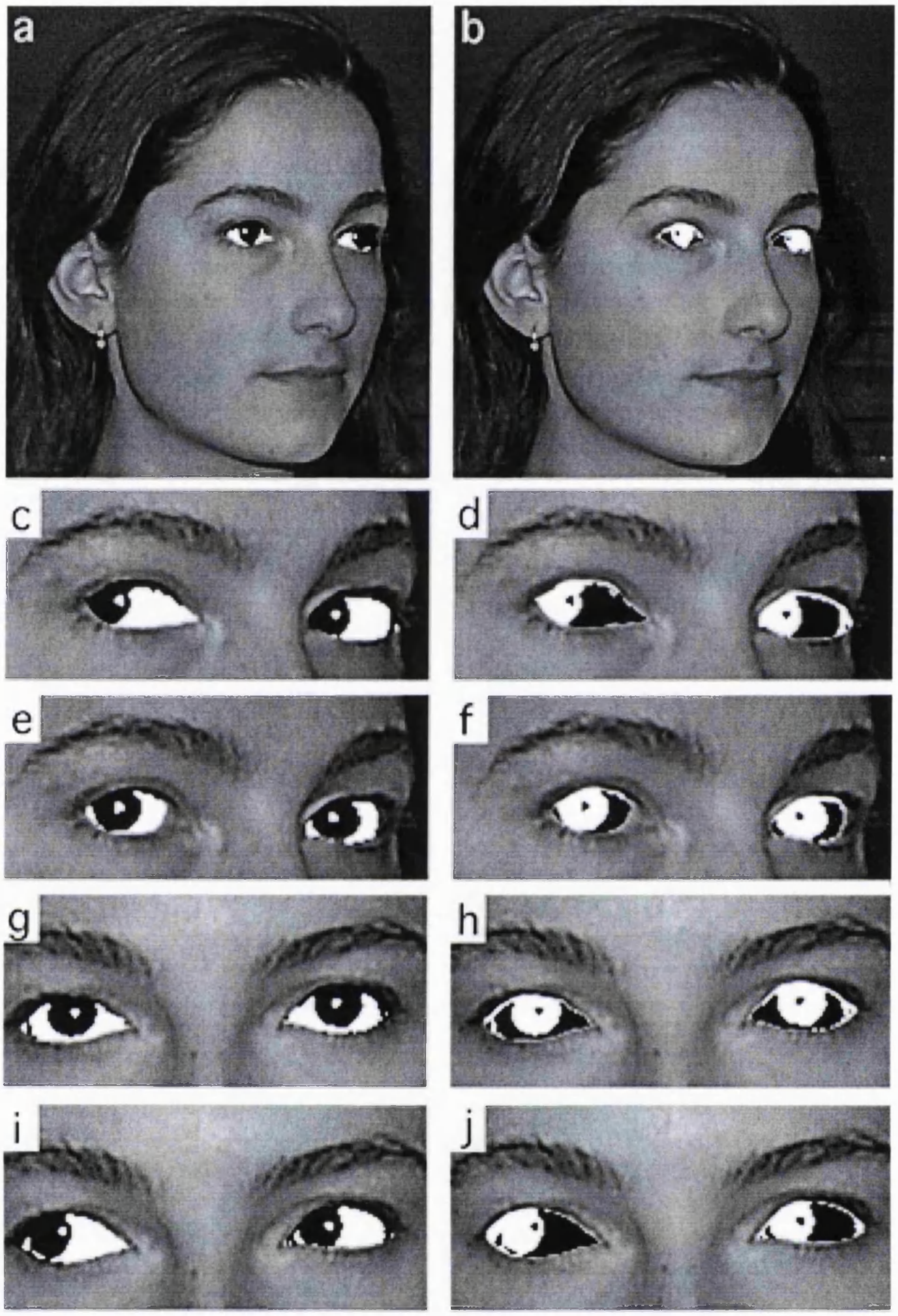


Fig. 2.1. Example of stimuli from Experiment 1. (a) Positive eyes, with head and gaze both directed 30^0 to the observer's right; (b) same as in (a), but with eyes now in negative polarity. All stimuli used comprised a full-face picture (as in (a,b)), but the illustrations in (c-j) show just the region around the eyes for brevity. Example in the left column have positive eyes, while those in the right column have negative eyes: (c,d) eyes-left with the head facing right; (e,f) eyes-straight with the head facing right; (g-h) straight eyes in a straight head; (i,j) eyes – left in a straight face. Left-right reflections of the stimulus types shown were also possible, for all cases except (g,h).

General Method

Subjects: Eight people took part in each of the experiments, but none of them participated in more than one. These volunteers responded to advertising, and each received a monetary payment (£2.50) for their time and expenses. They were naive as to the purpose of the experiment. All were required to use fingers on their preferred hand to perform the button-pressing task which indicated their perception of gaze direction. They all had normal or corrected-to-normal vision by self-report. The subjects were requested to perform the task in a fairly speeded manner. This emphasis on rapid judgements was to avoid protracted ruminations, in the hope of tapping the subjects' natural or spontaneous gaze perception.

To make sure the subject understood the task, at the beginning of the experiment an example of one positive-contrast stimulus, and one negative-contrast stimulus, were presented together on the screen, for each of the conditions described below. Subjects were told what the correct answer was in each case. No feedback on accuracy was given in the subsequent experimental trials, as we wanted to record subjects' natural tendencies in the task, rather than to train them extensively.

Apparatus and Materials: For convenience, and to avoid distraction, the experiments all took place in a dark sound-proof booth. The subject was sat in front of a video screen (a 37 cm x 30.5 cm Sony Triniton Multiscan 100 SX colour monitor), driven by an 8500/120 Power Macintosh computer. The distance between the subject's head and the screen was 70 cm, maintained constant across the subjects by the use of an adjustable chin-rest. Stimulus production, presentation time and response recording was carried out by a custom program written by myself in VScope 1.2.5 software (Enns et al., 1990). Each trial began with the appearance of a central fixation asterisk ($1^{o}.15'$ x $1^{o}.31'$ of visual angle), and then a grey-scale computer image (15^{o} x $15^{o}.15'$ of visual angle), which in the initial studies was always of the same young woman, digitally photographed with a neutral facial expression, when looking and/or facing towards one of three different positions. The possible positions used for both the looker's head and eyes were, -30^{o}, 0^{o} and 30^{o} degrees, referring to the looker looking (and/or turning the head) towards the left, straight ahead, or towards the right of a digital camera. Those positions will henceforth be referred to as "right", "middle" and "left" from the camera's perspective (equivalent to the subject's perspective in the experiment). The original set of stimuli was composed of nine different digital photographs loaded into the computer. From the point of view of the observer, these comprised three different eye directions (right, middle, left) and three different head positions (head left, right or straight) fully crossed to produce the nine possibilities. In fact, the head straight/eyes right stimulus and the head straight/eyes left stimulus that were shown were actually generated by changing the eyes within the head straight/eyes middle stimulus in the following way. Adobe Photoshop 4.0 software was used to select and copy just the eye region from the original head straight /eyes left stimulus, and separately from the original head straight/eyes right stimulus. Either eye regions were then pasted into the original head straight /eyes middle stimulus to create, respectively, the head straight/ eyes right stimulus and the head straight/left stimulus. This was done in order to hold head orientation (and all other details of the face) *exactly* constant across different eyes positions that were intended to have the same face. This was to avoid unintended differences in the face, or in the wisps of hair that were visible etc., between different gaze conditions. In the same way, the head left/eyes right stimulus and head left/left stimulus were made by pasting the appropriate eyes into the single face from the head left/eyes middle stimulus. All "head right" stimuli were then obtained by flipping horizontally all the "head left stimuli" in Adobe Photoshop to produce a perfect mirror image. Finally, to simplify the contrasts that were present in the eye region, and to facilitate their reversal, Adobe Photoshop was used to make just the eye regions become two-tone[1]. For negative stimuli, the contrast was subsequently reversed for just these eye regions (see Fig. 2.1 for examples of the stimuli used).

Experiment 1

The first experiment aimed to test whether, as hypothesised, subjects would make significantly more mistakes in judging the direction of seen gaze when the eyes had a negative contrast polarity. In a three-choice task, people were asked to indicate how they perceived the direction of gaze; looking towards their right, their left, or straight at them.

[1] A two-tone image is created in Adobe Photoshop by using the "Threshold" command to convert greyscale or colour images to high-contrast black-and-white images. This command allows the user to specify a certain level as a threshold. All pixels lighter than the threshold is converted to white. All pixels darker than the threshold is converted to black (see Adobe Photoshop 4.0 manual).
The same threshold was used for positive and for negative polarity stimuli in all these experiments.

Subjects: Eight volunteer subjects (4M and 4F, aged between 21 and 35 years old) participated in the experiment.

Design: There were three orthogonal factors of interest: the contrast polarity of the eyes, the photographed looker's head orientation and the looker's eye direction. All were within-subject factors. The factor of primary interest was the contrast polarity of the eyes. A significant increment in error-rate was expected when subjects made their judgements on the negative contrast stimuli, compared with the positive contrast stimuli. Different eye directions for the looker were also included among our factors to explore whether the different sensitivity to direct versus diverted gaze, as found by previous authors (Cline, 1967; Anstis et al, 1969), would play any role in the present experiment. In particular, the present design could test whether contrast polarity would only affect the deviated gaze directions (i.e. away from the viewer), which are usually harder to judge. The looker's head orientation was also manipulated, as this has previously been found to influence gaze judgements (Cline, 1967; Antis, et al., 1969; Gibson & Pick, 1963), as described in the literature review of Chapter 1. Would tilting the head away from a frontal view be even more disruptive for gaze perception when the eyes had negative rather than positive polarity? In particular, one possibility could be that when the eye contrast was reversed, people might then rely more on the head orientation as a cue to make their judgement. If so, one might expect subjects to make less errors for negative stimuli when head and eyes were congruent (i.e. both diverted towards the same direction, or both straight ahead), than when they were incongruent (that is, head oriented towards the right or the left, but eyes straight ahead or oriented the other way; or head straight with deviated eyes).

In Experiment 1, the three possible different eye-directions were fully crossed with the three possible head-orientations, leading to 9 different spatial arrangements. These were in turn crossed with the two possible contrast polarities, leading to a 2 (contrast) x 3 (head orientation) x 3 (eyes direction) factorial within-subject design (see Fig.2.1 for examples of stimuli used).

Procedure: Each subject was tested in one experimental session which lasted approximately 25 min. They were presented with 360 trials, divided into 6 equal blocks, with the 18 conditions being equiprobable in a random sequence. Every block was followed by a few minutes rest. The subjects were requested to perform the three-alternative forced-choice decision task in a rapid manner. They were instructed to judge where the person in a computerised photograph was looking, by rapidly pressing either the 1-key (marked "L") for the "left response", the 2-key (marked "C") for the "straight ahead/centre response", ~~and~~ or the 3-key (marked "R") for "right response", all on the numerical key pad of a standard computer keyboard. No training session was given other than the example of each condition together with a specification of its correct response at the very start, as described earlier. The subjects were instructed as follows:

"Each trial begins with a star-shape at the centre of the screen. This is your fixation point. Then, a picture of someone looking at different locations will be presented. Your job is to press the left button if you think she is looking toward your left, or the middle button if she is looking straight at you, or to press the right button if she is looking toward your right. You should use different fingers of your best hand. Some pictures might look weird, but you should just make the response concerning where the eyes are looking which seems most natural to you. Once you have pressed a button in response, the next trial starts. The computer gives you a rest after about 60 trials. Then press the space-bar to start the next set of trials. The computer will say when the experiment has finished. The whole experiment lasts about 20 minutes".

Then, a brief example was given of how the pictures looked for each condition, and what the correct response would be for each. That is, at the beginning of the first session, an example of both normal and reverse-contrast eyes stimuli were presented together, for a given combination of head orientation and eye position (as in Fig.2.1a plus 2.1b), with one next to the other, along with the correct answer. On the subsequent experimental trials, only one face was ever shown at a time, never two together unlike these example displays. The sequence of events on each experimental trial was as follows. The fixation asterisk appeared at the centre of the screen for 448 ms. This was followed by an image of the looker gazing towards one of the three possible different positions (while facing towards one of them) which lasted until response, or for a maximum of 1112 ms. A maximum interval of 4432 ms was allowed for response execution. The sequence in which the different face/eyes stimuli were presented was random, and each condition from the possible eighteen given by the 2x3x3 factorial design was equiprobable within each block of 64 trials. After a short delay of 500 ms, needed to prepare the screen for the next display, an analogous sequence of events was repeated to produce the next trial.

Results: All analyses reported here concerned the number of correct responses, as the main interest was in evaluating any change in accuracy for positive versus negative contrast in the eyes. Moreover, as it turned out, error rate was too high with negative contrast stimuli to allow any meaningful RT analysis (the RTs for positive eyes are considered later, in Chapter 5). Since the task was extremely easy when the eyes' contrast was positive, subjects' performance was close to ceiling in that condition. As a consequence, the data we obtained were not normally distributed and the variances between conditions were not homogeneous[2], leading to a violation of standard assumptions for using parametric tests. None of the non-parametric tests was suitable for our experimental design, so we applied an Arcsine-transformation to the raw data in order to normalise them[3]. The intersubject mean percentages of correct responses for the untransformed data in Experiment 1 are plotted in Fig.2.2).

[2] The standard deviation and the mean of the percentages of correct responses for positive eyes contrast condition were respectively, 13.05 and 93.5, whereas for negative eyes contrast condition they were 36.55 and 52.34, respectively.

[3] I used the Arcsine transformation (see Turkey (1977) and Box (1953)). After this transformation, the standard deviation and the mean of the number of correct response for positive contrast conditions were respectively 0.23 and 1.42, while those for the negative contrast conditions were 0.50 and 0.82. The respective variances were 0.05 and 0.25. These fit the standard criterion for homogeneity, according to which "...if the largest variance of one data set is no more than four times the smallest variance of the other data set, the analysis of variance is most likely to be valid" (Howell, 1992 p. 308).

It can be seen from this figure that the results appear symmetrical across left/right reflections of the stimuli; and also that negative contrast polarity led to much higher error rates, except when both gaze and head were directed straight at the observer (central datapoints).

A three-way within-subject ANOVA was conducted on the transformed data, with a 2 (positive versus negative polarity of the eyes) x 3 (left, straight, versus right head) x 3 (left, straight versus right eyes) factorial design.

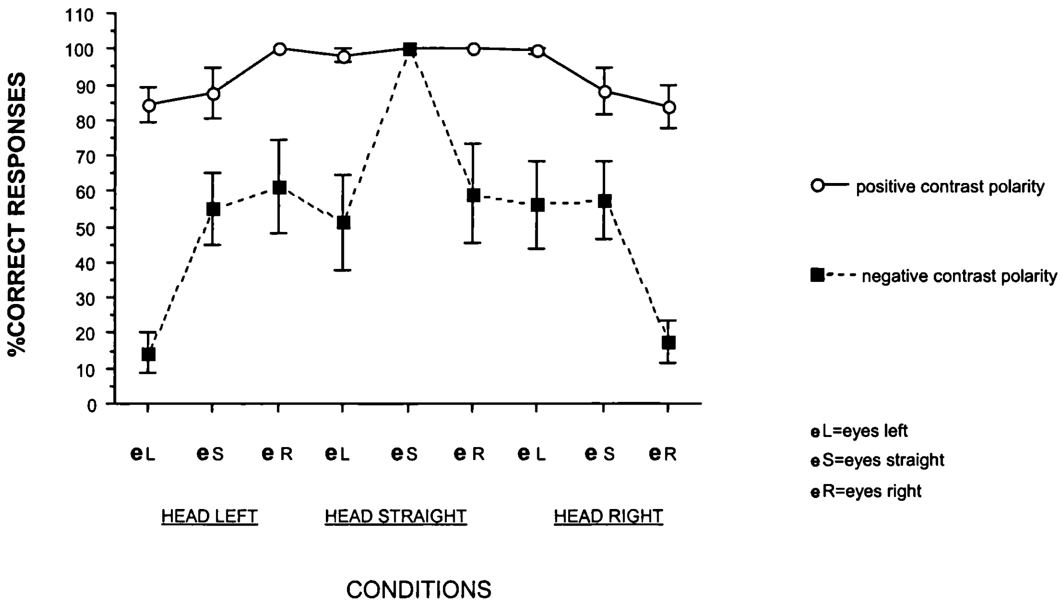


Fig. 2.2. Untransformed mean percent of correct responses in judging the direction of gaze in Experiment 1. Percentages are plotted as a function of eye polarity for different combinations of gaze direction and head orientation. The bars indicate standard errors.

The analysis showed a large influence of contrast polarity, with worse performance for negative eye stimuli overall (52.34% correct overall versus 93.5% for positive; $F(1,7)=28.8$, $p<.001$). A significant main effect of head orientation ($F(1,7)=25.3$, $p<.001$) and a significant main effect of eye direction ($F(1,7)=10.0$, $p=.002$) were also shown. The two-way interactions were significant: ($F(1,7)=20.8$, $p<.001$), for polarity x eye direction; $F(1,7)=9.7$, $p<.001$, for head orientation x eye direction; and $F(1,7)=3.9$ $p<.05$, for polarity x head orientation), all as subsidiaries of the three-way interaction ($F(4,28)=3.3$, $p<.05$), which had two sources. First, negatives impaired performance for every case except direct-gaze in a straight face (central datapoints in the graph of Fig. 2.2); note that only in this exceptional case can gaze direction be judged by the symmetry of the image alone (see Fig. 2.1(g) and 2.1(h)). Second, negatives produced the largest impairments when the eyes and head were both deviated in the same direction (outer datapoints in Fig. 2.2), with many erroneous “straight” responses in this negative condition (with its “congruent” head and eye directions). Recall that Anstis et al. (1969) had previously found people make some errors, even for positive stimuli, when the eye is deviated in the same direction as the head (as for the present congruent condition). The interaction suggests that this particular problem is exaggerated with negative stimuli.

The most important result is the much worse performance with negative than positive eyes. Planned comparisons confirmed that the negative conditions were significantly worse ($p<.01$ or better) than the corresponding positive condition, for every case except direct-gaze/straight head.

Discussion

Overall, the results confirmed the basic prediction, showing that people made significantly more mistakes with the negative contrast stimuli. As hypothesised, the polarity of contrast does matter for perceiving the correct direction of seen gaze (except when gaze is directly at the viewer, with a frontal view of the face). The ease of perceiving direct gaze in a frontal view of the face, even with negative contrast polarity, could have several different explanations. As one possibility, if the rule used by the visual system when perceiving the direction of gaze is to consider the white part of the eyes as the sclera and the darker part as the iris (as hypothesised), then in just the frontal view when gaze is direct and the contrast polarity reversed, the white part (which becomes the darker part with negative polarity) may be too small to fit the mental template for an iris (see Fig.2.1 (h)). Therefore, this may be the one case where people perceive gaze direction correctly both in positive *and* negative contrast, because it is virtually impossible to misassign the sclera. Another possibility as mentioned earlier, is that direct gaze in a frontal view may be a special case simply because this is the only view in which the relative symmetry between the two eyes can allow the correct judgement (Ehrlich and Field, 1993). In any case, the difficulty with negative eyes is shown in all the other conditions, except for direct gaze in a frontal view of the face. This contrast polarity effect on gaze perception is a novel result that has never been reported before, and so the next experiment aimed to replicate it, within a simpler design.

Experiment 2

The present experiment sought to replicate the polarity effect found in Experiment 1, by means of a simpler design (and task) which should be more adaptable to further manipulations, in future studies testing alternative explanations for the polarity effect. For example, potential confounding factors such as the familiarity of colour for the eyes themselves, the presence or absence of highlight reflection on the eyes, or even the polarity of the face within which the eyes appear, might have played a role in the previous experiment, as we discuss later. All these possibilities are addressed in later experiments (see Chapter 3). The next study simply repeated the basic comparisons of Experiment 1, but with a simpler design that could be adapted for further study.

Subjects: Eight new subjects (1M and 7F) took part in the present experiment. All were volunteers and none had participated in the previous experiment.

Design: The next experiment employed the same conditions as in Experiment 1, except that the head left/eyes right and head right/eyes left conditions were dropped for both positive and negative contrast, to simplify the design. Moreover, the head straight/eyes straight conditions were now presented twice as often, for both positive and negative contrast conditions, so as to have the same number of trials for each condition in the design that is explained below. The statistical analysis pooled across the "left" and "right" levels for both the head and the eyes factors; this seems justified since no left/right differences were expected, and also given the symmetry in results that was apparent across left/right reflections in Experiment 1 (see Fig.2.2). This pooling produced a much simpler design. In this new design, the levels of head and eyes factors could be recorded as simply "straight" versus "deviated", rather than left versus right versus straight. The final design was thus a 2 (positive contrast vs. negative contrast of the eyes) x 2 (head straight vs. head diverted) x 2 (eyes straight vs. eyes diverted) design. For all the remaining methodological aspects, Experiment 2 was identical to Experiment 1.

Results and discussion: A three-way within-subject ANOVA was conducted on the transformed data[4], but now with the simpler 2 (positive and negative contrast) x 2 (straight versus tilted head) x 2 (straight versus diverted eyes) factorial design. The ANOVA again showed a significant main effect of contrast polarity ($F(1,7)=50.5$, $p<.001$), indicating that, overall, subjects made significantly more mistakes with negative contrast for the eyes (see Fig.2.3). There was also a significant main effect of head orientation ($F(1,7)=29.3$, $p< .001$), while that for eye direction approached significance ($F(1,7)=5.98$; $p=.04$).

[4] The same Arcsine transformation was conducted as for Experiment 1. Before the transformation the standard deviation and the mean of the percentages of correct responses for positive contrast conditions were 19.81 and 87.08 respectively, whereas for negative contrast conditions these were 55.83 and 53.54. After the Arcsine transformation the standard deviation and the mean of the number of correct responses for positive contrast conditions were 0.30 and 1.3, while the ones for the negative contrast conditions were 0.43 and 1.0. The transformed data should therefore allow robust ANOVA analysis (see Howell, 1992).

Finally, there was a significant two-way interaction between contrast polarity and eye direction ($F(1,7)=14.8$, $p<.001$). Simple effect tests showed a significant effect of eye deviation only for negative contrast polarity ($F(1,7)=12.0$, $p<.05$), not for positive contrast ($F(1,7)=0.00$, $p=1.0$), thus suggesting that negative polarity led to greater difficulty with deviated gaze. Of the remaining interactions, head x eyes was nonsignificant, contrast x head was marginal ($F(1,7)=4.0$, $p=.09$) with a tendency for a greater cost of negative contrast with a deviated head, and head x eyes x contrast was nonsignificant ($p>.4$), even though there was clearly no effect of contrast for just the head straight/eyes straight condition, as also found in Experiment 1 (see Fig. 2.3).

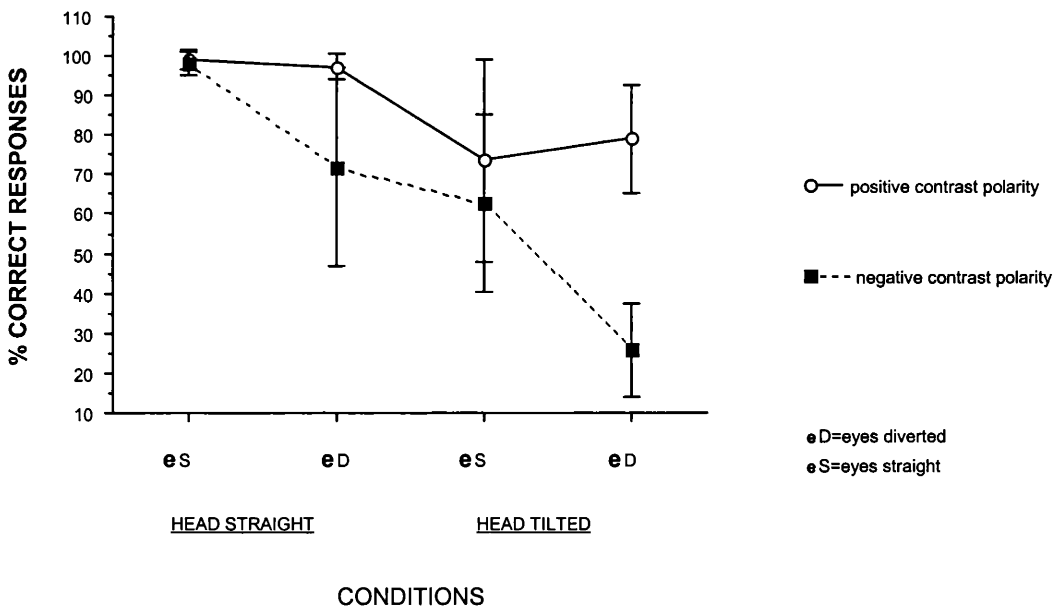


Fig. 2.3. Untransformed mean percent of correct responses in judging the direction of gaze in Experiment 2. Percentages are plotted as a function of eye contrast polarity for different eye direction and head orientation conditions. The bars indicate standard errors.

In sum, there was an effect of eye polarity, which appeared larger with deviated eyes. As found in Experiment 1, contrast had little influence when both the head and the eyes were straight. The basic results of our initial study were thus replicated with a simpler design.

Experiment 3

The next experiment was carried out to check whether the contrast polarity effect on gaze perception found in Experiment 1 and 2 might somehow be specific just for the eyes of the single person who had been photographed in the two previous experiments, and thus not generalisable to different people. For example, it might have been due to some unique aspect of her particular eye and/or face features. This possibility was tested in the present experiment, where for each condition photographs of ten different people, of different age and gender, were now used. The influence of contrast polarity, as found in Experiment 1 and 2, was expected to be replicated, with worse performance for negative eyes once again.

Subjects: Eight (1M and 7F) new people participated in the experiment and all were naïve subjects.

Design: The present experiment employed the same design as in Experiment 2, except that now each condition used photos of ten different people (i.e. five female and five male) as stimuli (see Figures in Appendix 1 for examples of the stimuli). The design was again a 2 (positive contrast vs. negative contrast of the eyes) x 2 (head straight vs. head diverted) x 2 (eyes straight vs. eyes diverted) within-subject design. For all the remaining methodological aspects, Experiment 3 was identical to Experiment 2.

Results: A three-way within-subject ANOVA was performed on the transformed data[5], It again showed a significant main effect of contrast polarity ($F(1,7)=27.5$, $p<.001$), replicating the contrast polarity effect already found in Experiments 1 and 2 (see Fig. 2.4). There was also a significant interaction between contrast polarity and eye direction ($F(1,7)=12.0$, $p= .01$). Simple effect tests unexpectedly showed a significant effect of eye deviation only for positive contrast polarity ($F(1,7)=6.99$, $p<.05$). There was also an interaction between head and eye orientation ($F(1,7)=9.7$, $p<.02$), because deviated eyes were only harder with a straight head. All the remaining interactions and the main effect of eye direction and head orientation were non significant.

A further three-way ANOVA with the same within-subject factors as before (i.e. contrast polarity x head x eyes) was also performed on transformed data, but now across materials (i.e. the different people used in the photographs), instead of subjects. This produced very similar results. As in the previous analysis, it showed a significant main effect of contrast polarity ($F(1,9)=52.8$, $p<.001$), and a significant main effect of head orientation ($F(1,9)=99.37$, $p<.001$). There was again a significant two-way interaction of contrast x eyes ($F(1,9)=14.80$, $p<.001$) and head x eye ($F(1,9)=52.98$, $p<.001$).

[5] The same Arcsine transformation was conducted as for Experiment 1 and 2. Before the transformation the standard deviation and the mean of the percentages of correct responses for positive contrast conditions were 20.86 and 84.5 respectively, whereas for negative contrast conditions these were 31.50 and 63.66. After the Arcsine transformation the standard deviation and the mean of the number of correct responses for positive contrast conditions were 0.29 and 1.2, while the ones for the negative contrast conditions were 0.40 and 0.9. The transformed data should thus permit robust ANOVA analysis (Howell, 1992).

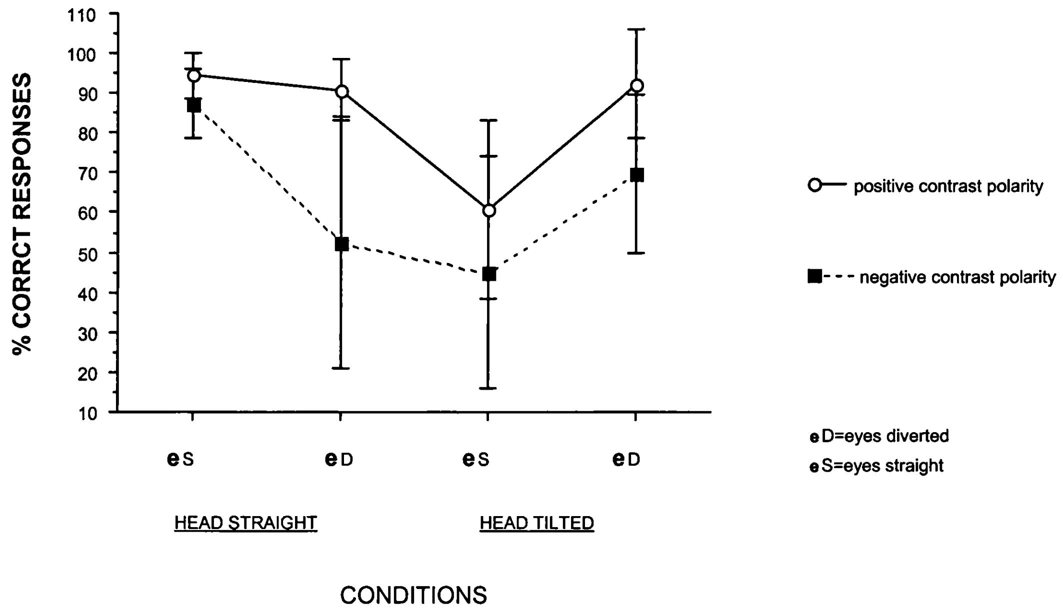


Fig. 2.4. Untransformed mean percent of correct responses in judging the direction of gaze in Experiment 3. Percentages are plotted as a function of eye contrast polarity for different eye directions and head orientation conditions. The bars indicate standard error.

The three-way interaction was also significant ($F(1,9)=6.44$, $p<.05$). The crucial finding is that effect of contrast polarity was reliable not only across subjects, but also across materials.

Discussion

These results, although different in some details from what was found in Experiment 2 (compare Figures 2.3 and 2.4), clearly show once again that negative polarity disrupts gaze perception. There were two main differences from Experiment 2. First, among the positive stimuli, performance was notably poor for the head diverted/eyes straight condition in the present experiment. I suspect that this may be due to the stimuli used for this particular condition, in which the direct gaze was only approximate (to within a few degrees of the camera viewpoint) due to limitations in the photographic method used when photographing many different people. Second, among the negative stimuli, performance was not as poor for the head diverted/eyes diverted condition in the present study as for this same condition in Experiment 2 (compare Figures 2.3 and 2.4). This difference might conceivably be due to the somewhat variable position of "highlights" (light reflections) on people's eyes in the different photographs (see Fig. 2.5). This highlight becomes a dark region with negative polarity, and so might conceivably be treated as the pupil in the negative condition, which could influence performance (as tested in Chapter 3). The position of the true pupil and iris relative to the sclera is systematic for particular conditions, but the position of the highlight depends on the particular lighting conditions of the photograph, and so can vary between pictures of different individuals. This might explain the slight discrepancies in the detailed results for the present experiment with photographs of ten different individuals, versus the results for photos of one individual in Experiment 2. I return to the issue of highlights later (see Chapter 3). For now, the most important point is that the basic difficulty of negative polarity was replicated using pictures of different individuals, and was reliable across the materials.

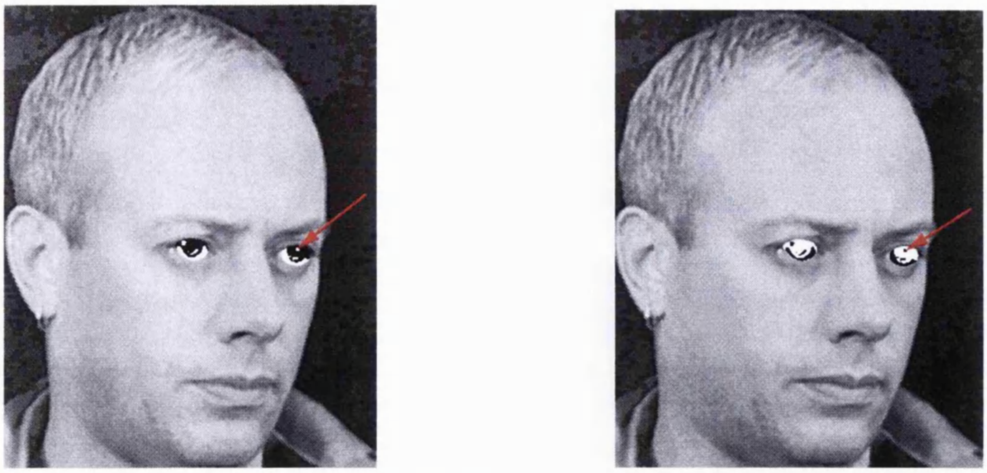


Fig. 2.5. The red arrow indicates the "highlight" (light reflection on the eye), both in positive contrast polarity (on the left) and in negative contrast polarity (on the right). In negative contrast polarity the reflection of the light might be mistaken for the pupil or iris, as considered in Chapter 3.

Experiment 4

The next study tested whether inverting contrast-polarity disrupts judgements of gaze direction more than other directional judgements; specifically, more than for judgements of the direction in which a seen head is facing. Face stimuli like those from Experiment 1, 2 and 3 were used, but now presenting the whole image either in negative polarity or in positive polarity (see also Chapter 3), to test whether negative polarity would impair judgements of whether the seen *head* was turned to the right, to the left, or was facing the viewer. A more subtle difference in head-orientation discrimination (5 degrees to left or right of centre) was used than in the previous studies (where the head had been tilted 30^0), and many subjects were tested, to assess whether any impact of contrast polarity whatsoever could be found in a head-orientation task. In fact, if the contrast polarity effect found in the previous experiments is "specific" for gaze perception rather than simply affecting any directional judgements for faces, then reversing the contrast polarity of the whole head should not affect the judgement of head orientation.

Subjects: Thirty-four new subjects (12 M and 22F) participated in the experiment. As before, they were all volunteers and naive as to the purpose of the experiment. None of them took part in any of the previous experiments.

Stimuli, Design and Procedure: The stimuli again each comprised a pictured face, now with the head facing straight at the viewer, or 5 degrees to the left, or 5 degree to the right. Gaze was now always in the same direction that the head faced. The whole image could be positive or negative. The three-choice task was to judge whether the head faced left, straight or right. Each subject underwent 5 blocks of 120 trials with the 6 possible stimulus types (head facing left, right or straight, all crossed with positive versus negative polarity for the whole image) being equally likely in each block.

Results and discussion: A two-way ANOVA (head direction x polarity) showed no effect of polarity ($F(1,33)=0.002$, n.s.), a significant effect of head direction ($F(2,66)=25.2$, $p<.001$, with best performance for straight heads), and no interaction ($F(2,66)=1.4$, n.s.).

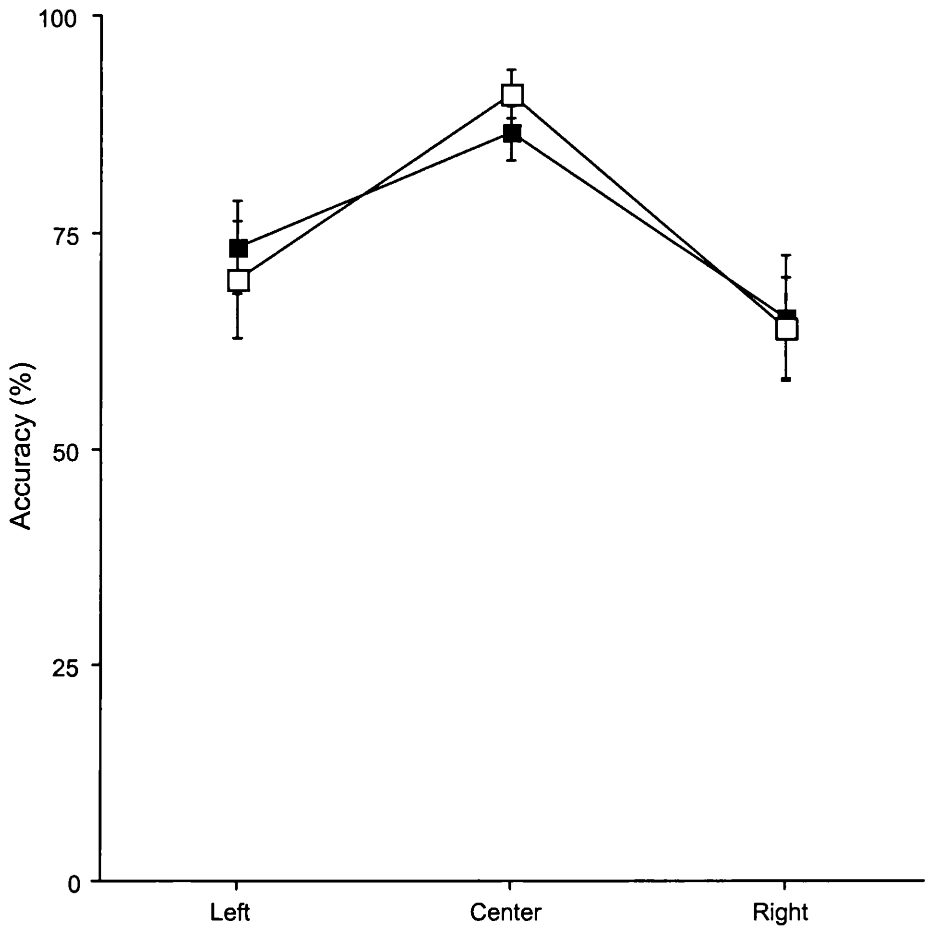


Fig. 2.6. Mean percent of correct responses in judging the direction of the head in Experiment 4. Percentages are plotted as a function of head polarity and head orientation (bars indicate standard errors). Filled symbols are for negative faces, open for positive faces.

In contrast to the dramatic effects of contrast polarity on gaze-direction judgements in Experiment 1 through 3, head-direction judgements were uninfluenced by such polarity (see Fig. 2.6), even when many subjects were tested in a demanding head-orientation task (requiring 5^0 discriminations).

Conclusions

The main finding which clearly emerges from these studies is that reversing the contrast polarity of the eye region dramatically disrupts people's ability to judge where the seen eyes are looking. Reversing the contrast between the lighter part of the eyes (the sclera) and the darker part of the eyes (the iris) makes the judgement of where another person is looking extremely difficult. Thus, the new and interesting finding is that, for an accurate perception of gaze direction, the irises *must* be darker than their immediate surround. However, there might be several factors that could have played a role in this contrast polarity effect, as considered further in Chapter 3.

The experiments reported here show that perception of gaze direction is dramatically impaired for eyes seen in negative contrast polarity. This effect of polarity arises even though negatives share all the "geometric" properties of positive eyes which have been emphasised in previous accounts of gaze perception (e.g. Anstis et al., 1969; Cline, 1967; Gibson & Pick, 1963).

This effect on <u>gaze</u> perception cannot simply be reduced to previous known influences on <u>face</u> processing. Although at first glance it may appear reminiscent of previous findings that negative images of faces are harder to recognise as known individuals than positive images (e.g. Galper, 1970; Philips, 1972), in fact the latter face effect cannot explain the present gaze effect. All the faces used here were unknown to the subjects, and no face recognition was required by the task. Moreover, the effect on gaze perception remains even when just the eyes are shown alone (as can be confirmed by suitable inspection of Fig. 2.1). Furthermore, the present gaze effect is found regardless of the polarity of the surrounding face (see Chapter 3). Finally, the difficulty of recognising familiar faces when shown in negative polarity is commonly attributed to a disruptive effect on the interpretation of shadow cues to the 3D structure of a face (e.g. Kemp et. al, 1996); shadow cues to 3D structure seem very unlikely to indicate the direction of the eyes in their orbits.

I propose that the effect of contrast polarity on gaze processing arises because the visual system follows an inflexible contrast-rule for gaze perception, invariably treating the dark part of the eye-image as the part that does the looking. Evidently this "rule" cannot be overridden for negative eye stimuli, even though the geometry of the image is just the same as for the positives which are accurately perceived (so that, in principle, negatives might be judged just as accurately based on geometric cues). The great difficulty with negatives thus suggests the involvement of a dedicated "expert" system, applying an obligatory rule in the processing of gaze stimuli; similarly to that implied in the face inversion effect. Face inversion disrupts face recognition more for faces than for other classes of objects (e.g. Yin, 1969); analogously, reversal of contrast polarity may disrupt directional judgements more for eyes than for other classes of stimuli (e.g. judgements of head orientation are unaffected, see Experiment 4).

However, factors other than just the contrast polarity of the eye region may have played a role in Experiment 1 through 3. Perhaps, for example, gaze perception is impaired only when the polarity of the eyes does not match that of the *surrounding* face. Moreover, stimuli that look "unusual" (like those in negative polarity) might be more difficult to process simply because people are more familiar with the colouring of the positive contrast polarity eyes (like those frequently encountered in black-and-white newspapers pictures) than for those with negative polarity. These and other issues will all be addressed in the Chapter 3.

Chapter 3

THE CONTRAST POLARITY EFFECT ON GAZE PERCEPTION: EXAMINING THE POSSIBLE ROLES OF UNUSUAL COLOURS, FACE CONTEXT, HIGHLIGHTS AND MOTION

The present chapter further investigates the effect of contrast polarity on gaze perception, as found in Chapter 2, in several new conditions, to examine alternative possible accounts for the effect.

The next experiment tested whether the effect found in the initial experiments (see Chapter 2) was not due to the polarity of contrast *per se*, but rather to people's possible familiarity with the colouring of a black iris and white sclera, as portrayed in black-and-white photos of faces (e.g. as found in most newspapers). This relatively frequent exposure to positive black-and-white colouring in photos might be the only reason that just the negative contrast stimuli look "bizarre", which might make them difficult to deal with in some nonspecific way. Accordingly, it seemed necessary to replicate the basic effect using unusual stimuli that would look bizarre even in the positive contrast case. To test this, an unusual colour pattern for the iris and the sclera was now used; dark red and light green (see Fig. 3.1 (c) and 3.1 (d)).

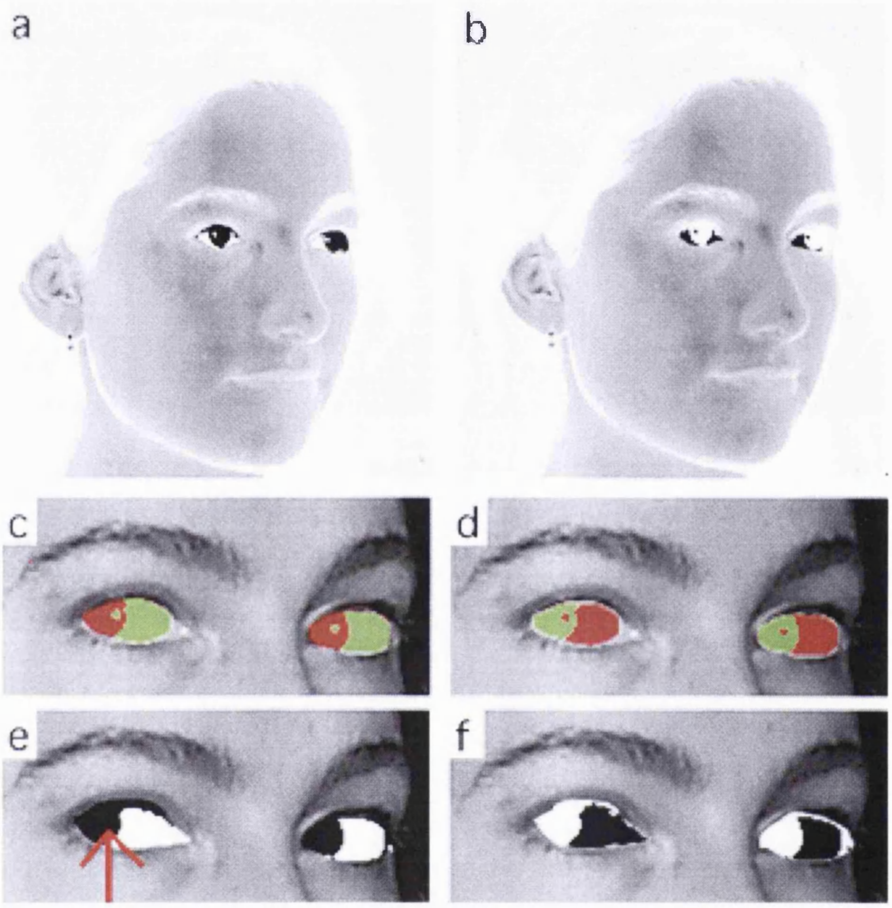


Fig. 3.1. Example stimuli from Experiments 5,6,7, and 8. (a,b) Positive-eyes and negative-eye stimuli, respectively, within a surrounding negative face context, as used in Experiment 6. In all experiments, the stimuli comprised a full-face picture (as in (a,b)), but the illustrations in (c-f) show just the region around the eyes for brevity. Examples in the left column have positive eyes, while those in the right column have negative eyes. (c,d) Red-and-green eyes, as used in Experiment 5. (e,f) Eyes with the "highlight" on the iris removed, as used in Experiment 7 and 8 (see arrow region, and also Fig. 2.5 in Chapter 2).

Experiment 5

This study compared positive and negative versions of red/green eyes to the previous positive and negative black-and-white eyes. If contrast polarity is critical, rather than merely familiarity with a particular colouring, a similar effect should be found even with bizarrely coloured stimuli, in which the positive contrast examples are also highly unusual and should never have been encountered before, in newspapers, etc.

Note that, if the absolute *level* of contrast matters, in addition to its polarity, the black-and-white negatives might be somewhat harder than the red-and-green negatives, since the former have higher contrast despite the same polarity.

Subjects: Eight new subjects (4M and 4F, ranging 21-35 years in age) took part in the experiment. They were paid volunteers and naive as to the purpose of the experiment.

Design: In the present experiment, the previous design was slightly modified because an additional factor (i.e. the colour of the eyes) was added. To simplify the design still further in order to accommodate this additional factor, the head straight/eyes straight conditions were no longer included, since in all previous experiments they were found to be very close to ceiling for both positives and negatives. Therefore, the design now comprised the contrast polarity factor, the head facing left or right, the eyes gazing left or right, and the two possible colouring of the eyes. The displays which were mirror reflections across left and right were now pooled, and the data analysed in terms of congruency, i.e. whether head and eyes pointed in the same direction (both deviated together; see Fig. 3.1 (a,b) for examples) or not (head deviated one way, eyes the other; see Fig. 3.1 (c,d) for examples). Accordingly, this led to a 2 (positive vs. negative contrast) x 2 (black-and-white vs. red-and-green eyes) x 2 (congruent vs. incongruent) within-subject factorial design. The subjects were presented on each trial with a computerised photo of the looker gazing either to the left or to the right only (since direct gaze had been removed), and correspondingly now performed a 2-choice task. For all the remaining methodological aspects, the present experiment was identical to those in Chapter 2.

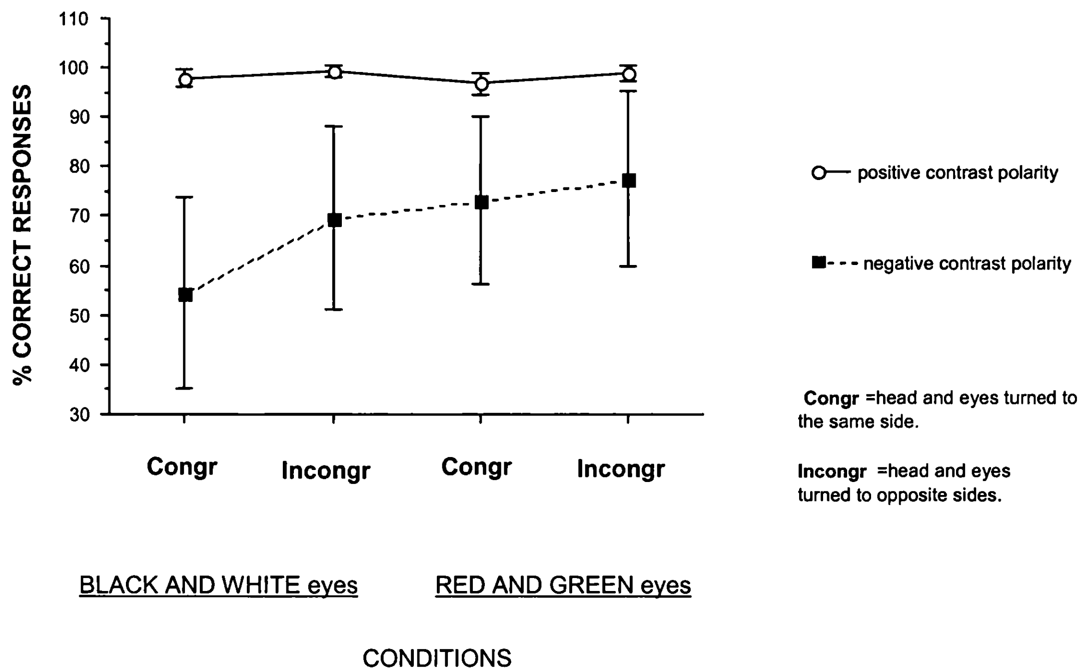


Fig. 3.2. Untransformed mean percent of correct responses in judging the direction of gaze in Experiment 5. Percentages (bars indicate standard errors of the mean) are plotted as a function of congruency, polarity and colour.

Results and discussion: A three-way within-subject ANOVA was conducted on the transformed data[1]. The graph above (Fig.3.2) summarises the results. There was again a significant effect of contrast on accuracy ($F(1,7)=42.6$, $p< .001$), showing as before that subjects made more mistakes when the contrast polarity of the eyes was reversed. The main effect of colour was significant as well ($F(1,7)=27.2$, $p< .001$), with somewhat better performance for red-and-green eyes overall. The significant interaction between contrast and colour ($F(1,7)= 33.5$, $p< .001$) arose because colour affected performance only with negative polarity (i.e., there was a simple effect of colour under negative contrast polarity, $F(1,7)=8.4$, $p<.001$; but not for positive contrast ($F(1,7)=.95$, n.s.). More crucially, the simple effect of contrast polarity was still significant even for red-and-green eyes ($F(1,7)=35.9$, $p<.001$); (see Fig. 3.2).

Overall, subjects made many more mistakes in their judgements with reverse contrast stimuli, both for black-and-white stimuli and for red-and-green stimuli, although they did slightly better with the red-and-green negative patterns than the black-and-white negative patterns. That is, the impairment produced by negative contrast was reduced for red-and-green eyes compared with black-and-white, but the effect was still there. There was no significant effect of congruency ($p>.3$) and all the other interactions were non significant.

[1] The same Arcsine transformation was conducted as for the previous experiments. Before the transformation the standard deviation and the mean of the percentages of correct responses for positive contrast conditions were 2.17 and 98.18 respectively, whereas for negative contrast conditions these were 33.16 and 68.62. After the Arcsine transformation the standard deviation and the mean of the number of correct responses for positive contrast conditions were 0.10 and 1.48, while the ones for the negative contrast conditions were 0.46 and 1.01. The transformed data should thus allow robust ANOVA analysis.

The crucial result for present concerns was the replication of the "contrast polarity effect" of the eyes for the fifth time, even when a different pattern of colour in the eyes (red and green) was used, so that even the positive contrast stimuli now looked unusual and "bizarre". There was some reduction in the contrast effect for red/green versus black/white. Note that the absolute difference in contrast between black and white is greater than that for red and green. This suggests that the *size* of the contrast difference matters somewhat, in addition to its polarity. Nevertheless, contrast polarity clearly remains a critical factor, with significantly worse performance when the iris was darker even for the red/green stimuli.

Experiment 6

The next experiment investigated the possible role of the "face-context" in producing the contrast polarity effect. It could be argued that reversing the contrast polarity of the eyes may have disrupted performance in the previous experiments simply because these negative eyes still appeared within a positive face, and so had an inappropriate polarity for their surrounding context. On this account, if the eyes had been presented within a negative face (See Fig. 3.1 (a,b)), it is logically possible that the contrast polarity effect would now favour negative rather than positive eyes.
That is, appropriate interpretation of the eyes may depend on the contrast polarity of the face in which they appear. If, on the other hand, the visual system invariably treats darker regions of the eye as the iris, regardless of the

face context, then the previous effect of worse performance for negative eyes should be replicated even within negative faces.

Subjects: Eight new subjects (4M and 4F) were drawn from a similar age range as in Experiment 5.

Stimuli: As before the stimuli were all monochrome pictures of the same person with positive or negative gaze stimuli, but now each were presented within either positive (see Fig. 2.1 (a,b) in previous chapter) or negative faces (see Fig. 3.1 (a,b)).

Design: The design was the same as in Experiment 5, but now the additional factor was the contrast polarity of the surrounding face, rather than the monochrome versus coloured eyes. In sum, this was a within-subject factorial design with a 2 (positive vs. negative contrast of eyes) x 2 (positive vs. negative contrast of face) x 2 (congruent vs. incongruent head-and eye-direction) structure. The task was once again a two-choice left versus right response.

Procedure: This was the same as for all the previous experiments, except that now all the pictures were presented against an intermediate grey background, to keep the difference in contrast between the face and the surrounding background the same for both positive and negative faces (see Fig. 3.1 (a,b)). For all the remaining methodological aspects the present experiment was identical to Experiment 5.

Results and discussion: A three-way within-subject ANOVA was performed on the transformed data[2]. It again showed a significant main effect of eye polarity ($F(1,7)=26.7$, $p<.001$), but all the others terms and interactions were non significant (all $ps> .1$).

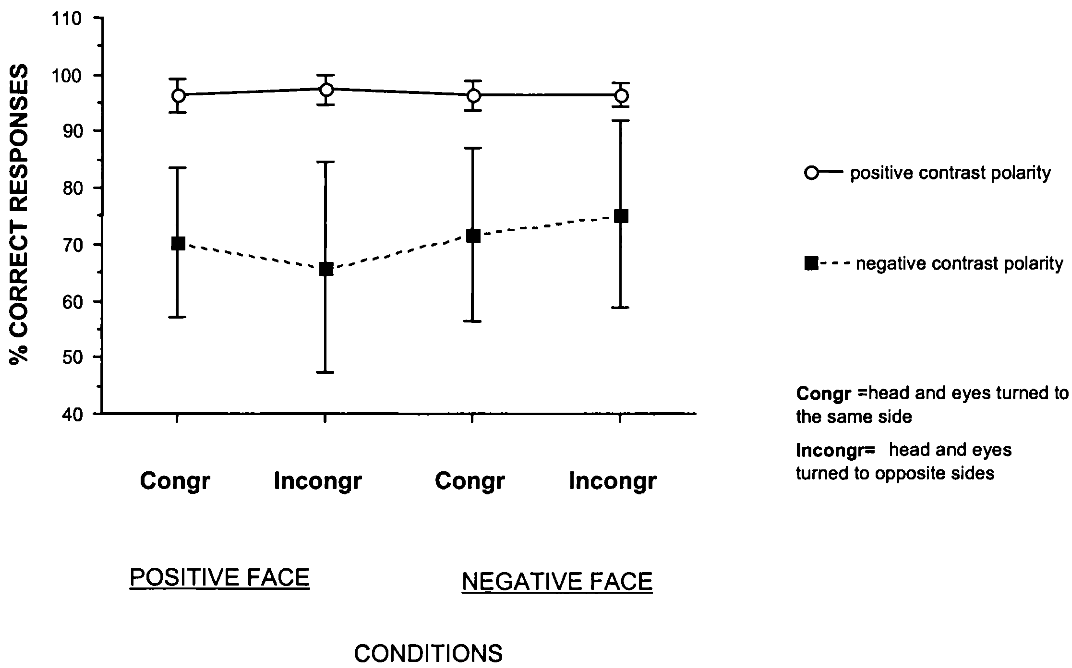


Fig. 3.3. Untransformed mean percent of correct responses in judging the direction of gaze in Experiment 6. Percentages (bars indicate standard errors of the mean) are plotted as a function of congruency, of positive or negative face context, and positive or negative eye polarity.

As can be seen from the graph (Fig.3.3), for both positive and negative *faces* performance was better when the *eyes* had positive polarity; when the eyes had negative polarity, people did badly even within a negative face context.

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[2] The same Arcsine transformation was performed as for the previous experiments (Howell, 1992). Before the transformation the standard deviation and the mean of the percentages of correct responses for positive contrast conditions were 4.13 and 96.61 respectively, whereas for negative contrast conditions these were 28.64 and 70.77. After the Arcsine transformation the standard deviation and the mean of the number of correct responses for positive contrast conditions were 0.13 and 1.44, while the ones for the negative contrast conditions were 0.35 and 1.03. The transformed data should thus allow a robust ANOVA analysis.

This experiment therefore demonstrates that the contrast polarity effect found across the previous experiments cannot be explained solely in terms of "face-context", as it is found even within negative faces. Even if the surrounding face is also presented in negative contrast, this extremely obvious cue evidently cannot be used to modify the usual gaze-perception rule.

Experiment 7

The next experiment addressed another potential interpretation of the eye-polarity effect. This concerns the possible role of light reflections on the visible part of the eyes (i.e. the specular "highlight" which is often present near the iris and pupil as discussed earlier, and as indicated by the arrowhead in Fig. 2.5 in the previous chapter. This highlight is thought to be potentially quite informative about the angle of the eyes with respect to a light source. For instance, sophisticated infra-red eye monitors (trackers), which are often used by experimenters to measure if subjects made any eye movements, exploit exactly this source of information. Those machines use the reflection of infra-red light on the eye ball to track the eye. The reflection of light allows them to constantly monitor eye position. Our visual system might use natural highlights in a somewhat similar manner (although the nature of the highlight will depend on the ambient illumination). If so, the contrast polarity effect might be just due to the influence of contrast reversal on perception of the highlight (e.g. this might be mistaken for the pupil under negative polarity, as discussed in Chapter 2; see also Fig. 2.5). In the present experiment, this possibility was tested by removing the highlight from the eyes, for half of the stimuli (both in the positive and negative sets; see Figs. 3.1(e,f)) and presenting these randomly mixed with the usual stimulus that included the natural highlight.

Subjects: Eight new subjects (4M and 4F) were drawn from a similar age range as in the other experiments.

Stimuli and Design: The natural highlight on each eye was removed using Adobe Photoshop, to generate the new stimuli (see examples in Fig.3.1 (e,f)). The design was identical to the one used in the previous two experiments, with the only difference being that now the presence versus absence of a highlight was the additional factor of interest, rather than monochrome versus coloured eyes, or face polarity. This led to a 2 (positive vs. negative contrast) x 2 (presence vs. absence of highlight) x 2 (congruent vs. incongruent) within-subject factorial design. All the other methodological aspects were the same as for Experiments 4 and 5. The task was again a two-choice left versus right response.

Results and discussion: A three-way within-subject ANOVA was conducted on the transformed data[3].

[3] The same Arcsine transformation was performed as for the previous studies (Howell, 1992). Before the transformation the standard deviation and the mean of the percentage of correct responses for positive contrast conditions were 3.12 and 98.04 respectively, whereas for negative contrast conditions these were 4.07 and 48.58. After the Arcsine transformation the standard deviation and the mean of the number of correct responses for positive contrast conditions were 0.11 and 1.5, while the ones for the negative contrast conditions were 0.55 and 0.75.

It again found a significant main effect of contrast ($F(1,7)=37.1$, $p< .001$), plus a marginally significant effect of congruency ($F(1,7)=1.56$, $p=.054$), whereas the main effect of highlight was far from significance ($F(1,7)=.4$, $p>1$). Only the interaction between contrast polarity and congruency was significant ($F(1,7)=5.95$, $p< .05$), due to a congruency effect (significantly better performance for congruent stimuli than incongruent stimuli) only for negative polarity eyes (69.92% vs. 27.22%, respectively; $F(1,7)=14.43$, $p< .01$). All the remaining interactions were not significant (all ps> .2); see Fig.3.4.

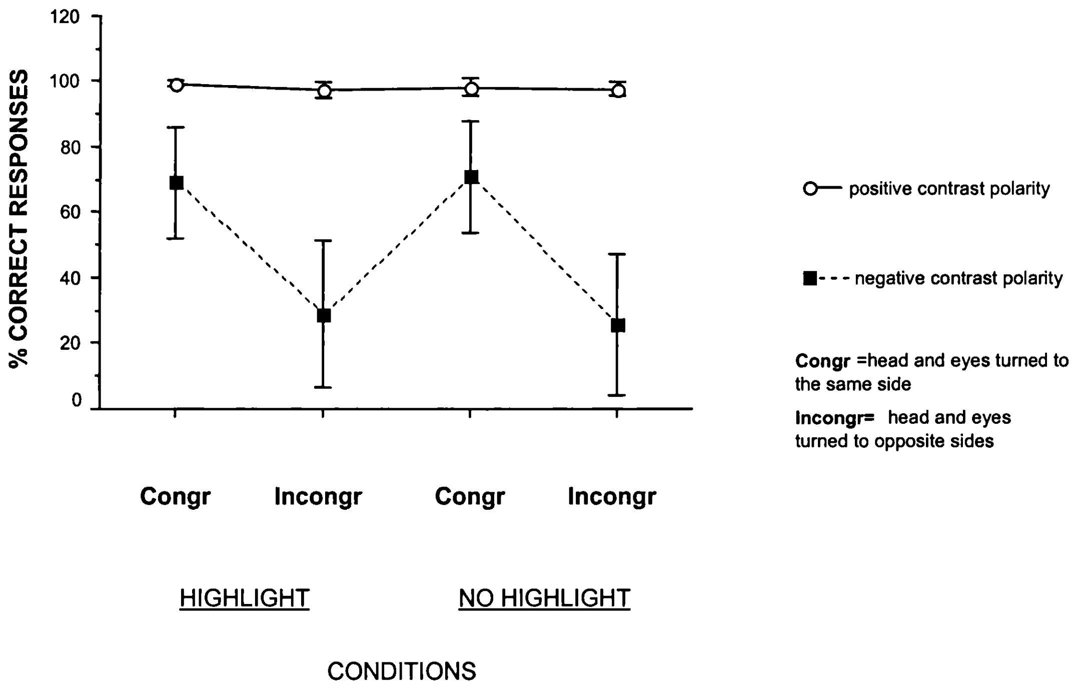

Fig. 3.4. Untransformed mean percent of correct responses in judging gaze for Experiment 7. Percentages (bars indicate standard errors of the mean) are plotted as a function of congruency and polarity.

As in all the previous experiments, subjects did badly with reverse contrast stimuli, now regardless of the presence or absence of highlights. Thus, the contrast polarity effect does not appear to depend on any influence of the contrast manipulation on the perception of highlights in particular. However, the effect of congruency found for negative stimuli in the present experiment was unexpected, as subjects now did consistently better for congruent than incongruent stimuli, which is an unusual pattern in comparison with the previous experiments. This raises suspicions that subjects may have adopted a somewhat different strategy in this experiment, as compared with the previous studies. Recall that, as the literature review (see Chapter 1) showed, for positive-polarity eyes subjects can find the congruent condition somewhat harder than the incongruent (provided their performance is below ceiling; see Anstis et al., 1969; see also Chapter 5). This may be because when the head turns with the eyes (as in congruent conditions), the eyes can deviate less in their sockets for a given change in gaze direction. Note also that the present proposal for the difficulty of negative-polarity eyes suggests that the visual system invariably assigns the darker portion of the eye as the iris, which could lead to a misassignment of iris and sclera for negative-polarity eyes (indeed, to a reversal of which part is treated as which). Such a complete reversal could lead to "congruent" stimuli in effect behaving like "incongruent" stimuli under negative contrast polarity (because the largest extent of sclera will always point in the opposite direction to the true iris in a deviated eye).

The fact that this particular pattern of congruency effects (i.e. the congruent condition now being easier, rather than harder as in Anstis et al.'s classic 1969 study) was clearly apparent for negative stimuli only in the present study, suggests that the inclusion of stimuli with no highlights in the present study may have altered subjects' strategies somewhat compared with the previous studies. In particular, the fact that highlights were absent in an unpredictable 50% of the stimuli may have led subjects to ignore them even when they were present, since they could no longer provide any consistent cue. This possibility is examined in the following experiment.

Experiment 8

As in the previous experiment, this experiment was designed to test if highlight information may affect the contrast polarity effect. However, now by blocking highlights-present versus highlights-absent in the stimulus presentation, the highlights were made consistently available throughout some blocks and, thus, more likely to be used for gaze discrimination when available, as potentially in Experiments 1 through 6.

Subjects: Eight new subjects (5M and 3F) were drawn from a similar age range as in Experiment 5.

Stimuli, Design and Procedure: As in Experiment 7, the highlight on each eye could be removed. The design was similar to the one used in the previous experiment, but now the factor of whether highlights were present or absent was blocked, so that their potentially informative presence could be anticipated when they were presented. Once again the design was a 2 (positive vs. negative contrast) x 2 (presence vs. absence of highlight) x 2 (congruent vs. incongruent) within-subject factorial design, and the task was again a two-choice left versus right response.

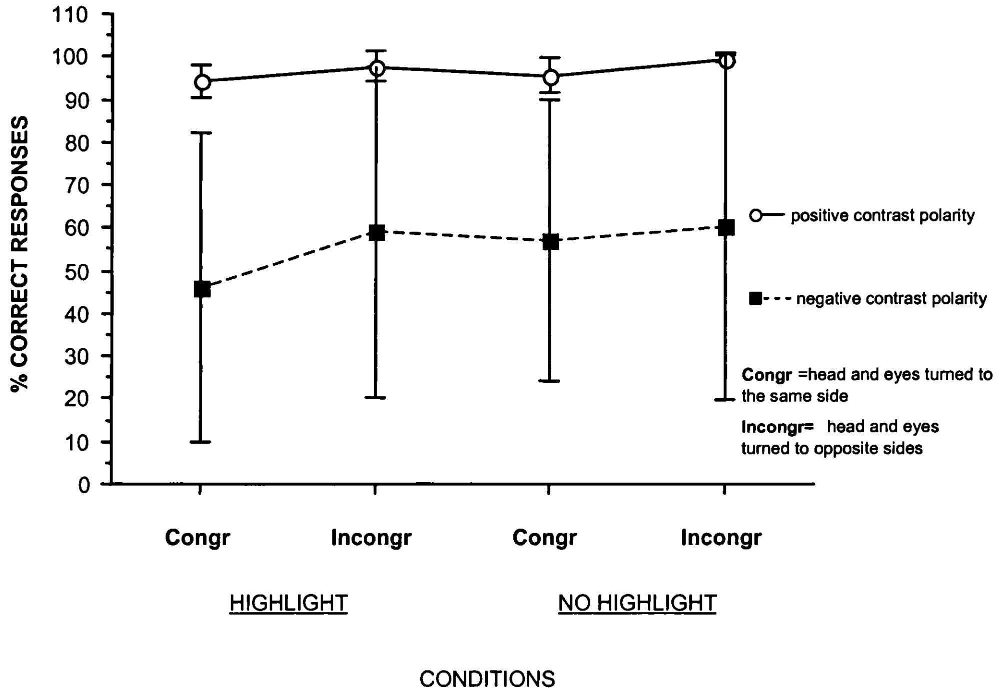

Fig. 3.5. Untransformed mean percent of correct responses in judging gaze for Experiment 8. Percentages (bars indicate standard errors of the mean) are plotted as a function of polarity and congruency.

Results and discussion: A three-way within-subject ANOVA was conducted on the transformed data[4]. It again showed a significant main effect of contrast ($F(1,7)=7.65$, $p< .05$), with a better performance for positive than negative polarity stimuli (96.62% vs. 55.47%). Neither the main effect of highlight nor the main effects of congruency were significant ($p>.1$). Moreover, the contrast polarity factor did not interact with highlights present versus absent ($F(1,7)=.93$, $p>.1$); all the remaining interactions were also not significant (all ps> .2).

[4] The same Arcsine transformation was conducted as for the previous studies (Howell, 1992). Before the transformation the standard deviation and the mean of the percentages of correct responses for positive contrast conditions were 4.25 and 96.62 respectively, whereas for negative contrast conditions these were 44.48 and 55.47. After the Arcsine transformation the standard deviation and the mean of the number of correct responses for positive contrast conditions were 0.0 and 0.05, while the ones for the negative contrast conditions were 0.02 and 0.03.

As in the previous experiment, subjects' performance was worse with reverse contrast stimuli, now regardless of the presence of absence of highlights even though this factor could be anticipated within a blocked design unlike Experiment 7. Subsequently, a mixed ANOVA was carried out with the same three within-subject factors as before (contrast polarity, highlight and congruency), but with experiment (Experiment 7 vs. Experiment 8) as a between-subject factor. This showed a significant interaction between experiment and congruency ($F(1,14)=5.37$, $p<.05$), confirming a different pattern of congruency effect in Experiment 7 compared to Experiment 8, presumably due to the fact that the presence of highlights in the eyes were unpredictable for Experiment 7, as discussed earlier.

Thus, the contrast polarity effect does not appear to depend on any influence of the contrast manipulation upon the perception of highlights in particular. That is, the contrast polarity effect apparently cannot be attributed to the potential impact of polarity on interpretation of the highlights themselves, even if highlights can play some role in gaze perception, as shown by the change in congruency effects when highlights are predictably present.

Experiment 9

The last experiment of this chapter investigated whether motion cues, in dynamic gaze stimuli, would help to detect the direction of seen gaze, especially in the case of negative polarity. In all the previous studies, static eye stimuli were used and it was found that reversing the contrast polarity of eyes made judgements of gaze direction very difficult. By employing dynamic eye stimuli, the aim here was to test whether motion would serve as an additional cue, and possibly help to disambiguate gaze direction in negative stimuli.

Recall that the polarity effect may be due to assigning the wrong part of the eye as iris versus sclera. Motion may help by disambiguating which bit is the iris and which bit is the sclera, as only the circular iris may be matchable across successive frames of apparent motion (see below). Moreover, in real life we see moving eyes and thus motion may be a more ecological cue for the visual system. Therefore, it was expected that adding movement might enhance gaze perception, perhaps especially by helping to segment the iris from the sclera in negative polarity stimuli.

Method

Subjects: Twelve new subjects (7M and 5F, ranging 23-40 years in age) participated in the experiment and were naïve as to its purpose. As before they were all volunteers. None of them took part in any of the previous experiments, but they did all participate also in Experiment 11, reported in the next chapter.

Apparatus and Materials: The participants sat in a dark soundproof booth at 60 cm from the computer monitor. The experiment was run on a Power Macintosh G3 with a 17-inch AppleVision colour monitor using VScope software (Enns et al., 1990), as before.

Stimuli and Design: The stimuli were similar to those used in the previous experiments, but all conditions now had a straight head, to simplify the design even further as the main factors of interest were now just the contrast polarity in the eyes, and any movement of the seen eyes. The possible movement in the eyes was generated by always presenting two frames showing the same face, but with different eye stimuli in rapid succession. The eyes in the first frame of the "static" condition were artificially occluded, such that they appeared to be "closed", while for the dynamic stimuli, the eyes looked straight ahead in the first frame. In both conditions, this first frame was immediately followed by a picture with deviated gaze (see Fig. 3.6). Thus, both the "static" and the "dynamic" gaze stimuli comprised two successive frames, with the relevant information for the judgement appearing in only the second frame. The reason for always using two frames in all conditions will be explained further in Chapter 4.

The sequence of events was as follows. After the appearance of the central fixation asterisk (lasting for 565 ms), the first frame (either with the "closed" eyes or the straight gaze) appeared for 200 ms. Subsequently, the eyes either "opened" to revealed a deviated "static" gaze, or appeared to move to look left or right (dynamic stimuli), but with this actually caused by the onset of the same deviated gaze frame as for the static condition. This second frame lasted until response.

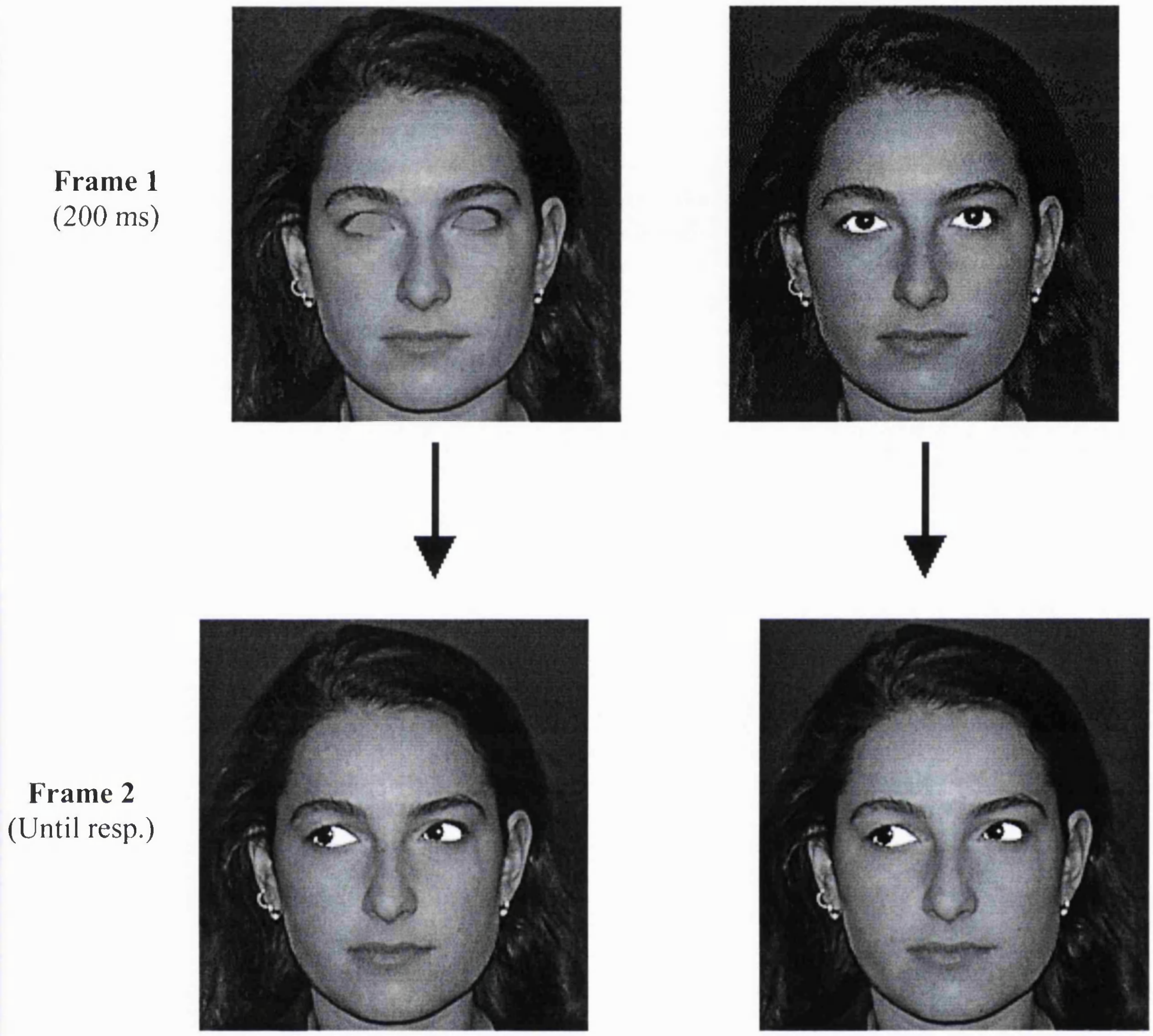

Fig. 3.6. Example of the two successive stimulus frames used in Experiment 9 to generate the apparent movement. An initial frame with "closed" eyes shown here (on the top left) was used to generate "static" stimuli, while an initial face with straight eyes (shown here at top right) was used to generate "dynamic" stimuli.

The previous congruency factor was dropped, being replaced with the moving/static factor. The other factor of interest was the contrast polarity. Therefore, the final design was a within-subject factorial design with a 2 (positive vs. negative contrast of eyes) x 2 (static vs. dynamic gaze structure). The task was once again a two-choice left versus right response.

Procedure: Each subject was asked to judge whether the eyes of the computerised face in the final frame on each trial were looking to his/her left or right. On the computer keyboard the subject had to press the "A" key to indicate "Left" gaze in the second frame or the "\" key for "Right" gaze in the second frame. These particular new response keys were chosen to better match the spatial direction of the gaze stimuli, and for compatibility with Experiment 11, reported later in Chapter 4. All the remaining procedural aspects and instructions were the same as in all previous experiments.

Results and discussion: A two-way within-subject ANOVA was conducted on the transformed data[5]. It showed a significant main effect of contrast ($F(1,11)=10.9$, $p<.01$) and a significant main effect of static/moving gaze ($F(1,11)=18.6$, $p<.01$). The interaction between the two factors was also significant ($F(1,11)=6.1$, $p<.05$).

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[5] The same Arcsine transformation was conducted as for the previous studies (Howell, 1992). Before the transformation the standard deviation and the mean of the number of percentages responses for positive contrast conditions were 8.65 and 94.06 respectively, whereas for negative contrast conditions these were 38.55 and 63. After the Arcsine transformation the standard deviation and the mean of the number of correct responses for positive contrast conditions were 0.16 and 1.39, while the ones for the negative contrast conditions were 0.48 and 0.93.

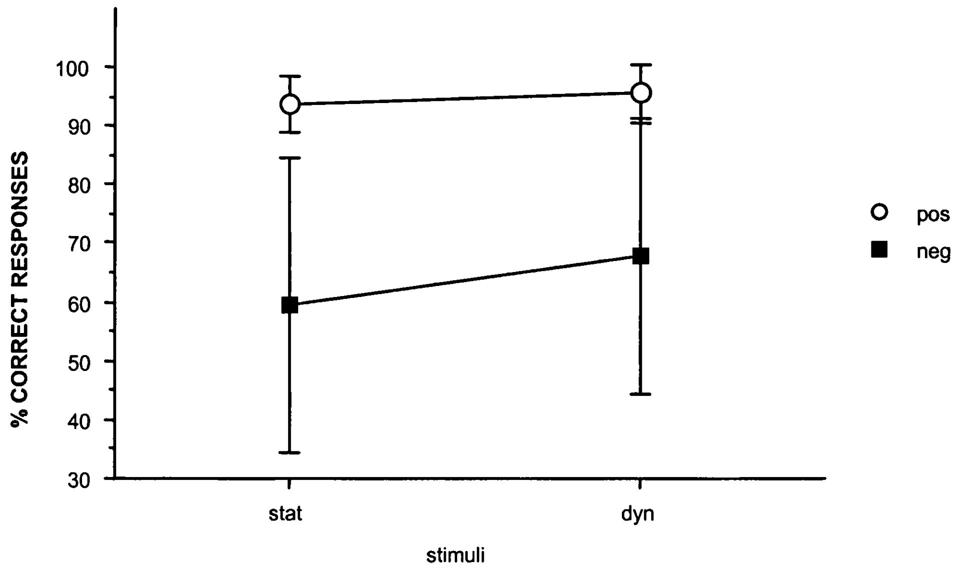


Fig. 3.7. Untransformed mean percent of correct responses in judging gaze for Experiment 9. Percentages (bars indicate standard errors of the mean) are plotted as a function of "static" versus "dynamic" stimuli.

Simple effect analysis showed a significant effect of polarity for both static stimuli ($F(1,11)=617.58$, $p<.0001$), and dynamic stimuli ($F(1,11)=456.24$, $p<.0001$). Negative stimuli were judged less accurately than positive ones (63% vs. 94.6%, respectively), as usual. There was also a significant effect of dynamicity on both positive stimuli ($F(1,11)=9.20$, $p<.01$), and negative stimuli ($F(1,11)=42.64$, $p<.0001$). Overall, static stimuli were judged less accurately than dynamic stimuli (76.6% vs. 81.6%, respectively). The interaction arose because the benefit of movement was bigger for negative stimuli, as predicted (see Fig. 3.7).

The present findings confirmed a (slight) superiority of dynamic stimuli in determining gaze direction, as originally hypothesised. It confirms also for dynamic stimuli the contrast polarity effect found previously with static stimuli, showing once again a difficulty in judging gaze direction when the iris becomes lighter than the surrounding sclera. This polarity effect is found both when the eyes are static and dynamic. Adding movement to the eyes does improve observers' performance with negative polarity stimuli somewhat (and more so than for positive eyes, although ceiling effects may be involved in the latter case), but this benefit from motion does not completely outweigh the cost of having the wrong contrast polarity in the eyes.

General Discussion

The findings in the present chapter confirmed the result found in Chapter 2, showing that reversing the contrast polarity of the eye region dramatically impairs people's ability to discriminate gaze direction. In other respects, the exact colour of the sclera and of the iris (provided that the former is lighter than the latter), and also the contrast polarity of the face context, matter relatively little. For example, *positive* contrast polarity for the eyes was shown to be a crucial factor for accurately perceiving gaze direction even within the context of a *negative* face (Experiment 6). The influence of highlights is not required to produce this contrast polarity effect either (Experiment 7 and 8), although highlights may play some role in gaze perception when they are consistently present.

The contrast polarity effect suggests that the human visual system relies on a general rule, namely that irises are typically darker than their surrounding sclera, in addition to utilising the more general geometrical cues about eye shape that have been emphasised by previous authors (e.g. Anstis, Mayhew, and Morely, 1969; Gibson & Pick, 1963; Ehrlich & Field, 1993). The present findings cannot be reduced to the insights of these previous studies concerning purely geometrical cues, as contrast polarity leaves all geometrical factors constant. On the other hand, the present results do not necessarily conflict with the importance of geometric cues. Instead, they suggest that these cues can only be appropriately extracted *after* the assignment of iris and scleral regions, based on the usual contrast polarity.

The involvement of "expert" systems may be implied here, in a similar sense to that often inferred from the effects of inversion on face processing. Inversion disrupts recognition more for faces than for other classes of object (e.g. Yin, 1969). Analogously, reversing the eye contrast polarity impairs directional judgements more for eyes than for other classes of stimuli (e.g. judgements of head orientation are not disrupted; Experiment 4 in Chapter 2). Furthermore, just as evidence from neuroscience and neuropsychology has documented the existence of specialised neural systems involved in the processing of faces (e.g. Gross et al., 1972; Kanwisher et al., 1997), so there is now some evidence for such neural specialisation in the processing of gaze, within somewhat different neural areas (e.g. Perrett et al., 1990; Hoffman & Haxby, 2000).

There has long been controversy over whether specialised processing of faces is pre-programmed genetically, or is the consequence of acquired "expertise" during extensive exposure to faces; or instead reflects some specific combination of nature and nurture (e.g. Diamond & Carey, 1986; Johnson & Morton, 1991; Gauthier et al., 2000). Similar issues arise for the contrast-polarity specificity uncovered here for gaze perception. Since even young babies are highly sensitive to gaze-direction (at least in "positive" stimuli; e.g. Maurer, 1985; Hood et al., 1997), developmental work with the positive and negative stimuli introduced here could reveal whether the contrast-rule for gaze perception reflects learned or innate expertise in gaze processing. The present stimuli could also be used to test whether contrast-specific expertise in gaze perception is lacking in individuals who exhibit (or go on to show) dysfunctional social attention, as in autism (e.g. Frith, 1989; Baron-Cohen, 1995, Happe', 1999).

The possible effects of congruency between head and gaze direction (e.g. for Experiment 7 versus 8) merit further study. Chapter 5 will address the issue of how the visual system takes into account the orientation of the head when making gaze direction judgements.

A further interesting matter would be to relate the present findings on factors determining deliberate, explicit gaze perception to the gaze cues which are critical for directing the observer's attention in an automatic manner. As discussed in the literature review of Chapter 1, several authors have recently shown (Langton & Bruce, 1999; Driver et al., 1999; Friesen & Kingstone, 1998) that subjects' visual attention can be automatically directed by seeing someone else's gaze, at least when that person is seen in positive polarity. However, as yet nothing has been determined about which part or which features of the eyes are responsible for such cueing effects. The following chapter will investigate this issue systematically. If, as hypothesised, the contrast polarity of the eye region plays a major role in directing an observer's attention, then reversing the contrast polarity should have a disruptive effect on the size of any cueing effect from seen gaze. The next chapter also tests whether dynamic gaze cues particularly affect orienting of attention in the observer.

Chapter 4

ATTENTIONAL CUEING EFFECTS FROM SEEN GAZE, IN RELATION TO EYE CONTRAST POLARITY

The previous chapters have illustrated factors affecting explicit judgements of the direction of gaze. However, the perception of gaze also affects other processes, such as orienting of attention. Recently, gaze direction has been shown to produce attentional cueing effects (e.g. Driver et al., 1999; Friesen and Kingstone, 1998). Specifically, behavioural studies of gaze perception in adults have shown that gaze influences the direction of social attention by automatically triggering the attentional focus of another. Typically, people are faster at detecting the appearance of a target when it appears in the same direction of seen gaze even when told that the gaze was not informative about target location (Friesen and Kingstone, 1998; Langton and Bruce, 1999). Recently, Driver et al. (1999) have also shown that orienting attention in the direction of a seen gaze can still occur automatically even when the person has some strategic reason not to orient his attention in the direction of seen gaze. That is, even when the subjects were informed that the probability of a target appearing on the opposite side of gaze direction (i.e. invalid trials) was four times higher than on the same side (i.e. valid trials).

Visual orienting of attention is typically demonstrated and studied using the cueing paradigm introduced by Posner (1980). It consists of asking people to make a simple response (e.g. a keypress on a computer keyboard) to the onset of a visual target which can appear at any one of several locations in a display. One of those locations is previously cued by a directional cue such as an arrow in the centre of the screen, or by a sudden event happening in the periphery (e.g. a flash of light or a sound). Typically, performance is better and faster at detecting the target when it appears in the cued location, regardless of whether or not the observers move their own eyes in the direction indicated by the cue (Posner et al., 1980; for reviews see also Driver et al., 1999 and Langton and Bruce, 1999). Moreover, visual attention can be oriented either automatically or voluntary (Muller and Rabbitt, 1989) depending on the nature of the cue. A sudden cue appearing in the periphery of the visual field automatically triggers attention towards that location, even when uninformative regarding the likely location of the target. In contrast, orienting of attention according to a central cue, for example an arrow, which is predictive of where the target may appear, is voluntary and under strategic control by the subject. It arises only when the cue is informative. Different mechanisms are thought to underlie these two different ways of orienting attention (e.g. Muller and Rabbitt, 1989), which also have a different time courses. Reflexive, or "exogenous" orienting of attention typically produces its best cueing effect at short cue-target stimulus onset asynchronies (SOAs) of around 100-150 ms, whereas endogenous orienting takes longer (300-400 ms) to initiate, but has more durable effects.

The present experiments used a modified version of the Posner cueing paradigm to examine attentional cueing effects from seen gaze, similar to that described in the study by Driver et al. (1999). Moreover, I combined the study of attentional orienting with the negative contrast-polarity manipulation studied in the previous chapters of this thesis, to determine whether contrast polarity of seen eyes can affect not just gaze perception but also social attention. In the previous chapters, I proposed that the disruptive effect caused by reversing the contrast polarity in the eyes arises because the visual system follows an inflexible rule, invariably treating the dark part of the eye image as the part that does the looking. It was suggested that this may involve a dedicated "expert" system, applying this obligatory "rule" in the processing of gaze stimuli. As gaze perception is thought to be a key step in social cognition (e.g. Baron-Cohen, 1995), what would happen if we employed negative contrast polarity stimuli in tasks which tap into social attention? If it was true that social attention relies mainly on gaze perception (e.g. Perrett et al., 1990), then I would expect a reduced gaze cueing effect, or no effect at all for negative polarity eyes, assuming that social attention shifts are driven by the results of explicit gaze perception.

Recall also that in the previous chapter, the perception of gaze direction improved, particularly in negative polarity, when the movement was added to eye image. The improvement with motion for negative eyes is presumably due to the apparent movement helping the visual system to identify the iris, by better segregating it from the surrounding sclera. It would be interesting to see whether the gaze cueing effect follows the same rules on this point as for the explicit gaze judgements. For example, by restoring better gaze perception with movement, is it thus possible to bring back the gaze cueing effect? Similar to what was described in the previous chapter for gaze perception, what happens to the cueing effect if instead of using a static eye-cue, we add movement to the gaze, so that now the cue-gaze becomes dynamic? Do dynamic eye-cues play a role in cueing effect? All these questions were addressed in the following experiments.

Experiment 10

The aim of the present experiment was to investigate whether the contrast polarity effect described in Chapters 2 and 3 could also play some role in orienting an observer's attention in response to seen gaze direction. As mentioned earlier on, the direction of seen gaze can act as a cue to orient attention even when the observer does not have any motivation or intention to do so (e.g. Driver et al., 1999). My aim was to test whether inaccurate gaze perception, such as that emerging for eyes shown in negative contrast polarity (see Chapter 2 and 3) would disrupt orienting of attention. This issue was first addressed by means of an adaptation of the Posner cueing paradigm (Posner & Cohen, 1984), in which cartoon eyes were now used as central directional cues (see also Friesen and Kingstone, 1998). Eyes were presented both in positive and negative contrast polarity and might be used by the visual system to exogenously shift the observer's attention. This was tested in a task requiring the discrimination of peripheral targets on the side the central eyes looked towards, or (equally likely) on the other side.

Method

Subjects: Ten volunteer subjects (5M and 5F, aged between 20 and 35 year olds) participated in the experiment. They were all unaware of the purpose of the experiment. They received a monetary reimbursement of £5.00 for their collaboration and had normal or corrected-to-normal vision by self-report.

Apparatus and Materials: The experiment took place in a dark sound-proof booth. The subject sat in front of a computer screen (a 37 cm x 30.5 cm Sony Triniton Multiscan 100 SX colour monitor), driven by an 8500/120 Power Macintosh computer. The distance between the subject's head and the screen was approximately 70 cm, and maintained by the use of an adjustable chin-rest. The program regulating the stimulus presentation and recording of RTs was generated in VScope 1.2.5 software (Enns et al., 1990). Each trial began with the appearance of a central fixation asterisk ($1^{\circ}.15'$ x $1^{\circ}.31'$ of visual angle), appearing against a grey background and followed by a pair of cartoon eyes ($7^{\circ}.78'$ x $1^{\circ}.64'$ of visual angle, see Fig. 4.1), deviated 30° towards the left or the right of the subject. The eyes could be presented in positive or negative polarity and were made using Adobe Photoshop 4.0 as described in Chapter 2. A target (i.e. a checkerboard) could then appear on the side the eyes gaze towards, or on the opposite side, in an upper or lower positions (see Fig. 4.2). The reaction times taken to discriminate whether the target appeared up or down were recorded by the computer from the onset of the target.

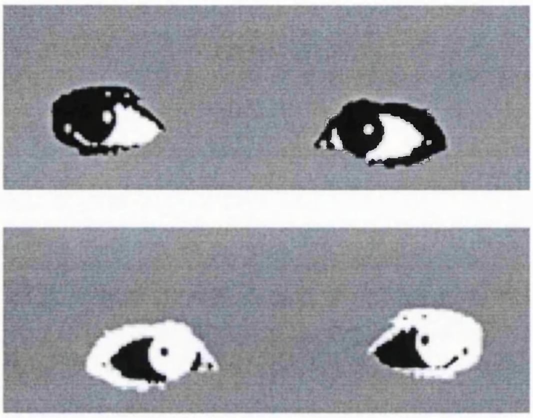


Fig. 4.1. Example of stimuli from Experiment 10. Positive eyes above and negative eyes below.

Design: There were three orthogonal factors of interest, all within-subject factors: the polarity of the eyes (positive or negative), the difference in time between the onset of the eye cue and the onset of the peripheral target checkerboard (i.e. SOAs: 200ms or 400 ms) and the validity between target and the side of the gaze (i.e. valid: same side vs. invalid: opposite side). All 8 conditions produced by combining of the levels on the three factors were equiprobable.

Procedure: Each subject was tested in one experimental session, which lasted approximately 45 min. They were presented with 768 trials, divided into 8 equal blocks of 96 trials each, with the 8 conditions produced by the 2x2x2 design being equiprobable and presented in a random sequence within each block. Every block was followed by a few minutes rest. The subjects were requested to discriminate whether the target was upper or lower (regardless of its side), by pressing two different keys on the computer keyboard as fast as possible. They and were informed that the direction of gaze did not predict where the target would appear. They were asked to press the space bar on the computer keyboard if the target appeared downward or to press the H-key if it appeared upward, regardless of target side (see Fig. 4.2).

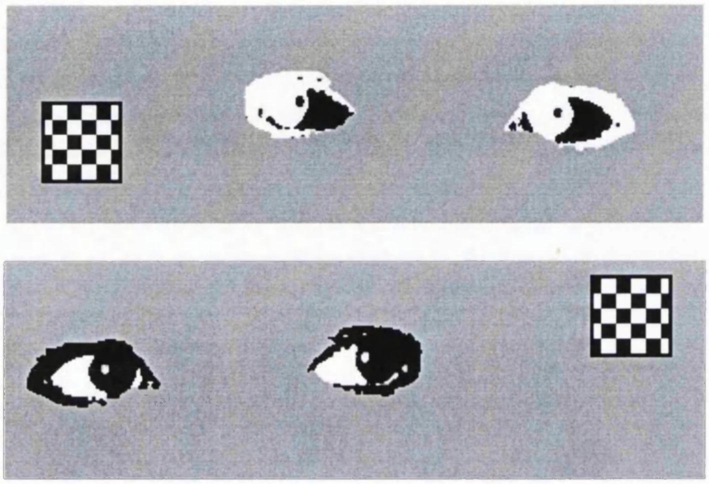


Fig. 4.2. Example of eye stimuli and target from Experiment 10. Top row shows an example of a downward target with negative eyes, the bottom row an example of upward target with positive eyes.

The use of the up/down decision, regardless of target side, was intended to test for a “true” effect of attention, rather than the lateral response bias that might have been induced by leftward or rightward looking eyes if a left response had to be made for a target appearing on the left, and vice versa (see Spence and Driver, 1994).

At the beginning of the experimental session, a few trials were given as examples and the first block of trials was subsequently discarded from the analysis as practice. The sequence of events on each experimental trial was as follows. The fixation asterisk appeared at the centre of the screen for 568 ms. This was followed by the eyes gazing towards the left or the right which could last either 200 ms or 400 ms before onset of the peripheral target. The cue was uninformative (in terms of gaze direction) with respect to the location of the

subsequent target, as it was equally likely to look towards one side or the other regardless of where the target subsequently appeared. When the target appeared, the eyes remained visible. This display lasted until response, or for a maximum of 1119 ms. The target appeared either on the same side or on the opposite side of the gaze direction (see figures below), equiprobably.
A maximum interval of 3006 ms was allowed for response execution. After a short delay of 500 ms, needed to prepare the screen for the next display, an analogous sequence of events was repeated to produce the next trial. Feedback on accuracy was given after each trial and at the end of each block.

Results: Data from one subject were not included in the analysis due to his high inaccuracy in the responses (> 10% errors). The first block of trials was discarded from the analysis as practice. The median RTs per subject for each condition were entered into a three-way ANOVA with validity (valid vs. invalid), SOAs (200 ms vs. 400 ms) and eye polarity (positive vs. negative) as within-subject factors (see Table 4.1).

		Valid	Invalid	Valid	Invalid
Eye polarity	Soas	200	200	400	400
Positive		440	451	415	432
Negative		443	450	422	428

Table 4.1. Summary table of means of median RTs (ms) for all conditions in Experiment 10.

The analysis showed significantly faster RTs for valid than invalid trials (respectively, 430 ms vs. 440 ms: $F(1,8)=23.51$, $p<.01$) as well as faster RTs for long SOA compared to short ones (respectively, 424 ms vs. 446 ms: F(1,8)=30.67, p<.001). The interaction between validity and polarity was also significant (F(1,8)=23.51, p<.01), with a reduced validity effect for negative eyes (see Fig. 4.3).

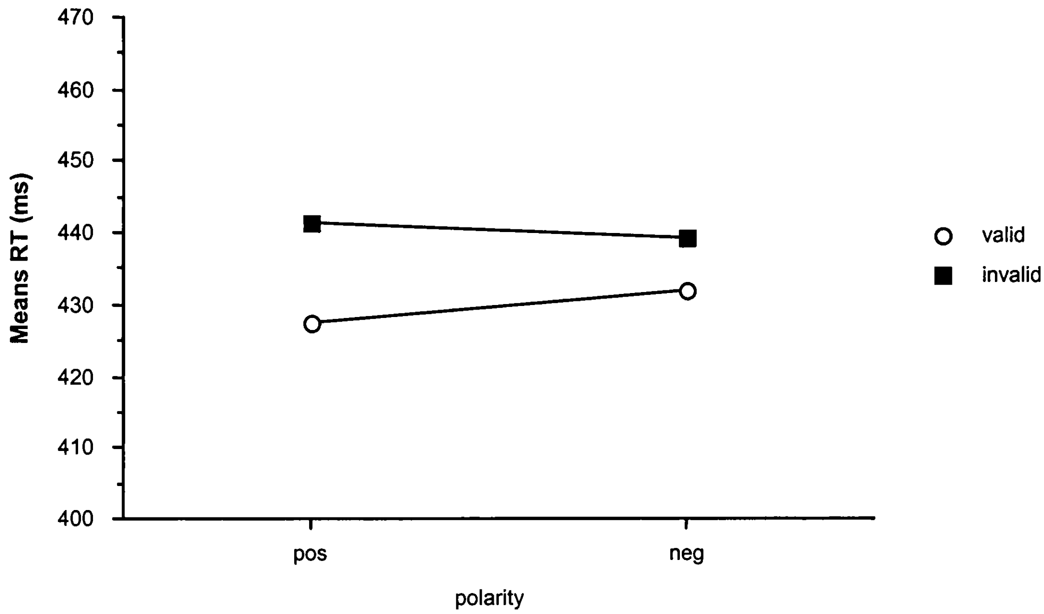


Fig. 4.3. Inter-subject means of median RT for correct responses in the target discrimination task of Experiment 10. RTs are plotted as a function of polarity and validity.

The percentages of errors were also analysed and entered into a three-way ANOVA as before (see Table 4.2).

		Valid	Invalid	Valid	Invalid
Eye polarity	Soas	200	200	400	400
Positive		2.12	3.31	3.04	4.10
Negative		1.71	1.85	1.59	3.83

Table 4.2. Summary table of means percentages of errors for all conditions in Experiment 10.

The analysis showed only a significant effect of validity ($F(1,8)=6.30$, $p<.05$) due to a significant increase in the percentage of errors for invalid trials compare to valid one (3.27% vs. 2.12%, respectively). However, the overall percentage of errors was low (only 2.7%).

Discussion

Two main findings emerge from the present experiment. First of all, as previously reported in the recent literature (e.g. Driver et al., 1999; Friesen and Kingstone, 1998; Langton and Bruce, 1999), the direction of seen gaze can trigger the attention of an observer towards the side that the seen eyes look at, speeding up judgements for a target appearing on the same side (i.e. producing a cueing effect). Second, the new result is that when the gaze is presented with a negative contrast polarity, this cueing effect becomes smaller and the advantage for the target appearing on the same side is reduced. This suggests that the contrast polarity of the eyes is not just crucial for consciously perceiving the direction of gaze (as in Chapters 2 and 3), but also for influencing the orienting of attention in the direction of seen gaze. Nevertheless, the effect found in the present experiment was relatively small. Possibly as the positions of the target were fairly ambiguous (as both upward and downward positions were very close to the line of gaze of the eye), and the eyes used always looked up slightly (see Fig. 4.2). Thus, in order to replicate such an effect and to improve the stimuli, a follow-up experiment was carried out, which aimed to replicate and strengthen the results, and also to investigate any effect of dynamic eye cue stimuli on gaze perception.

Experiment 11

This experiment aimed to investigate whether moving eyes would enhance gaze perception, and restore the cueing effect that was reduced for negative polarity eyes in Experiment 10. In the previous chapter, movement has been shown to be a useful cue to restore gaze perception by helping the perception of gaze direction more for negative polarity stimuli.

As in Experiment 10, in the present experiment participants were asked to discriminate a peripheral target (i.e. up/down discrimination task), which could appear either on the same side the eyes were gazing towards (valid conditions) or on the opposite side (invalid conditions). However, now improved stimuli were used. A picture of a real person gazing to the left or the right was used (as in the previous chapters) instead of the more "schematic" eyes of Experiment 10. In doing so the aim was to use stimuli more similar to those already used in the previous chapters on explicit gaze judgements, and also more like those used in Driver et al.'s (1999) study. In addition, the peripheral targets now appeared further up and further down, and the slightly upwards inclination of the central gaze was now eliminated. Moreover, the eye-cues (i.e. the gaze) could be either static or dynamic (as in Experiment 9, Chapter 3).

Method

Subjects: Fourteen people (8M and 6F), aged from 23 to 40, took part in the experiment. All participants were volunteers and were recruited through advertisement. They were paid £5.00 for their collaboration and were naïve as to the purpose of the experiment[1].

Apparatus and Materials: The experiment was run on a Power Macintosh G3 with a 17-inch Apple Vision colour monitor, using V-scope software 1.2.5. The participants sat in a dark soundproof booth approximately 70 cm from the monitor. A scanned photograph of a female face (as in the previous chapters) was used to produce the eye-cues. The face (8^0 x 8^0 of a visual angle) was set against a grey background (see Fig. 4.4) and could gaze 30^0 either to the right or to the left of the subject. Left and right gaze were mirror images of each other, so that no asymmetries in the stimulus apart from the deviated gaze could be responsible for any differences in lateral orienting of attention produced by the gaze cue. Both the static and dynamic conditions were generated by rapidly superimposing two frames of the same picture one upon the other (see also Experiment 9 in Chapter 3).

[1] The same subjects participated also in Experiment 5 reported in Chapter 3 within the same experimental session. These two experiments lasted about 20/25 min each. Experiment 5 was actually run immediately after Experiment 11; they were reported in reverse order here only for ease of exposition.

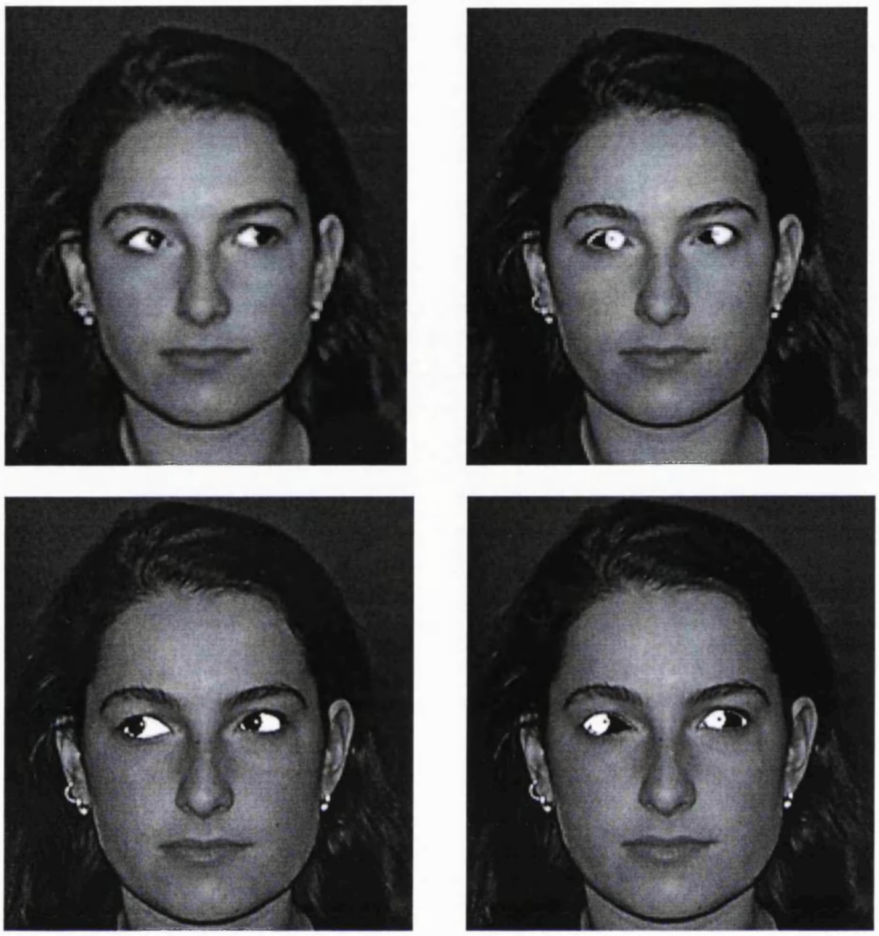


Fig. 4.4. Example of stimuli from Experiment 11. Upper panels show examples of a face looking to the right of the observer, while the lower panels depict a face looking to the left. Left column examples show eyes in positive polarity, right column show of eyes in negative polarity.

However, by using Adobe Photoshop 4.0, for the static conditions the eyes in the first frame were occluded by filling them in with grey colour that approximately matched the average face tone; then they appeared to be "closed". By contrast, for the dynamic stimuli, apparent movement was created by having a straight gaze rather than the eyes closed in the first frame (see Fig. 4.5), immediately followed by a deviated gaze in the subsequent frame. The "closed" eye first frame was used in the "static" condition, in order that both conditions should comprise two successive frames.

Fig. 4.5. Example of initial frames used in Experiment 11, to generate apparent movement or "opening" when followed by the second frame (which was depicted in Fig. 4.4). A face with "closed" eyes (on the right hand side here) was used as the first frame to generate static stimuli, while a face with straight eyes (on the left hand side) was used to generate dynamic stimuli.

The positive and negative polarity of the eyes was created as described in Chapter 2. The target was a peripheral square checkerboard identical to that used in Experiment 10, but appearing somewhat higher or lower (approximately 0.95' of visual angle above or below the line of gaze).

Design: There were four main factors, all within-subject: eye polarity (positive vs. negative); the type of cues (static vs. dynamic), the SOA between cue and subsequent target (200 ms vs. 400 ms), and the validity (valid vs. invalid). As in Experiment 10, the target could appear either downward or upward either to the left or to the right of the subject with equal probability. The task was again to discriminate as rapidly as possible whether the target appeared upward or downward, regardless of its side. For all the remaining methodological aspects the present experiment was the same as in Experiment 10.

Procedure: Subjects sat in front of a computer screen and a short practice section was given. The whole experimental session lasted approximately 20 min. The procedure was similar to that in Experiment 10. For the static conditions, the sequence of events on each trial was as follows. Each trial began with a central fixation point (i.e. an asterisk) lasting for 565 ms. It was followed by a picture of a face with the eyes "closed", which after 200 ms "opened" to revealed a deviated static gaze, either to the left or to the right of the observer and lasting until response. The gaze could be presented either in a positive or negative polarity (see Fig. 4.4). The target could appear either 200 ms or 400 ms after the deviated eye cue. The participants were instructed to discriminate as fast as possible the elevation (up versus down) of the target. As before, the gaze was uninformative (see Fig. 4.6). Their response was followed by a "+" appearing on the computer display if their response was correct or by a "-" if it was incorrect. The whole sequence of events was repeated to produce the next trial. Within each block, all the conditions were equiprobable, and were presented in a random sequence. The whole experiment lasted about 20 min. and was divided into four blocks of 192 trials each. Feedback on the overall accuracy was given at the end of each block, followed by a short break.

The sequence of events for dynamic trials was identical to the static trials with the exception that the initial closed eye was replaced by a display with open eyes that stared directly at the subject. The two frames in sequence conveyed apparent motion. Note, however, that only the second frame had deviated gaze, and these frames were identical to those used in the "static" gaze conditions also, with identical timing.

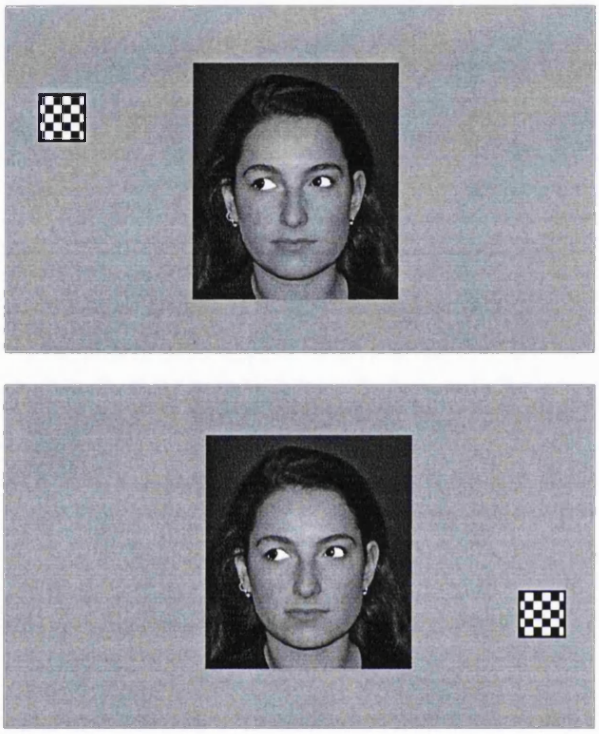


Fig.4.6. Example of cues and targets from Experiment 11; "valid" trials (upper panel) and "invalid" trials (lower panel), shown here for positive eyes.

Results: The median RTs were computed for each subject and were entered in a within subject ANOVA with polarity (positive vs. negative), type of eye-cue (static vs. dynamic), SOA (200ms vs. 400 ms) and validity (valid vs. invalid) as within-subject factors. The four factors were fully crossed in a 2x2x2x2 factorial design (see Table 4.3). A significant main effect of SOAs was found showing faster RTs (420 ms vs. 437 ms) as SOA increased ($F(1,13)=12.20$; $p<.01$).

		Static				Dynamic			
		Valid		Invalid		Valid		Invalid	
Eye polarity	Soas	200	400	200	400	200	400	200	400
Positive		430	416	438	426	429	410	448	423
Negative		442	429	432	415	438	421	442	425

Table 4.3. Summary table means of median of RTs (ms) for all conditions in Experiment 11.

Interestingly, there was a significant interaction between polarity and validity (F(1,13)=22.63; p<.001) (see Fig. 4.7).

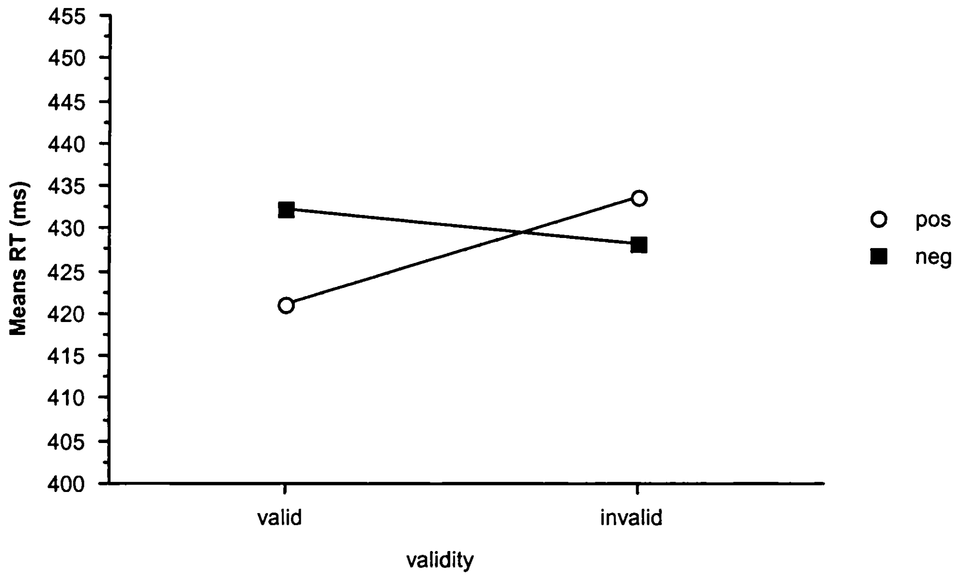


Fig. 4.7. Inter-subject means of median RT for correct responses in the target discrimination task of Experiment 11. RTs are plotted as a function of validity and polarity.

Mean contrast analysis showed faster RTs for valid positive polarity eye-cue than invalid positive polarity ones (421 ms vs. 433 ms, respectively; F(1,13)=25.51; p<.001), whereas for negative polarity the validity effect tends to reverse (432 ms vs. 428 ms) but it did not reach significance(F(1,13)=2.81;

p> .1 n.s.). Finally, the interaction between type of cue (static versus dynamic) and validity was also significant (F(1,13)=5.99; p<.05) (see Fig. 4.8).

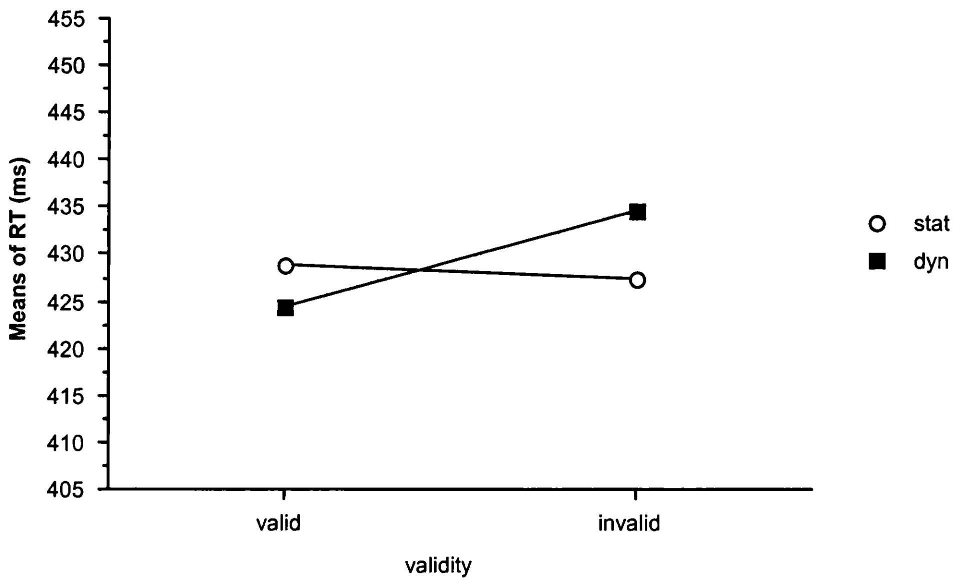


Fig. 4.8. Inter-subject means of median RT for correct responses in the target discrimination task of Experiment 11. RTs are plotted as a function of validity and type of eye-cue (static versus dynamic).

Mean contrast analysis showed this was due to a significant validity effect only for dynamic eye-cues (F(1,13)=8.99; p<.05). RTs for valid eye-cues were faster than for invalid cues when dynamic (424 ms vs. 435 ms, respectively), but this was not the case for valid and invalid eye-cues when static (428 ms vs. 427 ms, respectively; F(1,13)=0.22, n.s.). In addition, the three-way interaction between polarity, kind of eye-cue and validity was far from being significant (F(1,13)=2.21; p>.1 n.s). No other effect or interactions in the analysis were significant (all ps>.1).

		Static				Dynamic			
		Valid		Invalid		Valid		Invalid	
Eye polarity	Soas	200	400	200	400	200	400	200	400
Positive		1.19	1.19	1.34	2.23	1.78	1.49	1.64	2.53
Negative		1.49	2.53	1.93	2.23	1.78	1.34	1.19	1.19

Table 4.4. Summary table of means percentages of errors for all conditions in Experiment 11.

The percentages of errors were analysed as before although the overall percentage of error was only 1.7% (see Table 4.4). The four-way ANOVA showed a significant interaction of polarity and type of eye-cue ($F(1,13)=5.36$, $p<.05$) (see Fig.4.9), which affected only the negative polarity stimuli and was mainly due to a drop in the percentage of errors for dynamic eye-cue conditions compare to static ones (1.3% vs. 2%, respectively; $F(1,13)=4.43$, $p=.055$).

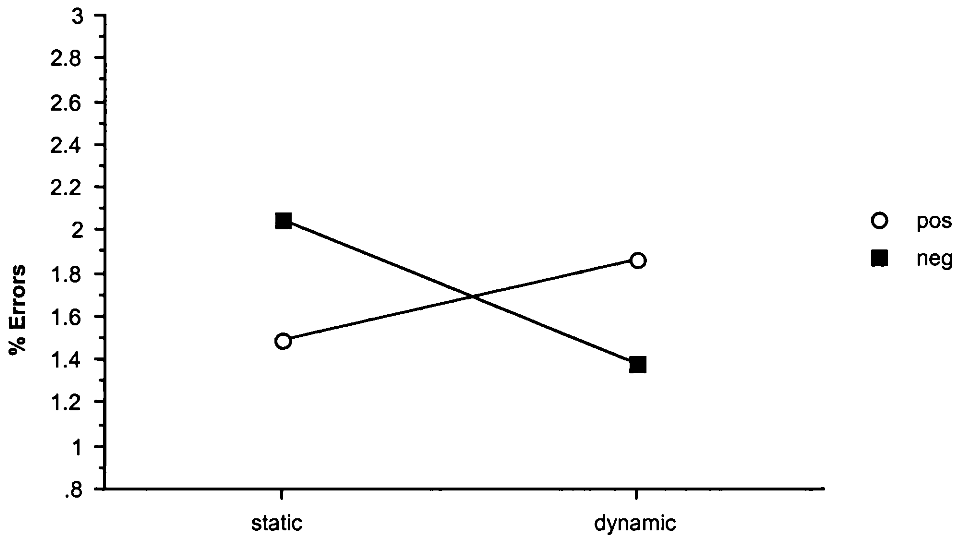


Fig. 4.9. Mean percentages of errors in the target discrimination task of Experiment 11. Percentages are plotted as a function of type of eye-cue and polarity.

This result suggests that adding movement to the eye-cue help to conteract the effect of negative polarity as regards error rate.

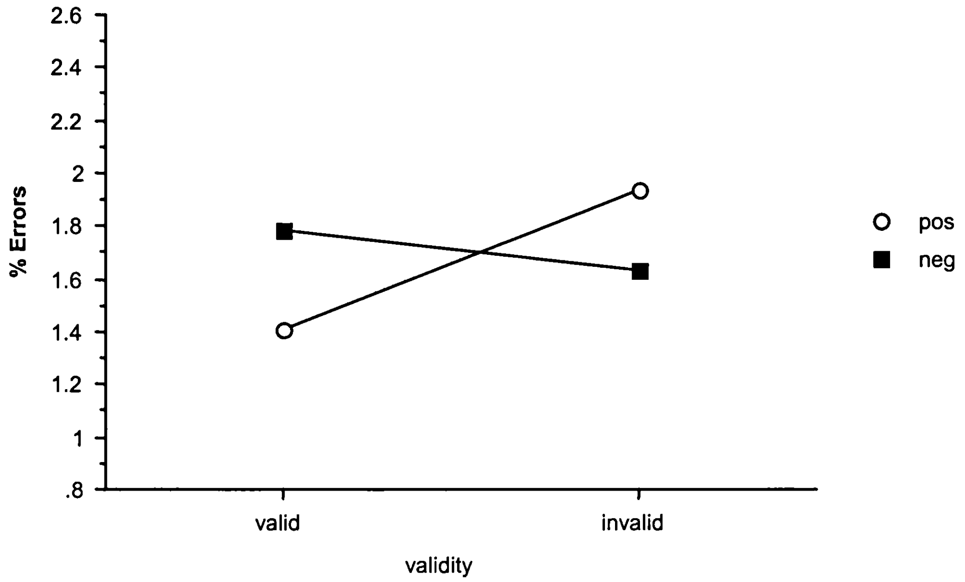


Fig. 4.10. Mean percentages of errors in the target discrimination task of Experiment 11. Percentages are plotted as a function of validity and polarity.

There was also a significant interaction of polarity and validity ($F(1,13)=5.70$, $p<.05$) the latter affected only the positive polarity conditions, showing a significant increase in the percentages of error for the invalid conditions (1.4% valid vs. 1.9% invalid; ($F(1,13)=6.90$, $p<.05$) (see Fig.4.10), in line with the gaze cueing effect reported in the RTs analysis. No other significant effect or interactions were significant (ps>.1).

Discussion

The main finding of the present experiment is that both contrast polarity and movement of seen eyes have an effect on gaze cueing. Reversing the contrast polarity in the eyes reduces substantially the cueing effect triggered by the gaze in its direction; instead, when the eye-cue is static the effect not only dissapears but tends to reverse. This seems to be due to the disruptive effect of negative contrast polarity on gaze perception, and is in line with the proposal I put forward in Chapter 3, stating that the visual system invariably interprets the darker part of the eye as the part which does the looking.

In both Experiment 10 and 11, the difference between longer and shorter SOAs is not surprising given that it has been already reported in literature (e.g. Driver et al., 1999; Langton & Bruce, 1999). The fact that faster RTs are shown at longer SOAs is thought to be because longer SOAs provide more general, and non-spatial alerting by any preceding cue.

The use of dynamic eye-cue has also an effect on gaze cueing; generally, it speeds up people's response and enhances the gaze cueing effect. Nevertheless, the beneficial effect of movement is not enough to help the visual system to completely override the disruptive effect of negative polarity and restore completely the advantage of valid trials in those conditions that is found for positive polarity eyes.

General discussion

The present chapter aimed to investigate whether the dramatic effect of contrast polarity on explicit gaze perception, as described in Chapters 2 and 3, may also influence the orientating of attention in the direction of seen gaze. In addition, dynamic and static eye stimuli were used, to test whether motion could act as an additional cue to help the visual system disambiguate the direction of gaze and, thus, direct the observer's attention to the same place (providing a gaze cueing effect). Two main results emerged from these studies. First, the contrast polarity of gaze does influence the orienting of attention in the direction of seen gaze, by reducing the gaze cueing effect of the eyes when they are presented in negative polarity. Second, dynamic stimuli can to some extent mitigate the disruption cause by the reversal of contrast polarity (see also Chapter 3), but cannot completely restore the gaze cueing effect for negative polarity eyes. Moreover, the trend for a reversal of the validity effect for negative polarity <u>static</u> stimuli further supports the proposal made in Chapter 2 and 3, stating that the perceptual system would invariably treat the darker part of a static eye as that doing the looking.

The other interesting issue arising from both the previous and present chapters concerns the role of motion in gaze perception and joint attention. Interestingly, Experiment 11 crucially showed that people were faster at discriminating the target when it appeared on the same side of gaze direction for dynamic eye stimuli, but not for static eye stimuli. This result is important because it brings further evidence that movement particularly help the perception of gaze direction, and may do so especially for negative polarity eyes (see Chapter 3). The apparent movement generated by two successive frames that differ only in the position of the iris. Although the movement does not seem to be such a powerful cue to gaze direction as contrast polarity, it does play some role in gaze perception and thus in joint attention. As far as I know, my experiments are the first behavioural ones with adults to show how motion can interact with joint attention.

Biological motion is usually used to refer to movement of living things (Johansson, 1973). In humans, moving/dynamic eyes in particular have been shown to selectively activate the superior temporal sulcus (STS), which is not activated by general motion (Puce et al, 1998). Very recently, an intriguing proposal has been made by Frith & Frith (2000) which strictly relates the perception of biological motion to the perception of intentions. According to them, the ability to recognise intention may depend on an ability to interpret movements of others. Therefore, it might not be surprising that perceiving the eyes moving towards one side would imply to an observer that the seen person has the intention to look in that direction, thus encouraging or facilitating joint attention behaviour.

Nevertheless, as far as gaze cueing is concerned, adding motion to the eyes does not seem to entirely restore the gaze cueing disrupted by negative contrast polarity of eyes (see also Chapter 3). However, it is noteworthy that there was no trend for a reverse cueing effect, unlike static negative polarity stimuli, implying that motion does seem to play a role in helping the visual system to segregate the iris, albeit it is not powerful enough to override the disruptive effect of contrast polarity.

Taken together, the findings reported in the present chapter, fit the proposal of several previous authors (e.g. Baron-Cohen, 1995; Perrett et al., 1990) that gaze perception can trigger joint attention behaviour (see also Driver et al., 1999; Friesen and Kingstone, 1998). Interestingly however, correctly perceiving gaze direction itself may not always be enough to develop joint attention behaviour and social orienting. For instance, people with autism have been described as deficient in the use of gaze direction and in the comprehension of mental states, but not in the perception of gaze direction per se (Baron-Cohen et al., 1995). Baron-Cohen and colleagues (1995) carried out a study in which healthy, mentally retarded children or children with autism were presented with cartoon faces, either with eyes averted or with eyes looking straight at the subject. The task was to decide which of the two faces was looking straight at the subject. In this gaze discrimination task, children with autism scored as well as normal or mentally retarded children, showing some ability to perceive gaze direction correctly. In contrast however, when gaze was directed towards one object among others (i.e. a package of Polo Mints), children with autism often failed to recognise the mental link between gaze direction and the object. They did not seem to be able to figure out that the reason why the face was looking at those candies was because the person "prefers" the Polo Mints to the others.

It would be interesting to follow up this work by testing whether people with autism are impaired in perceiving gaze direction when the eyes are presented in negative polarity, as for normal people (see Chapters 2 and 3). Alternatively, their perception of gaze direction might be unaffected by contrast polarity, for instance, they might be lacking the "expertise" in gaze perception arising during normal development that I suggested was responsible for the emergence of the usual contrast polarity effect (see Chapter 3). Therefore, in contrast with normals, people with autism might be unaffected by contrast polarity in their explicit judgements.

A further question is how contrast polarity might affect gaze-cueing effects in people with autism, if indeed they show any gaze cueing at all. A very recently, a study carried out by Swettenham et al. (2000) in normal children and children with autism, did investigate whether gaze as a social stimulus automatically cues attention in these populations. Similarly to the experiments described in this chapter, a spatial cueing paradigm was used in which a face cue was looking to the left or to the right of the subject. Static and moving faces were used too. Children were asked to detect as fast as possible the presence of a target, and the target could appear either in the same direction of gaze or in the opposite direction with the same probability. The authors found that, in line with the present experiments, normal children were faster at detecting a valid target than invalid. This was also true when a moving face turning the eyes to the left or right was used instead of a static one. In contrast, in children with autism neither static faces nor moving ones produced cueing of visual spatial attention. In the last chapter I will come back to this issue, suggesting a further possible way to investigate the contrast polarity effect in autism.

Chapter 5

EFFECTS OF HEAD ORIENTATION IN GAZE PERCEPTION

To understand where another individual is directing their attention, the whole face and the head might provide important cues in addition to those from just the eye region. For example, head orientation may influence information from the eyes, by contributing jointly to the computation of gaze direction. In young babies, head rotation along with a gaze cue helps the baby to orient their eyes in the same direction as the caregiver, thus, engaging the baby in joint-attention behaviour (e.g. Scaife and Bruner, 1975; Butterworth and Jarrett, 1991; Vecera & Johnson, 1995; Moore and Corkum, 1995). In adults, only a few past studies have considered how head orientation may be combined with the information from the eyes, and how the two influence judgements of gaze direction (e.g. Gibson & Pick, 1963; Anstis et al., 1969). Moreover, the interpretation of the findings from such studies is not always straightforward (see Chapter 1). Gibson and Pick (1963) suggested that the perception of gaze direction might be bound up with the representation of the head and its orientation in external space (see Chapter 1 and Fig. 5.1, which reproduces an illustration from Chapter 1). The phenomenon shown in Figure 5.1 may simply reflect the physical fact that when the head turns with the eyes, the latter have to deviate less in their orbits to look in that direction.

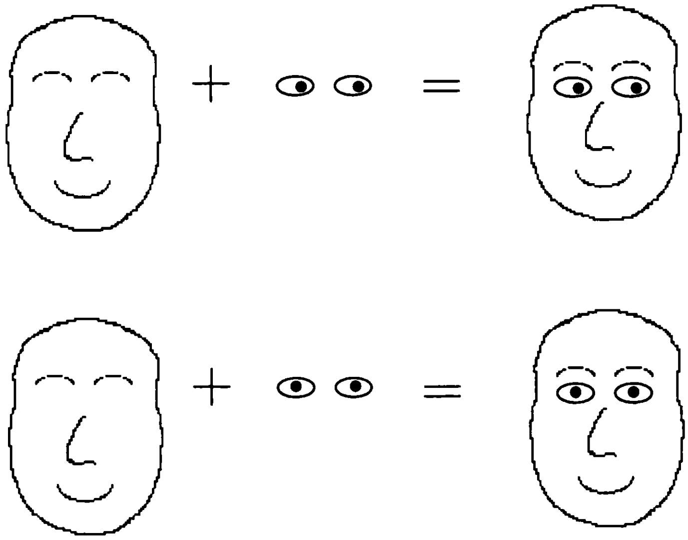
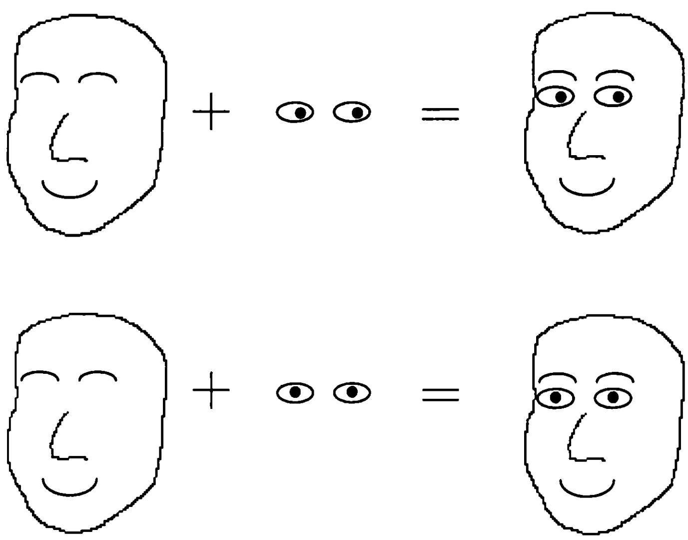


Fig. 5.1. The above two rows show eye-shapes surrounded by an almost frontal view of a face. The two rows beneath this caption show the same eye-shapes, but now surrounded by a turned face (From Gibson & Pick, 1963).

If you compare these figures, you should see the apparent shift in gaze direction when the head is turned. For instance, eyes gazing to the right in the straight head (top row above) seem to be gazing straight ahead in the turned head (top row below), while those which look straight ahead in the frontal view of the face (lower row above) seem to look to the left in the deviated head (lower row below).



In contrast, Anstis et al. (1969) argued that head orientation may play no role, as with real eyes observers could in principle determine where somebody else is looking regardless of head orientation, as all that may matter for gaze direction is the amount of visible sclera in the eyes (see Chapter 2). Using an artificial stimulus constructed from a ball, these authors showed that when manipulating its geometry by changing the position of the diaphragm which formed the artificial socket, the results obtained were the same as those found with a human looker, including the "head turned" effect. That is, the authors found that the apparent gaze of the artificial eyeball, when turned could be biased by turning the diaphragm surrounding it. This suggests that at least some of the effects of deviating the head might be due to the impact this has on the geometry of the projection from the eye itself, rather than depending on any direct perception of head angle based on a surrounding face. In particular, head orientation could play some indirect role due to the physical structure and operation of head and eyes, which couples them to some extent. According to Anstis et al. (1969), as the rotation of the head alters the amount of visible sclera to the observer for a given gaze direction, this could even mislead the perception of gaze direction. In fact, it may be the angle of the eye in the orbit which is responsible for making the eyes appear to gaze in slightly different direction (see Chapter 1).

Recent neurophysiological studies in monkeys have shown that certain neurones in the superior temporal sulcus (STS) respond to faces. More specifically they respond differently to different views of the head (e.g. frontal, profile and three-quarter views), as if providing a viewer-centred description of heads and faces (e.g. Perrett et al. 1990). Interestingly, many of those cells that respond selectively to the head angle of seen faces respond also to corresponding gaze direction within that face (Perrett et al., 1985). For example, cells that respond preferentially to a frontal view typically also show a preference for eyes gazing straight at the viewer. In other words, these sub-populations of STS neurones may code for conjunctions of head position and eye position. This could imply that gaze direction is processed in conjunction with other face information, in particular, with head orientation. Perrett et al. (1985) suggests that these two sources of information (gaze and head) may not be entirely independent, as they would be if gaze direction were processed by an entirely separate mechanism (e.g. a pure gaze module).

Langton and co-workers have carried out more recent studies (Langton & Bruce, 1999; Langton & Bruce, 2000) showing that head orientation can act as a cue for directing social attention. In everyday life, direct view of somebody else's gaze is not always available. Obscuring conditions such as shadows or a long distance can sometimes prevent us from clearly seeing the direction of gaze of an individual; nevertheless, we may still be able to infer to some extent what or where s/he is attending. Head orientation, gesture and/or body posture can all convey some information about a person's attentional status, and so direct the observer's attention towards the same direction. In their study, Langton and Bruce (1999) used different head orientations to cue a target which could appear in one of four possible locations with equal probability. They found faster detection times at the cued location (but only for short cue-target interval of 100 ms) suggesting that face cues, in particular head orientation, can automatically trigger attention, similar to findings for seen gaze in faces presented in a fixed frontal view in an otherwise similar study (Driver et al., 1999). More recently, Hietanen (2000) found that a head shown in both front and profile views, with averted gaze back to the observer, could cue target detection, in a manner that led the author to conclude that visual information from gaze direction and head orientation is integrated.

Thus, recent research has shown that seen head orientation may play a similar role to seen gaze direction in inducing shifts of attention. Nevertheless, the exact way in which eyes and head orientation are coded by the visual system with respect to one another is far from established. Intuitively, one might expect that turning the head in one direction would increase judgements that the person is attending in that direction, giving rise to a sort of positive "congruency effect" for head and eye direction, whereby turning both head and eyes in the <u>same</u> direction leads to a stronger effect. Indeed there is some limited evidence which could be interpreted to support such a view. In a recent study carried out by Langton and Bruce (2000), head and gaze cues were put in potential conflict by means of a Stroop-like interference paradigm. Participants were asked either to ignore the left/right orientation of the head and judge the left/right direction of gaze, or conversely to ignore the direction of gaze and judge the orientation of the head. Faster reaction times (RTs) were found for congruent gaze and head than for incongruent conditions in both tasks. On the basis of these results, Langton and Bruce argue that head and gaze cues produce equivalent but independent effects, with observers processing the two directional cues (i.e. head orientation and gaze direction) independently and in parallel even when they were asked to ignore one of the two.

But, a somewhat different result (in fact, the reverse of such a congruency effect) has been observed for unspeeded gaze judgements, as reported in Anstis et al.'s (1969) classic study, and described at length in Chapter 1. According to this study, perceiving gaze direction is actually more accurate when the eyes and the head are oriented in *opposite* directions ("incongruent") than when they are directed toward the same direction (congruent; see Fig. 5.1 earlier in this chapter, plus Chapter 1 for a full review). When head and eyes are deviated in opposite directions, the amount of visible sclera in the eyes (which in Anstis' view provides the only cue to gaze direction) is maximum, which should make the judgement of gaze direction easier. This discrepancy in the literature, between positive congruency effects (e.g. Langton & Bruce, 2000) and reverse congruency effects (e.g. Anstis et al., 1969) is intriguing, and reflects a rather fragmented picture of how the visual system takes into account different pieces of information (e.g. head and eyes) concerning somebody else's attention.

Based on his neurophysiological findings in monkeys (Perrett et al., 1985; 1992; 1994), Perrett postulates the existence of a mechanism for detecting the direction of attention (i.e. DAD; Direction of Attention Detector) which would combine information from different populations of cells analysing the direction of eyes, hand and body. These components are considered necessary to signal to the visual system a particular relevant posture or action. According to Perrett, this DAD mechanism would be organised hierarchically, such that information from the eyes, head direction and body postures would be processed by different layers of cells. In particular, information provided by the eye direction would be predominant over that provided by head orientation; with the latter in turn being more salient than the one provided by directional signals from the body. The system would respond in any case, on the basis of the best available evidence.

A slightly different view on how the visual system may process social attention and gaze direction has been put forward by Baron-Cohen (1995). His model deals not just with the perception of directional cues to someone else's spatial attention, but more widely addresses how people attribute mental states to one another (see Chapter 1). The so-called "mindreading" system was hypothesised to comprise several modules, but only one of these is responsible for processing directional cues and, in particular, for detecting another's gaze direction (EDD). Cues from head angle were not argued to play any special role in the development of the ability to understand other minds; instead the eyes were particularly emphasised by Baron-Cohen. Both Perrett's (1992) and Baron-Cohen's (1995) models do stress the importance of gaze in social cognition. However, they do not provide any detailed account for one of the effects of head/eye relations described earlier (i.e. the reverse congruency effect on accuracy in unspeeded judgements; Anstis et al., 1969). This appears problematic for the Perrett view, as that account assigns only a minor role to the head compared to gaze, and stresses the importance of the conjunction of congruent head and eyes. The Baron-Cohen model equally seems to provide no explanation for the various congruency and reverse congruency effects, as it gives little or no role to the head in social attention. Furthermore, the recent work by Langton and Bruce (2000) suggests that the head may be taken into account when interpreting eye gaze, contrary to the previous statements of Anstis et al. (1969), according to whom the shape and the geometry of the eyes are enough.

Analysis of "reverse congruency effects" in previous experiments of this thesis

A new analysis made on response times in my own experiments (those reported in Chapters 2 and 3), only for positive polarity[1] stimuli actually shows the opposite results to the pattern reported by Langton and Bruce (2000), but a similar pattern to the "reverse" congruency effect in the classic studies of Anstis et al (1969) (see Table 5.1).

				Std. Error	
Experiments	**Nr. Subjs**	**Congr**	**Incongr**	**Cong**	**Incong**
Experiment 1	8/8	764 ms	622 ms	36.27	19.29
Experiment 5	7/8	608 ms	554 ms	32.96	32.80
Experiment 6	6/8	620 ms	578 ms	55.60	26.97
Experiment 7	5/8	664 ms	605 ms	36.60	26.73

Table 5.1. Summary table of data from the analysis of "reverse" congruency effect on RTs in my previous experiments. First column on the left reports the proportions of subjects who showed slower reaction times (RTs) for congruent compared to incongruent conditions in each experiment. The second and third columns show the mean RTs for congruent and incongruent conditions, and in the forth column their standard errors, respectively.

[1] Performance for negative stimuli was too inaccurate to allow RT analysis. Hence, RTs were not considered in Chapters 2 and 3, as these had aimed to compare positive and negative stimuli directly.

RT data for positive gaze stimuli from the previous experiments which had included the "congruency" factor (see Chapter 2 and 3) were entered into a mixed ANOVA with experiments (Exp. 1, 5, 6, 7) as the between-subject factor and congruency (congruent vs. incongruent) as the within-subject factor. This analysis showed a significant effect of congruency ($F(1,30)=15.85$, $p<.001$) due to slower RTs for congruent conditions (644 ms) than incongruent (590 ms; note that this is therefore a "reverse" congruency effect); no effect at all of the experiment ($F(1,30)=1.09$, n.s.), and only a marginal interaction between experiment and congruency ($F(1,30)=4.17$, $p=.05$), due to the trend for a larger effect in Experiment 1.

Thus, on the gaze discrimination task in my previous experiments, significantly faster responses were made for positive stimuli when head and gaze were averted towards opposite directions (i.e. incongruent) compared to the same direction (i.e. congruent). As mentioned earlier on, this reverse congruency effect may arise because the eye has to deviate further in its orbit to look in a particular direction when the head is deviated the *other* way, leading to a more deviated-looking eye for a given gaze angle, which may thus be easier to detect (see Anstis et al., 1969; but note that this is the opposite result to that reported by Langton & Bruce, 2000).

To recap, the perception of gaze direction seems somehow to involve an influence of head orientation and thus the perception of eye position relative to the head, but how these two components are related is very controversial, and the existing evidence is mixed, with conflicting results (i.e. positive congruency effects, e.g. Langton & Bruce, 2000, versus reverse congruency effects, e.g. Anstis et al., 1969, plus the RT analysis of the present experiments above) having been reported. Thus several experimental questions arise based on the available literature reviewed here. Firstly, what is the exact role of head orientation in the perception of gaze direction? Is head orientation really important to determining gaze perception? What determines whether positive or reverse congruency effects are observed? Finally, what part of the head (e.g. internal features, head outline, see Fig. 5.2) conveys head orientation?

Fig. 5.2. Example of internal features and head contour extracted from the face shown in the central panel. The features (left) added to the head (right) reproduce the original face (central), but do they in isolation still convey head orientation? Or only when combined together in the face? Adapted from Wilson et al. (2000).

Recently, a study conducted by Wilson et al. (2000) aimed to study the accuracy with which people can discriminate head orientation, and brought new evidence to bear on how head orientation is perceived. The authors manipulated independently the internal face features and the head contour (see Fig. 5.2) and found that the perception of head orientation discrimination is driven both by the deviation of the head profile from bilateral symmetry, and also by the deviation of nose orientation from vertical. However, the latter seemed to be the principal cue when the face orientation is sufficiently asymmetric (e.g. a 30^0 head orientation).

Therefore, there seem to be at least three different sources of information that might in principle convey head orientation during gaze perception; 1) internal features, in particular, the geometry of the eye-region alone when the face is deviated (as emphasised by Anstis et al., 1969); 2) cues concerning nose orientation (i.e. the direction in which the nose is pointing); 3) the head contour (i.e. cues to head-angle from external features of the face). How are these taken into account during gaze perception? Furthermore, when oriented congruently or incongruently, are gaze direction and head orientation processed independently (as claimed by Langton & Bruce, 2000), or combined together (see Perrett, 1992)? Is a different pattern of results found when different part of the face and head are concealed (see Fig. 5.3).

The experiments reported in the present chapter aimed to test the impact of these different sources of information, by examining the influence of head orientation on gaze-direction judgements when presenting either a) the whole face (e.g. Fig. 5.3 (a,b)), upper panels; the face with the nose masked (Fig. 5.4 (a,b), lower panels); just the eye region (Fig. 5.3 (c,d) upper panels), getting rid of all other head orientation cues apart from the bridge of the nose and d) just the eyes, with all parts of the nose masked and no head orientation cues present other than those in the eyes themselves (Fig. 5.3 (c,d), lower panels).

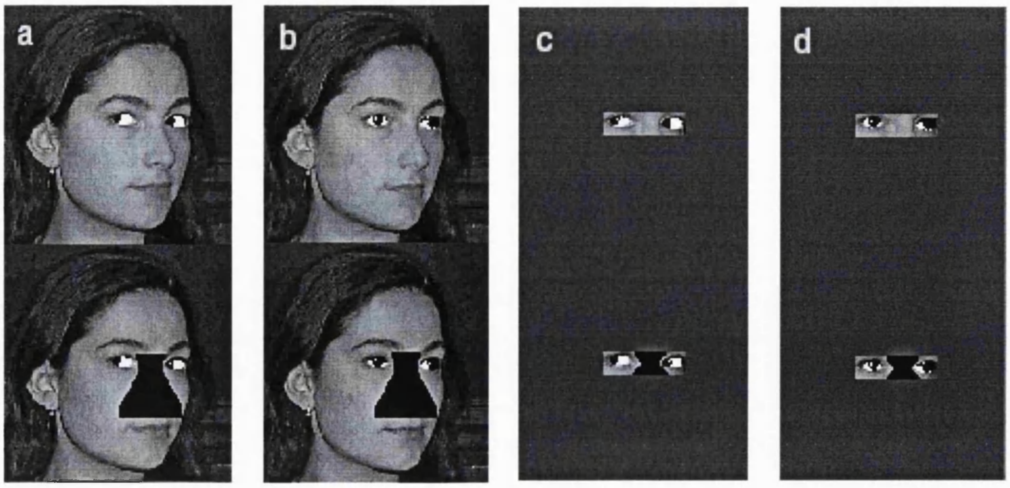


Fig. 5.3. Example of stimuli from Experiment 12, used to test the impact of different sources of information to head orientation and gaze direction. A and B are examples of whole face stimuli, with or without the nose masked (lower and upper panels, respectively). C and D show examples of the same face stimuli but with just the eye region visible within a "letterbox" window, with or without the nose masked (lower and upper panels, respectively). In B and D, head and gaze direction are "congruent" while in A and C they are "incongruent".

In addition, another important question was also addressed in the following experiments, that is, if any effect of the head was found, would this depend on the time taken to judge gaze direction? The many conflicting previous studies not only used different tasks to investigate the perception of head orientation and gaze direction, but also used either unspeeded versions of these tasks emphasising the accuracy of gaze perception (e.g. Anstis et al., 1969) or speeded task RT methods (e.g. Langton & Bruce, 2000). In fact, it may be that the visual system uses different directional cues depending on how quickly the decision should be made. For example, the size of the directional cue may well influence the visual system under time pressure, assuming that big cues such as the head are extracted faster. In contrast with Perrett's hierarchy, head orientation might now override the eyes under time pressure as, due to its size, it could be extracted more rapidly. To my knowledge, this issue has not been investigated previously, and so will be addressed in the present chapter.

Experiment 12

The present experiment sought to determine the effect of facial cues (such as head orientation, nose orientation, etc.) on gaze-direction judgements, by means of testing whether or not some influence from the head (either a positive congruency effect, i.e. better performance when the head and eyes deviate the same way; or a reverse congruency effect, i.e. better performance when deviating the opposite way) could emerge in gaze judgements. If head orientation did not play any role in gaze perception at all, and it was merely the geometry of the eyes alone (Anstis et al., 1969) that was responsible for some previous reports of reverse congruency effects, there should not be any difference in gaze perception between the four conditions describe above (see Fig. 5.3). In the effort to solve the many discrepancies in the existing results, two new experiments were carried out in which the same stimuli and the same task were used. In the first, <u>speeded</u>, experiment, the subjects were asked to judge as quickly as possible the direction of gaze (left versus right) by pressing the appropriate button on the computer keyboard under the conditions already mentioned above (e.g. when the whole face was visible and when different parts of the face were concealed; see Figure 5.3). In the second study, less time pressure was applied.

Method

Subjects: Eight new volunteer subjects (3M and 5F, aged between 21 and 35 year olds) participated in the experiment. All were unaware of its purpose.

Apparatus and Materials: The experiment took place in a dark sound-proof booth. The subject sat in front of a computer screen (a 37 cm x 30.5 cm Sony Triniton Multiscan 100 SX colour monitor), driven by an 8500/120 Power Macintosh computer. The distance between the subject's head and the screen was approximately 70 cm. Stimulus production, presentation time and response recording was carried out by a custom program written by myself in VScope 1.2.5 software (Enns et al., 1990). Each trial began with the presentation of a central fixation asterisk (1 °.15' x 1 °.31' of visual angle), and then a grey-scale computer image was presented. It could be either the digitally photographed whole face of a young woman (15 °.80' x 15°.80' of visual angle); or just her eyes presented in isolation as if seen through "a letterbox" (5°.32' x 1°.5' of visual angle) against a grey background. In both cases the same stimulus (either the whole face or the eyes in isolation) could be presented with or without the nose masked (see Fig. 5.3).

The looker's eyes were deviated 30° degrees to the left or right. Orthogonally to this, her head could also be deviated 30° to the left or right. Head angle and gaze direction could thus be congruent or incongruent.

Design: There were three orthogonal factors of interest, all within-subject: the context in which the eyes appeared (within the face or in isolation); the presence of the nose (visible or masked); and the congruency between head and eye orientation (i.e. congruent, deviated in the same direction; incongruent, deviated in opposite directions). This design sought to determine how different sources of information from the face (e.g. head orientation, as given by the nose or face outline) contribute to the perception of gaze direction. I also wanted to test whether a reverse congruency effect, as predicted by Anstis (1969), could be found across several conditions even in a speeded task. Since in all conditions the geometry of the seen eyes was held constant, as well as the position of the eyes within the orbits. Anstis' account (see Chapter 1) would predict faster reaction times (RTs) for all the incongruent conditions, due to a geometrically-induced reverse congruency effect. The opposite would be predicted from Langton and Bruce (2000). However, if any effect of head angle was due to nose orientation, for example, it should be found only in those conditions with the nose visible (see Fig. 5.3 upper rows). Similarly, effects due to external features of the face should only be found when the whole face was visible (see Fig. 5.3 (a,b)).

Procedure: Each subject was tested in one experimental session which lasted approximately 25 min. They were presented with 384 trials, divided into 6 equal blocks, with the 8 conditions (congruent/incongruent X whole face/letterbox X nose visible/masked) being equiprobable in a random sequence within each block. Every block was followed by a few minutes rest. The subjects were requested to perform the two-alternative forced-choice decision task (i.e. do the eyes look left or right) in a very rapid manner. A strong emphasis was placed on the speed of reaction time responses. They were instructed to judge where the person in a computerised photograph was looking as fast as they could, by pressing either the 1-key (marked "L"), for the "left response", or the 2-key (marked "R") for "right response", on the numerical keypad of a standard computer keyboard. No training session was given other than one example of each condition, together with an indication of the correct response for that example.

The sequence of events on each experimental trial was as follows. The fixation asterisk appeared at the centre of the screen for 450 ms. This was followed by an image of the looker gazing towards one of the two possible directions (i.e. left or right) which lasted until response, or for a maximum of 1119 ms. A maximum interval of 3006 ms from the onset was allowed for response execution. After a short delay of 500 ms, needed to prepare the screen for the next display, an analogous sequence of events was repeated to produce the next trial. No feedback on the accuracy of subjects' performance was given.

Results

The results obtained were interestingly in the *opposite* direction to that observed previously by Anstis et al. (1969), and also by myself, as reported earlier on in this chapter for the RT analysis of positive stimuli. The data were entered into a three-way ANOVA with context (whole face vs. just eyes), nose (present vs. absent) and congruency of head and eye direction (congruent vs. incongruent) as within-subject factors (see Table 5.2).

	Congruent		Incongruent	
	Whole face	Just eyes	Whole face	Just eyes
Nose	449.19	467.31	490.50	483.69
No Nose	450.44	469.50	500.94	470.94

Table. 5.2. Means of median RTs (ms) for each condition in Experiment 12.

There was a significant congruency effect ($F(1,7)=10.87$, $p<.05$) showing faster RTs for congruent (459 ms) than for incongruent (486 ms) conditions), consistent with Langton and Bruce (2000).

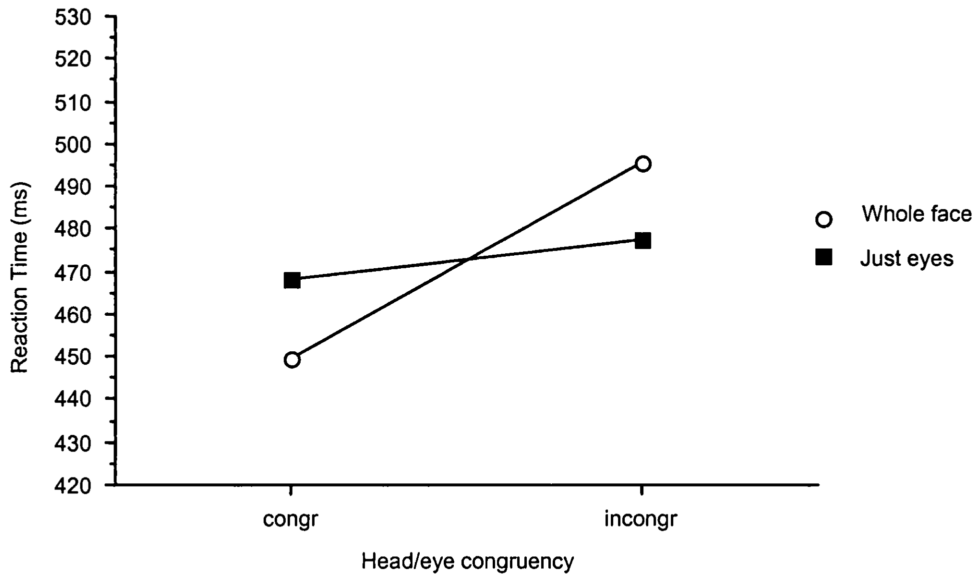


Fig. 5.4. Inter-subject means of median RT of correct responses in gaze direction task target of Experiment 12. RTs are plotted as a function of congruency and face context.

The interaction between face context and congruency was also significant ($F(1,7)=10.19$, $p<.05$), with the mean comparisons analyses showing significantly faster RTs ($F(1,7)=31.39$, $p<.001$) for congruent (450 ms) than incongruent (496 ms) trials for the whole-face displays only (i.e. when the whole head was visible), suggesting that in the present study the congruency effect was due primarily to external features of the seen head (see Fig. 5.4). When the head was not visible, the difference between congruent and incongruent trials was not significant (468 ms vs. 477 ms, respectively, $F(1,7)=1.18$, $p>.1$). The other terms in the ANOVA were nonsignificant, with no influence of the nose manipulation on RTs.

	Congruent		Incongruent	
	Whole face	Just eyes	Whole face	Just eyes
Nose	3.71	3.32	8.60	6.25
No Nose	2.93	3.12	7.62	3.91

Table. 5.3. Summary table of means percentages of errors for all conditions in Experiment 12.

The percentages of errors made by the subjects were also analysed. The overall percentage was only around 5% (see Table 5.3). The percentages of errors for each condition were entered into a three-way ANOVA with the same factors as before. This showed only a significant effect of the nose ($F(1,7)=6.47$, $p<.05$) due to a significant increase in errors when the nose was visible (5.5%) compared to when the nose was masked (4.4%).

Discussion

These findings were very intriguing, as the (positive) congruency effect for full-face stimuli in RTs goes in the opposite direction to previous data from Anstis et al (1969), and to my analysis of response times (see earlier on in this chapter) of the experiments presented in Chapter 2 and 3. However, they provide a conceptual replication of the findings reported by Langton and Bruce (2000), in showing faster RTs for judging gaze direction while ignoring head orientation when head and gaze were congruent. I suggest that a possible resolution to the apparent discrepancy between the positive congruency effect in this study and Langton and Bruce (2000), versus the <u>reverse</u> congruency effect in Anstis (1969) plus the previous studies in this thesis, may lie in the fact that no great time pressure was put on responses in Anstis et al. (1969) or the previous chapters in this thesis, while in both the present experiment and in Langton and Bruce's study, highly speeded responses were required. Therefore, it is possible that rather than being contradictory results, the different outcomes of these studies (i.e. positive versus reverse congruency effects) may be due to the change in methodology from speeded to unspeeded responses respectively. In the present reaction-time experiment, considerable emphasis was given to the speed of performance, while in the previous studies of Anstis et al. (1969), and the earlier chapter of this thesis, no great time pressure was exerted.

In addition, the fact that the possible congruency effect vanished when the eyes alone were present suggests that the information within the eye region itself as emphasised by Anstis, was not responsible for the present positive congruency effect.

Experiment 13

In the follow-up experiment, only the speed instructions were changed, leaving everything else unchanged from Experiment 12 (e.g. same stimuli and task). The participants were now asked not to rush and to perform the task as naturally as possible. If the previous time pressure was crucial to explain the positive congruency effect in the preceding experiment, we should obtain a different pattern of results in the present experiment, possibly even a reverse congruency effect.

Method

Subjects: Twelve new volunteer subjects (8M and 4F), drawn from a similar age range as in Experiment 12, participated in the experiment. As before they were unaware of the aim of the experiment.

Apparatus, Materials, Design and Procedure: These were exactly the same as for the previous experiment, except that now no emphasis was given to the time taken to make a response, and so a longer interval (i.e. a maximum of 5578 ms from the onset) was allowed for response execution.

Results and discussion: The data were analysed in the same way as before. Crucially, the observed congruency effect now tended to be in the reverse direction (i.e. slower response time for congruent than incongruent:

566 ms vs. 539 ms). This effect of congruency was not significant overall ($F(1,11)=1.70$, $p>.1$). However, there was now a significant interaction between nose and congruency ($F(1,11)=8.44$, $p<.05$). This was due to the reverse congruency effect being stronger when the nose was absent. There was also a significant three-way interaction between context, nose and congruency ($F(1,11)=11.48$, $p<.01$); (see Table 5.4).

	Congruent		Incongruent	
	Whole face	Just eyes	Whole face	Just eyes
Nose	563.92	547.88	542.54	540.00
No Nose	575.29	577.50	544.38	530.33

Table 5.4. Summary table of means of median RTs (ms) for all conditions in Experiment 13.

A subsequent ANOVA on the response time difference values between congruent minus incongruent conditions showed that the factor of nose played a significant role ($F(1,11)=8.89$, $p<.05$) in the reverse congruency effect, and further that nose direction interacted significantly with the context in which it appears ($F(1,11)=10.32$, $p<.01$).

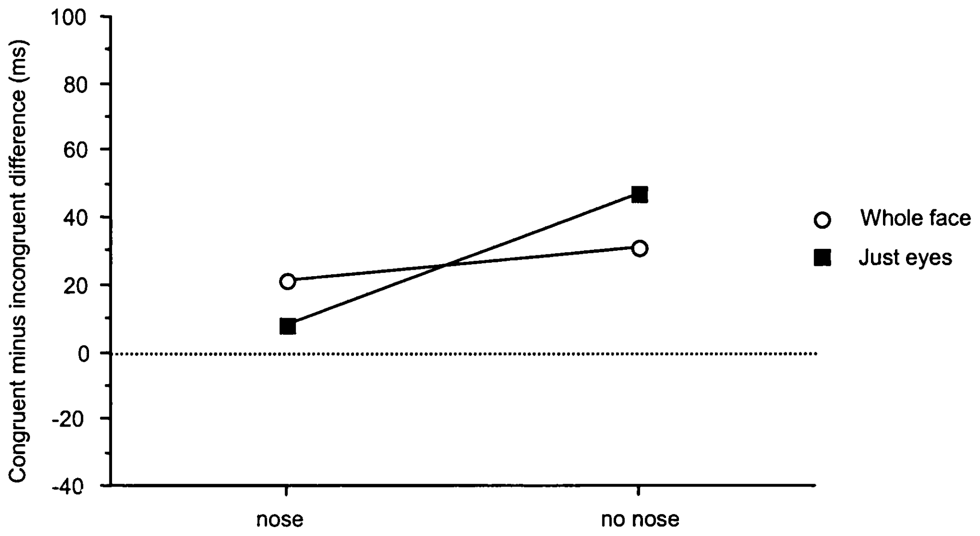


Fig. 5.5. Congruent minus incongruent difference values for inter-subject means of median RTs from Experiment 13. RT reverse congruency effects are plotted as a function of nose and context.

Specifically, the presence of a nose reduced the difference between congruent and incongruent conditions significantly more when just the geometry of the eyes was seen (F(1,11)=36.00, p<.001) compared to when the whole head was shown (F(1,11)=2.12, p>.1 n.s.) (see Fig. 5.5).

	Congruent		Incongruent	
	Whole face	Just eyes	Whole face	Just eyes
Nose	2.73	2.22	3.65	1.17
No Nose	1.82	2.74	3.52	2.08

Table 5.5. Summary table of means percentages of errors for all conditions in Experiment 13.

The overall percentage of errors was about 2.5%, less than that reported in the previous experiment (presumably due to the reduced time pressure). The three-way ANOVA with the same factors as before did not showed any significant effect (all ps> .1); see Table 5.5.

In sum, the above results suggest that changing the speed instructions drastically affect subjects' performance as a function of head/eye congruency, thus implying that time pressure might influence the facial cues taken into account by the visual system to judge gaze direction.

General Discussion

An effect of the congruency of head orientation with gaze direction was found on gaze judgements, which varied depending on time constraints given in the instructions to the subjects. Interestingly, when a speeded judgement was required (Experiment 12) for gaze direction, faster RTs were found when head and gaze were pointing in the same direction (positive congruency effect, as in Langton and Bruce (2000)), but only with the full face visible. However, when no emphasis was given on speed (Experiment 13), a more complex pattern of results was found, including now the pattern of a reverse congruency effect (i.e. faster response for incongruent conditions) which was maximum when only the eyes were visible and progressively reduced when other facial cues became visible, for example, adding the nose.

There are two main conclusions which can be drawn from these experiments. Firstly, the reverse congruency effect (as in Anstis et al, 1969; plus my RT analysis of the experiments in the previous chapters) is apparently found only under conditions which do not require a highly speeded responses. Under considerable time pressure, the head angle of the whole face apparently becomes weighted more highly, so that gaze in the same direction as the head then becomes easiest to judge. Secondly, contrary to the classic claim that the geometry of the eyes alone is sufficient to explain gaze perception (Anstis et al., 1969), my data indicate a more complex pattern of interaction between head-orientation cues and eye geometry. The nose and where it is pointing seem undoubtedly to help the human visual system to extract gaze direction from a tilted head. However, this influence is strongest when other head cues are not available, as shown by Fig 5.4 (c,d) upper panels. This is in accordance with Wilson et al.'s (2000) study, showing that nose orientation is the cue for head direction based on internal features when head orientation is otherwise hard to discriminate. Instead, when the whole head is visible, head cues other than the nose seem to take over (perhaps information from the profile or outer contours of the head). Moreover, people's sensitivity to these different sources of information varies with task demands, in particular as regards the required speed of the judgement. Given sufficient time, the human visual system can evidently work out a more precise geometry by integrating gaze information with other sources of information about the angle of the head.

Interestingly, what emerges from the present study can be related to what has been uncovered by Perrett in his single cell recording work (1985, 1992, 1994). My findings provide some behavioural evidence that the mechanisms responsible for the processing of head and gaze may be organised hierarchically, and that they may not be extracted completely independently, as contrary to Langton (Langton et al., 2000; Langton and Bruce, 2000). In fact, two different outcomes can be possible depending at least on two things: first, how fast the judgement of gaze direction has to be made; and second, which sources of information are currently available to the visual system. On the basis of my results one could argue that the visual system might give different weight to different facial cues according to the environmental demands (i.e. their visibility, or the required speed of the desired response). However contrary to what was claimed by Perrett, my results also suggest that the hierarchy emerging from the present study seems to weight the head more strongly than just the eye region when the visual system must rush to extract directional cues. This could be due to a difference in salience or speed of extraction due to size, with head being extracted faster than the eyes. The same neurones responding to the conjunction of head and eye (Perrett et al. 1985) might be "read out" earlier under time pressure.

Anstis' claim that perceiving the direction of gaze does not depend directly on head cues has only been partially confirmed by my study, as the reverse congruency effect this predicts was found only in unspeeded conditions. Moreover, other cues than just the amount of visible sclera are evidently taken into account by the visual system even when enough time is allowed for the decision; for instance, nose orientation (Experiment 12). It is worth noting that in both Langton and Bruce's (2000) and Anstis's (1969) studies, facial cues were visible within the stimulus. The present study showed that the effects previously described in literature (possible congruency, and reverse congruency effect) may depend exactly on which cues are available to the visual system, and the speed of the required response.

If we consider the time-course of processing information coming both from the head and from the eyes, one might expect that head orientation is extracted quicker than the eyes, thus leading to a stronger influence of head orientation over the eye direction at early stages of processing. With respect to that, evidence has been provided by a recent electrophysiological study carried out by McCarthy et al. (1999), aiming to assess the responsiveness of a face-related ERP component (N200) to particular perceptual features of faces. The authors found that the N200 amplitude was largest and shortest in latency when full faces were presented, and decreased and delayed when eyes, face contour, lips and noses were presented in isolation. Interestingly, the latencies to the latter facial parts were the longest, suggesting that such face parts may require additional processing time compared to full faces. Furthermore, the joint effects of eye and head position also affected the amplitude and latency of N200 in the right hemisphere. In fact, when head and eye were <u>both</u> diverted in the same direction (i.e. congruent) they evoked the smallest and shorter N200, whereas when the head was directed at the viewer but the eyes were diverted, N200 was largest and longer. In other words, the authors found that N200 amplitude and latency was affected by different conjunctions of eye and head. Conflicting directional information from the head and the eyes may initially require more time to be processed and integrated. However according to my findings (Experiment 13), at later stages of processing, eye direction may now become a more salient cue to infer the attentional status of an observer, compared to head orientation at an earlier stage. For example, the larger amount of sclera visible when eyes are turned away from the head could at a later stage totally or partially override head orientation, making the judgement of gaze direction for incongruent conditions easier, as Anstis reported in his unspeeded study.

As well as being consistent with recent electrophysiolocial studies (e.g. Sugase et al., 1999; McCarthy et al., 1999), the present findings are the first behavioural results which may resolve the previous apparent discrepancies concerning the combined effects of head and eye direction, with positive congruency effects arising in speeded situations (e.g. Langton & Bruce, 1999, 2000; plus the present Experiment 12); but the opposite reverse congruency effect arising in unspeeded situations (e.g. Anstis et al., 1969; plus Experiment 13), due to the relative processing speeds of head versus eye cues.

Chapter 6

LEFT VISUAL FIELD ADVANTAGE IN GAZE PERCEPTION

As discussed in previous chapters, there is already some evidence for the existence of dedicated neural structures for the processing of faces, and of gaze in the brain. Although this is still debated (e.g. Kanwisher, 2000; Tarr and Gauthier, 2000) much recent work seems to go in this direction. Some of the evidence also points to hemispheric specialisation, especially for faces.

The advantage of the right hemisphere in processing facial information is supported by neuropsychological and behavioural data (e.g. Benton, 1980; Etcoff, 1984). In particular, neuropsychological studies have suggested possible right-hemisphere predominance for face recognition. Lesions in the inferior occipitotemporal region can lead to a selective deficit in face processing known as prosopagnosia (Damasio & Damasio, 1989 review). Prosopagnosic patients lose the ability to identify familiar faces but not other classes of object (e.g. houses or cars). Although it is still controversial whether bilateral or unilateral lesions are always necessary to cause the deficit, it has been suggested that prosopagnosia may occur more often after unilateral damage to the right hemisphere but not to the left (De Renzi, 1986; De Renzi et al., 1994). In healthy people, additional evidence comes from functional neuroimaging data. Using functional magnetic resonance imaging (fMRI) in a face matching task, Clark et al. (1996) found that face perception activated regions in the ventral occipitotemporal cortex. The activation was larger in the right hemisphere. Activated areas extended from the inferior occipital sulcus to the lateral occipitotemporal sulcus and fusiform gyrus. In later work (McCarthy et al., 1997; Kanwisher et al., 1997) focal activation of the right lateral fusiform gyrus was found when faces were viewed among objects.

Bentin et al. (1996), using event-related potential (ERP) methods, found that human face perception evokes a negative component (N170) which was registered as largest over the posterior temporal scalp, and over the right rather than the left hemisphere. Since the N170 was even larger when the eyes were presented in isolation compared to when the whole face was presented, it was interpreted as reflecting the possible activation of an eye-sensitive region in the brain likely to be located in the right occipitotemporal sulcus (Bentin et al., 1996, but see Eimer, 1998, 2000). Single-cell recording studies with monkeys has shown that neurones within the superior temporal sulcus (STS) are sensitive to gaze and head direction (e.g. Perrett et al., 1990). Moreover, lesions to the temporal lobe can cause deficits in determining gaze direction in both monkeys and humans (Campbell et al, 1990). Hoffman and Haxby (2000) used fMRI to compare processing of face identity versus gaze direction in humans, and found that gaze perception activated the superior temporal sulci whereas regions in the inferior occipital and fusiform gyri were activated by face identity. Furthermore, one recent functional imaging study suggested a larger emotional response to direct gaze in the amygdala of the right hemisphere (Kawashima et al., 1999). Thus, different brain areas seems to be involved in different aspects of face processing (e.g. face identity versus seen gaze diversion), with possible right-hemisphere laterality in both cases.

A traditional source of purely behavioural evidence for possible hemispheric specialisation in face processing comes from visual field effects, specifically the left visual field (LVF) advantage in face processing tasks. Better performance for LVF stimuli than RVF stimuli has been found in several tasks (e.g. face identity or judgements of emotional expression, e.g. Christman and Hackworth, 1993) and has been interpreted in terms of the LVF projecting directly to the putatively specialised right contralateral hemisphere. Such visual field effects are particularly evident when chimeric faces (i.e. faces made of two halves from different pictures, joined together) are used as stimuli. For example, the side of the human face which falls in the observer's left visual field (i.e. the other person's right side) is apparently perceived by the observer as more closely resembling the person in question. Gilbert and Bakan (1973) showed that chimeric faces made of two right-side composites were chosen as more closely resembling the original picture than those made of two left sides. The reverse was true when the original picture was mirrored-reversed. The authors concluded that visual-field position was responsible for the asymmetrical perceptual bias and, attributed this to the right hemisphere specialisation for face processing (Gilbert & Bakan, 1973). Similar results have been reported for judgements of positive and negative emotional expression. Chimeric faces made by combining an emotive half-face with a neutral face were used as stimuli in a study by Christman et al. (1993) and a left visual field bias, as previously described for face recognition, was now found for judgements of both positive and negative emotions (i.e. the chimeric half within the left visual field dominated such judgements). Given these visual field effects in face processing, generally attributed to right hemisphere specialisation for face processing, a further step would be to investigate whether there is any analogous LVF advantage for gaze perception also. Such an investigation was undertaken here.

Experiment 14

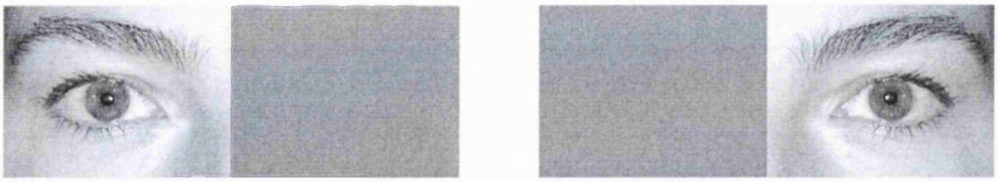
The present experiment aimed to investigate whether in normal subjects, a LVF advantage could be observed specifically for gaze stimuli. All previous studies (Gilbert & Bakan, 1973; Luh et al., 1991; Christman et al, 1993; Kowner, 1995) finding a left visual field advantage have only considered judgements on face identity or emotional expression, not gaze perception per se. I carried out two experiments in which subjects were asked to make a forced-judgement on gaze direction, while only the eye region of a face was visible, so that holistic processing of an entire face could not account for any effect of visual field.

The subjects were presented with either just one eye or two eyes, as it has been previously shown that seeing two eyes lead to more accurate judgements of gaze direction (Ehrlich & Field, 1993; see Chapter 1). This previous result implies that both members of a seen pair of eyes normally contribute to gaze perception, but here I was interested in determining whether one of the two seen eyes is more dominant. I included within the "two eyes" displays some chimeric displays, termed "incongruent", in which one of the two eyes looked straight at the subject while the other eye deviated. When only one eye was presented it could appear either in the subject's right or left visual field, while with two eyes, one appeared in the left visual field and the other in the right visual field. Each seen eye could look in different directions. Subjects were asked to judge the direction of seen gaze (i.e. whether the eye or eyes were looking left, right, or straight). If any visual field dominance was present, it could become apparent in the unilateral stimulation conditions (e.g. with more accurate performance for a LVF eye), and also in responses given to the bilateral incongruent conditions. In the latter case, it should be reflected in a greater percentage of response in the direction of the dominant seen eye (e.g. with LVF dominance, a higher percentage of straight responses when just the left visual field eye was straight, compared to when only the right visual field eye was straight in bilateral displays).

Method

Subjects: Nine new subjects (2F and 7M, mean age of 28) participated in the experiment; eight were right-handed and one was left-handed by self report. One was excluded from the analysis because he did not complete the whole experiment. All had normal or corrected-to-normal vision by self report. Participants were all volunteers who replied to an advert and received £ 2.50 for their participation in 30-min session. They were unaware of the purpose of the experiment.

Materials: The stimuli used were made from a set of photos of the same person with direct or deviated gaze. Her gaze was either direct (i.e. looking straight at a digital camera), or deviated 30° from this direct position either to the left or to the right of the camera. Subsequently, by means of Adobe Photoshop 4.0, just a rectangular window around the eyes was clipped from the image of the face (see Figs. 6.1 and 6.2). This use of a computerised technique was needed to eliminate any stimulus asymmetry which might have occurred within the stimulus itself (e.g. asymmetrical shadows and blemishes, or intrinsic difference between left and right eyes). A technique very similar to the hemifacial duplication one proposed by Kowner (1995), for creating chimeric faces, was used to generate all the present gaze stimuli, with only the right side of the original face being employed. In this way, none of the stimuli used contained any unintended intrinsic asymmetries, as LVF and RVF stimuli were mirror images of one another. Two different sets of stimuli were made, one set consisting of just one eye (unilateral stimuli, in the left or right visual field) and the other consisting of a pair of eyes (bilateral stimuli). From the original deviated and straight gaze stimuli, only the eye on the right of the image was used to create all the unilateral stimulus conditions, either straight or deviated. The original left eye was cut out in Photoshop 4.0 and replaced with a grey patch (see Fig. 6.1). Then, all these unilateral RVF stimuli were mirror-reversed to create the remaining unilateral LVF stimuli.

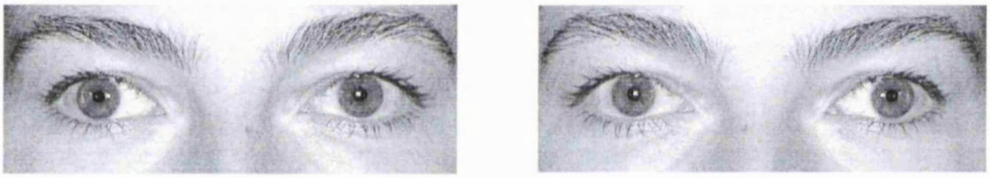


LS RS

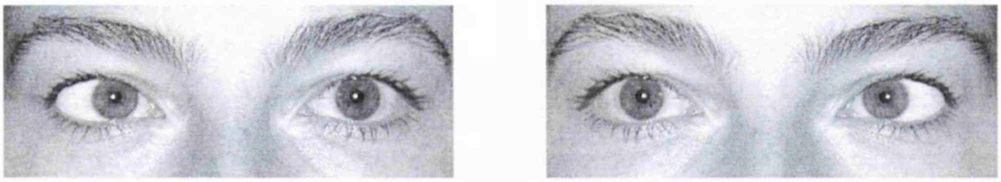
Fig 6.1 (a). Example of unilateral stimulus conditions: left eye straight (LS) and right eye straight (RS). Note that these are mirror images of each other.

LS-RS

Fig 6.1. (b). Bilateral straight stimulus condition: both left and right eye straight (LS-RS). Note that the two eyes are again exact mirror images of each other.



LT-RS LS-RT



LN-RS LS-RN

Fig. 6.2. Examples of bilateral incongruent stimuli. At top-left, an example of the left eye deviated temporally and the right eye straight (LT-RS); at bottom left, an example of the left eye deviated nasally and the right eye straight (LN-RS). At top right, an example of the left eye straight and the right eye deviated temporally (LS-RT). At bottom right, an example of the left eye straight and the right eye deviated nasally (LS-RN). Note that the white part of the eye (i.e. sclera) in the nasally deviated eye is larger than in the temporally deviated or straight eyes.

For the bilateral stimulus conditions 1/3 of the stimuli were bilateral straight gaze. The pair of straight eyes was made by copying, flipping and merging together the two unilateral straight eyes that had been produced which were mirror images of each other (see Fig. 6.1 (b)). In the bilateral conditions, the further critical manipulation was that for the remaining 2/3 of the trials ("incongruent" trials, see Fig. 6.2), the two eyes looked in different directions (i.e. one eye looked either slightly to the subject's right or left, while the other looked straight at the subject). The direction of gaze in each seen eye for these trials was manipulated by cutting out from an original deviated stimulus only the eye on the right of the image, and pasting it into the corresponding right straight socket from the original image of straight eyes which was used as a template. Hence, in the new pair of eyes (an incongruent stimulus) the right eye was now deviated while the left eye was still straight (see Fig. 6.2, LS-RT and LS-RN). These bilateral stimuli could also be mirror-reversed (in their entirety). Therefore, on an equal proportion of trials the right eye was deviated and the left eye was straight, or vice versa. Crucially for the aim of the experiment, all stimuli were presented within a narrow "letter-box" format (4.20^0 x 1.60^0) so that only the region near the eyes was visible, not other features of the face (see Fig. 6.1 and 6.2).

Design: There were two main display types: unilateral stimuli and bilateral stimuli. In the unilateral conditions, only one eye (looking either to the subject's left, to the right or straight ahead) was presented, either in the subject's LVF or RVF, all with equal probability. The other hemifield, with no seen eye, was covered with a grey patch (see Fig. 6.1 (a)).

In the bilateral stimuli, a pair of eyes was presented, one in the LVF and the other in the RVF (see Fig. 6.1 (b), plus 6.2). The two eyes could be both looking straight at the subject, or one looking always straight and the other deviated either temporally or nasally (see Fig. 6.2).
Finally, due to other ongoing experiments (see Chapter 7), the colour of the eyes was also manipulated, so that in the unilateral trials the iris of the eyes was green on half of the trials, whereas on the other half of the trials it was brown. In the bilateral trials, 1/3 of the stimuli contained two brown eyes, 1/3 contained a left brown eye and a right green eye, and the remaining 1/3 contained a left green eye and a right brown eye. Therefore, the total number of possible stimuli was 27. This irrelevant colour factor was eliminated in a subsequent experiment.

Apparatus and Procedure: The experiment lasted approximately 30 minutes, and took place in a sound proof booth to avoid distraction. The subject sat in front of a PC laptop computer (PC Toshiba Satellite 300/310 with 12.11" colour LCD screen) at a distance of about 57 cm from the computer monitor. The graphic mode was set to 640 x 480 pixel resolution with 24-bit colours using the Borland C++ and Genus Microprogramming Library software packages. The subjects were instructed to keep their fixation at the centre of the screen and to use their preferred hand to make their response. Participants were told to press three different buttons on the computer keyboard according to where they perceived the displayed eyes to be looking. The "B" button was assigned to the gaze perceived as diverted to the subject's left; the "N" button was assigned to the direct gaze; and the "M" button to the gaze perceived as deviated to the subject's right. On each trial, participants were asked to always make a forced-choice response about the direction of gaze. The subsequent trial would appear only after the subject's response. They were told to make their response as naturally as possible with no hurry. The experiment began with a practice block of 27 trials (one trial for each of the possible display types, in random order) and it was followed by a total of 540 experimental trials. The sequence of events was as follows. Each trial began with a fixation point (a small white dot) appearing at the centre of the screen for 500 ms, followed by the gaze stimulus (either one eye or a pair of eyes, see Fig. 6.1 and 6.2) which lasted 300 ms. All the stimuli were presented against a black background. All conditions were intermixed randomly. Subject's response (i.e. left, straight or right choice) was recorded by the computer and then the next trial appeared.

Results and discussion: As mentioned earlier, if any perceptual asymmetry was present for the bilateral eyes, it should be apparent in a corresponding increase or decrease in the percentages of straight responses, since one straight eye was always present in all the incongruent bilateral conditions. Accordingly, for bilateral trials, analyses focused on the percentages of straight ahead responses (see table 6.2) because they offer a straightforward index of any visual field asymmetry for unilateral conditions the analyses were done on the percentages of correct responses.

UNILATERAL LEFT VISUAL FIELD EYE ONLY

EYE DEVIATION	*% RESPONSES*		
	% LEFT	% STRAIGHT	% RIGHT
TEMPORAL	**83.56**	16.25	0.31
STRAIGHT	10.63	**86.25**	3.13
NASAL	3.75	18.13	**78.13**

UNILATERAL RIGHT VISUAL FIELD EYE ONLY

EYE DEVIATION	*% RESPONSES*		
	% LEFT	% STRAIGHT	% RIGHT
NASAL	**74.38**	20.94	4.69
STRAIGHT	2.5	**86.25**	11.25
TEMPORAL	0.31	21.25	**78.44**

Fig. 6.1. Table of the mean percentages of subjects' responses for all the unilateral stimulus conditions in Experiment 14. In bold are the percentages of correct responses on which the main statistical analysis were performed.

The twenty seven practice trials were discarded from analysis and the data were pooled across the irrelevant factor of colour. The data were then analysed separately for unilateral and bilateral, as follows. I first compared unilateral LVF stimuli to unilateral RVF stimuli, performing a two-way within-subject ANOVA on the percentage of correct responses (see Table 6.1) with two main factors: visual hemifield of the stimulus (i.e. left vs. right) and its gaze direction (i.e. seen eye actually gazing nasally, i.e. towards the nose; versus temporally, i.e. away from the nose; or straight). Significantly better performance ($F(1,7)=8.55$, $p<.05$) was found for the LVF stimuli compared to RVF ones (82.65% vs. 79.69% of correct responses), regardless of stimulus direction which showed no main effect, nor an interaction with visual hemifield (both Fs<1). This result suggests a better processing of the LVF unilateral gaze stimuli.

For the bilateral displays, the percentage of straight responses on incongruent trials (see Table 6.2) per subject were entered into a two-way within-subject ANOVA with two main factors: which of the two eyes was deviated (i.e. left eye or right eye), and in which direction the deviated eye was deviated: nasal (i.e. towards the nose, see Fig. 6.2, LN-RS and LS-RN) or temporal (i.e. away from the nose, see Fig.6.2, LT-RS and LS-RT). The results showed a significant main effect ($F(1,7)=8.62$, $p<.05$) of which eye was deviated but no significant effect of the direction of eye deviation (i.e. nasal vs. temporal, $F<1$), nor any significant interaction between these two factors ($F<1$). There was a significant increase in the percentages of straight response when the straight eye appeared in the subject's left visual field (83.44%) compared to when the straight eye appeared in the subject's right visual field (69.90%); see Fig.6.3. This reveals a significant LVF dominance for gaze stimuli, consistent with the LVF advantage found for unilateral stimuli.

BILATERAL STIMULUS CONDITIONS

DEVIATED EYE	*EYE DEVIATION*	*% RESPONSES*		
		% LEFT	% STRAIGHT	% RIGHT
LEFT VISUAL FIELD	TEMPORAL	27.92	**71.04**	1.04
	NASAL	1.67	**68.75**	29.58
RIGHT VISUAL FIELD	TEMPORAL	1.46	**80.42**	18.13
	NASAL	12.71	**86.46**	0.83
NONE	NONE	2.5	**93.75**	3.75

Table 6.2. Table of the mean percentages of subjects' responses for all the bilateral stimulus conditions in Experiment 14. In bold are the percentages of straight responses on which the statistical analysis were made.

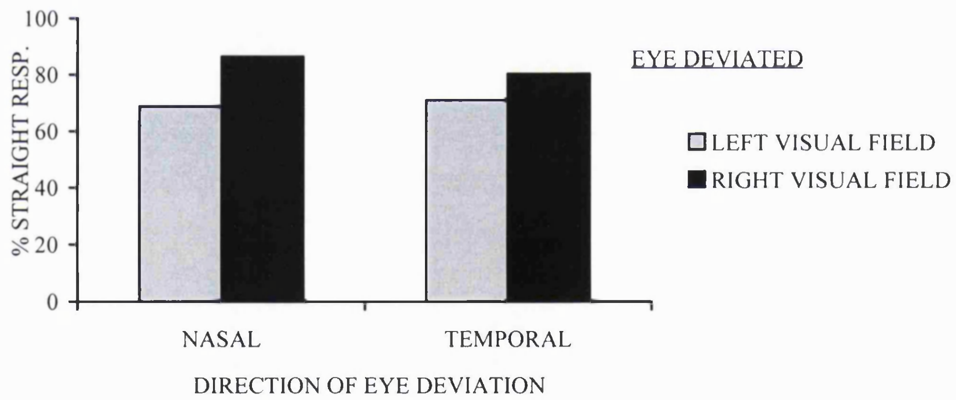


Fig 6.3. Graph of the mean percentage of straight responses in judging the direction of gaze for the bilateral incongruent stimulus conditions in Experiment 14. Percentages are plotted as a function of the direction of eye deviation for deviated left eye, or deviated right eye. Note that there were more straight responses when just the left eye was straight (i.e. when the right eye was deviated).

In addition, in order to test if, as reported in the previous study by Ehrlich & Field (1993), the subjects' performance improved when both eyes were present rather than just one, I also compared the percentages of straight responses for straight bilateral stimuli with straight unilateral stimuli in a one-way ANOVA. The results replicated the Ehrlich and Field's (1993) report showing significantly more accurate performance when the judgements were based on both eyes (93.75%) compared to when the judgements were based on just one eye (86.25%; ($F(1,7)=6.19$, $p<.05$), see Tables 6.1 and 6.2, plus Fig. 6.4).

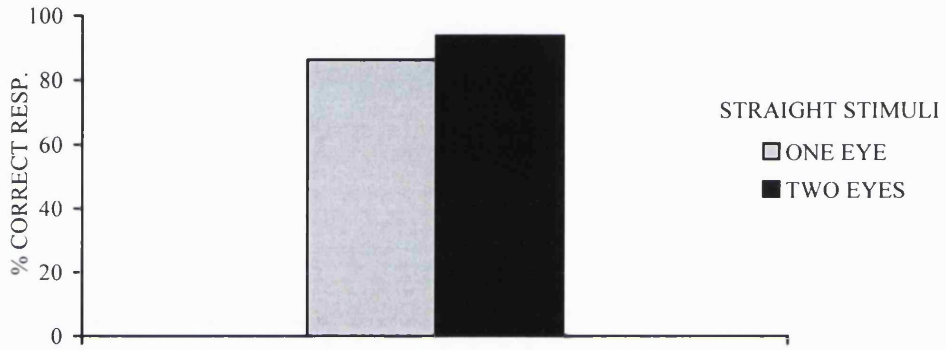


Fig. 6.4. Graph of the mean percentages of straight responses in judging the direction of gaze for bilateral straight stimuli and unilateral straight stimuli in Experiment 14. Percentages are plotted as a function of accuracy.

Experiment 15

A second experiment was needed in order to corroborate the apparent LVF advantage. In the previous experiment, even though the stimuli were not presented in free-vision but lasted only 300ms, the participants might still just have had sufficient time to move their own eyes during a display. To avoid this possible confound, I now presented the stimuli even more briefly, so that the participants did not have time to move the eyes while the stimulus was still present. A simpler design was used by dropping the unilateral conditions (since the left visual field advantage was bigger for the two eye conditions in Experiment 14), and by removing the irrelevant colour manipulation.

Method

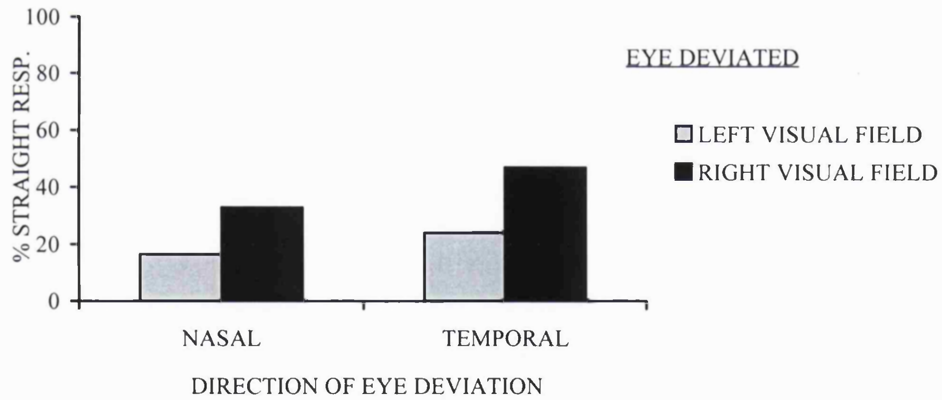
Subjects: Eight new subjects (4F and 4M, mean age of 26.88), all right-handed by self report, took part in the experiment. All participants were naive as to the purpose of the experiment and received £2.50 for their participation.

Design: To simplify the design, the previous unilateral stimulus conditions were dropped, as was the irrelevant manipulation of eye colour. No green eyes were presented through the whole experiment, but only pairs of brown eyes. Hence, the resulting design had only two factors; which of the two eyes was deviated (left or right), and the direction of that deviation in bilateral stimuli (temporal/nasal).

Apparatus, Materials Procedure: These were identical to the previous experiment, apart from the fact that now each stimulus lasted only 184 ms so that no stimulus responsive eye movements would be possible before the stimulus disappeared.

Results and discussion: The percentage of straight responses for incongruent stimuli were entered into a two-way within-subject ANOVA with the eye deviated (left or right), and the direction (temporal/nasal) of deviation, as the two factors. The results confirmed our previous finding, again showing a significant main effect of eye deviated ($F(1,7)=7.84$, $p<.05$, see Fig. 6.5 and

Table 6.3). That is, the percentages of straight responses increased when the eye in the left visual field was straight (39.88% vs. 20.31%). Moreover this time, the main effect of temporal/nasal deviation was also significant (F(1,7)=15.21, p<.01): the percentage of straight responses increased when the other eye was deviated temporally (35.50%) rather than nasally (24.69%), regardless of where the deviated eye appeared (i.e. LVF or RVF); there was no significant interaction between the two factors (F>1). This effect of temporal versus nasal deviation was probably due to the use of faster displays, which might have made the white part of the eye more important for judgement (i.e. the exposed sclera is larger in the nasally deviated eye than in the temporally deviated eye or straight eye; see Fig. 6.2).



6.5. Graph of the mean percentages of straight responses in judging the direction of gaze for the bilateral incongruent stimulus conditions in Experiment 15. Percentages are plotted as a function of the direction of eye deviation for both a deviated left and a deviated right eye. Note the increase in straight responses when the right eye is deviated (i.e. left eyes straight).

BILATERAL STIMULUS CONDITIONS

DEVIATED EYE	*EYE DEVIATION*	*% RESPONSES*		
		% LEFT	% STRAIGHT	% RIGHT
LEFT VISUAL FIELD	TEMPORAL	73.75	**24.12**	2.13
	NASAL	1.63	**16.5**	81.88
RIGHT VISUAL FIELD	TEMPORAL	2.63	**46.88**	50.5
	NASAL	64	**32.88**	3.13
NONE	NONE	10.89	**82.86**	6.25

Table 6.3. Table of the mean percentages of subjects' responses for all the bilateral stimulus conditions in Experiment 15. In bold are the percentages of straight responses on which the statistical analysis were made.

A mixed ANOVA was performed on the percentage of straight responses for incongruent stimuli with experiment (i.e. Exp. 14 vs. Exp. 15) as the between-subject factor and eye deviated (i.e. left visual field eye or right visual field eye) plus nasal/temporal deviation as within-subjects factors. This showed a significant ($F(1,14)=34.22$, $p<.001$) main effect of experiment, resulting from a significant decrease in the overall percentage of straight responses between Exp. 14 and Exp. 15 (i.e. 76.67% vs. 30.09%, respectively) and a significant main effect of eye deviated ($F(1,14)=15.63$, $p<.01$). This was due to a decrease in the percentage of straight responses when the left visual field eye was deviated and the right visual field straight, compared to when the right visual field eye was deviated and the left visual field straight (i.e. 45% vs. 62%, respectively), confirming, also across experiments, the existence of a LVF bias which did not interact with experiment. The main factor of nasal/temporal deviation did not reach significance ($F<1$), but the interaction between experiment and nasal/temporal deviation was marginal ($F(1,14)=3.88$, $p=.07$), showing in Exp. 15 a slightly stronger influence of nasally compared to temporally deviated eyes on the percentage of straight response (i.e. 25% vs. 35%, respectively). As discuss earlier, this was probably due to the use of faster displays in Exp.15 which might have made just the white part of the eye (i.e. sclera, which was larger in the nasally deviated eye than in the temporally deviated eye or straight eye, see Fig 6.2) a more salient cue for judging gaze direction. Once again this finding suggests a visual field effect on the perception of gaze.

General discussion

These two experiments found a visual field effect for gaze perception, for the first time. Interestingly, the observed LVF advantage is consistent with that previously found in several face tasks (e.g. Gilbert and Bakan, 1973; Christman and Hackworth, 1993; Luh et al., 1991) and usually attributed to right-hemisphere specialisation for face processing. However, the present effect cannot have been due to the processing of the <u>whole</u> face, since only the regions immediately around the eye were used as the gaze stimuli, neither could it have been due to an eye movement by the subjects, given that the same effect was replicated even for very brief displays (Experiment 15).

There are at least two ways this effect can be interpreted. On one hand, it might be that some of the previous findings regarding apparent LVF dominance in <u>face</u> perception (Gilbert & Bakan, 1973; Luh et al., 1991;

Christman et al, 1993; Kowner, 1995) might be due to the LVF dominance found here for eye perception, in principle just the eye region of whole-face stimuli might have triggered the effect. This seems particularly relevant for LVF advantages in emotional expression tasks, given the importance of eyes in such expressions (e.g. Argyle & Cook, 1976; Baron-Cohen et al., 1997). However, the LVF dominance found here might equally be part of a bias in face perception generally (even though whole faces were not shown), as eyes are face components. Gaze as part of the face may or may not be subserved by the same system as for other face-parts, although some evidence has already been brought in favour of distinct brain mechanisms for face and gaze processing as shown by recent imaging data (fMRI).

For instance, Puce et al. (1997b) found that, within the occipitotemporal cortex, changes in gaze direction activate areas different from those described for face recognition processing. Hoffman and Haxby (2000) outlined distinct neuronal networks for judging eye gaze and face identity, albeit both largely general within the neural system underpinning face perception. Furthermore, evidence of a distributed brain network involving the occipital part of the fusiform gyrus, the right parietal lobule, the right inferior temporal gyrus and bilateral middle temporal gyrus has also been reported by Wicker et al. (1998), specifically involved in the perception of eyes.

Whether or not the present left visual field dominance is due to a process specific to just the eyes alone, or rather to part-based processing of any face components (Clark et al. 1996; Bentin et al. 1996; Eimer, 1998), the present finding of a LVF advantage for gaze perception still brings new behavioural evidence for a possible right-hemisphere specialisation in gaze perception. It also suggests that accounts which attribute all LVF advantages to holistic processing of the <u>entire</u> face (e.g. Tanaka & Farah, 1993) are incomplete.

Chapter 7

GAZE PERCEPTION IN UNILATERAL NEGLECT

Unilateral spatial neglect is a quite common and disabling neurological syndrome following unilateral brain damage. Even though lesions to different areas may cause neglect, it is most often associated with right inferior parietal damage (Vallar et al., 1994). Patients suffering from neglect may lack awareness for sensory events in the contralesional side of space (i.e. towards the left after right damage) and often fail to orient their attention towards that side, even when no other deficits in the primary sensory pathways are present. In daily life their behaviour can be striking. They may orient and talk only to people standing on their right (i.e. the ipsilesional side) and ignore everybody and everything else on their left side. Their daily routine actions can also be affected, as patients with neglect may eat from only the right side of the plate, dress only the right side of their body, make up or shave only the right side of the face, even read from only the right side of a newspaper page.

On clinical examination, their spatial bias towards the ipsilesional side of space is apparent in several tests. On paper-and-pencil cancellation tests, where the patient is asked to search for and mark targets among distractors evenly distributed on a sheet of paper, they typically cancel only targets in the ipsilesional side of the space. Similarly, when required to mark the centre of a line they tend to shift the bisection point towards the ipsilesional side. Even when drawing from memory or copying pictures, neglect patients usually miss details from the contralesional side.

As mentioned earlier, spatial neglect can emerge after various unilateral lesions, but is most common and long-lasting after lesions involving the right inferior parietal lobe, in the angular and supramarginal gyri (i.e. Brodmann areas 39 and 40). Certain subcortical and frontal areas (Vallar, 1993; Vallar & Perani, 1986; Rafal & Posner, 1987; Husain and Kennard, 1997) can also be associated with neglect. Damage to the white-matter beneath the parieto-temporo-occipital junction (Leibovicth et al., 1998) may also be important. In sum, damage within an extended network of brain areas involving subcortical, frontal, cingulate and superior temporal structures, but most crucially the inferior parietal lobe, anatomically underpins the spatial bias of neglect patients.

Interestingly, a very similar neural system involving the right anterior cingulate gyrus (Brodmann area 24), the intraparietal sulcus of right posterior parietal cortex (Brodmann areas 39 and 40), and the mesial and lateral premotor cortices (Brodmann area 6) has been described by Nobre et al. (1997) as underlying visuospatial attention in normals based on functional imaging, providing further evidence for an attentional component in neglect. In fact, it has been suggested that one reason why neglect patients ignore the left-side information is because their attention is pathologically focused on the right-side of space, or cannot be disengaged from that side (e.g. Humphreys & Riddoch, 1993; Posner et al., 1984). The view of neglect as involving an inattentional deficit is not universally agreed (e.g. see Bisiach & Berti, 1987;

Bisiach, Luzzatti & Perani, 1979), but does provide a functional account for some aspects of the syndrome. For example, "extinction" during double stimulation can be observed in neglect patients, especially those with focal parietal lesions (see Driver et al., 1997). It is thought to be a pathological exaggeration of a phenomenon found also in healthy neurological people, namely a difficulty in distributing attention to multiple targets concurrently (Duncan, 1980). Patients with extinction can detect a single event in isolation even when it happens in the "bad" side of the space (i.e. left), but they will miss an event on this side when presented together with another concurrent one on the right side, showing that their spatial deficit emerges mainly in competitive situations. Neglect patients also have difficulties in switching attention from one location to another and tend to lock their attention onto local details of a configuration (e.g. Marshall and Halligan, 1995).

The spatial bias in neglect is ascribed not only to locations, but also to segmented objects and, particularly relevant to the aim of this chapter, to faces (and face components). Neglect patients can fail to report or recognise the left-side of a face or an object made by two different halves (i.e. chimeric stimuli), even when accurately traced. Nevertheless, some residual processing of the neglected side can still take place and may influence the conscious processing of the perceived one (e.g. see Young et al., 1992; Vallar et al., 1995; Peru et al., 1997).

A wide category of perceptual processing, most of which have been described as "preattentive" in healthy neurologically healthy people, can still take place for stimuli on the affected side in many neglect patients, but unconsciously. These include preservation of certain perceptual illusions (Mattingley et al., 1997; Ro & Rafal, 1996), figure-ground segregation (Driver et al., 1992), perception of symmetry (see Driver, 1999), and even semantic priming from the identity of a neglected or extinguished object (Berti & Rizzolatti, 1992; Berti et al., 1994; McGlinchery-Beroth et al., 1993). Recent patient studies have also shown that perceptual grouping can affect extinction, again suggesting that preattentive segmentation processes can be preserved (see Driver, 1996). Despite escaping awareness, contralesional neglected or extinguished stimuli can thus apparently still be processed by early vision, with some preserved unconscious processing of feature analysis, such as extraction of colour and shape, and even some activation of semantic responses. It is established that in neglect some residual processing may take place unconsciously.

The present chapter addresses such issues specifically for *gaze perception,* which is of clear importance for social and attentional function in daily life (see previous chapters), yet has been little studied in neglect patients to date. Recently, it has been put forward that the "ventral" visual pathway (e.i. occipital projection to temporal areas) may be responsible for the preserved unconscious perception in neglect patients, accounting for the implicit processing described above. Those areas, normally spared in neglect and extinction patients with their more "dorsal" lesions (Driver & Vuilleumier, in press) are also thought to be involved in gaze perception and face processing based on recent evidence (e.g. Campbell et al, 1990; Hoffman and Haxby, 2000). Since natural gaze stimuli comprise of two halves (i.e. left and right eyes), they can easily be transformed into a chimeric stimulus (see Chapter 6, Experiment 14) and thus employed to study processing of gaze stimuli in neglect. In addition as a social salient stimulus, gaze is particularly suitable for investigating whether or not social attention is impaired in neglect patients, along with their general deficit in spatial attention.

Previous work shows that normal perception of gaze direction is best when *two* eyes are seen, rather than one (Ehrlich & Field, 1993; see also Chapter 6). But it is unknown how the deficit in patients with neglect and extinction might affect gaze perception. For instance, does gaze perception benefit from preserved "grouping" together of the two eyes to convey gaze direction, despite the two eyes being concurrent stimuli and, thus, potential competitors for attention? Is the advantage in perceiving gaze direction that has been shown for two eyes (i.e. the "Ehrlich" effect; see Chapter 6, Experiment 14) still present in neglect? If the leftmost of the two eyes is extinguished from awareness in the patient, is there any unconscious residual processing still taking place implicitly and possibly influencing the perception of the right eye?

The present chapter examined whether a right-hemisphere damaged patient with left neglect and extinction might be unaware of the leftmost of two presented eyes, and yet still show some implicit effects from that eye upon gaze perception (see Fig. 7.1).

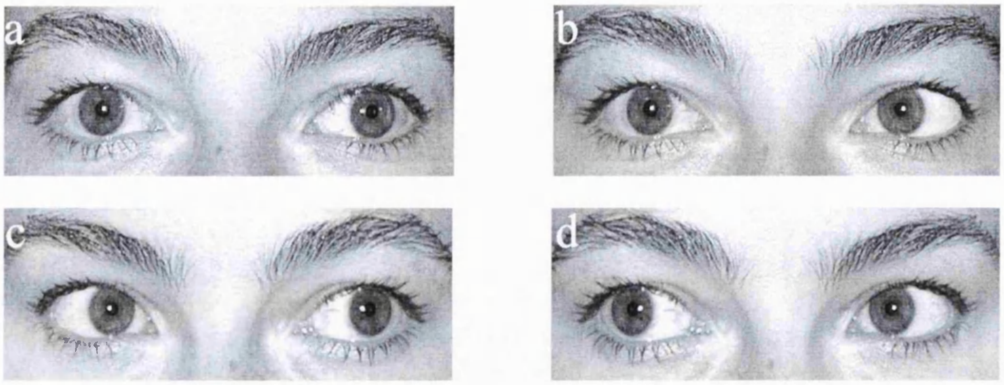


Fig. 7.1. Examples of "incongruent" bilateral gaze stimuli (a,b) plus bilaterally deviated gaze (c,d). Note that the right eye in (a) looks straighter than the same right eye in (b), at least for normal observers (see Chapter 6, Experiment 14).

CASE DESCRIPTION: PATIENT SD

At the time of testing, SD was a 63 year-old woman with chronic hemispatial neglect, as confirmed by line cancellation and bisection tasks, and with reliable visual extinction on confrontation testing. Her performance on bisection tests was also reported in a previous study (Ro & Rafal, 1996), in which she was extensively studied as a single case showing preserved implicit processing of left-sided visual stimuli to generate geometric visual illusions. Her neglect has increased somewhat since then. SD suffered two sequential strokes involving the posterior branches of the right middle cerebral artery. The first stroke involved the inferior, middle and superior temporal gyri, the supramarginal and angular gyri and the superior parietal lobule. The second stroke extended the infarct to involve more of the sensory, motor and dorsolateral prefrontal cortex, leaving her with a left hemiplegia and hemianesthesia. As the lesion spared the occipital cortex, SD had no visual field deficits. This was confirmed by a standard neurological confrontation test, in which the patient was asked to detect the wiggle of the examiner's index finger in various different locations, while fixating the examiners' nose. As can be seen from the reconstruction of SD's lesion shown in Fig.7.2, it is a large and extensive lesion but, nevertheless, such lesions provide useful information for localising preserved processing and functions, the focus of the current investigation concerning gaze perception.

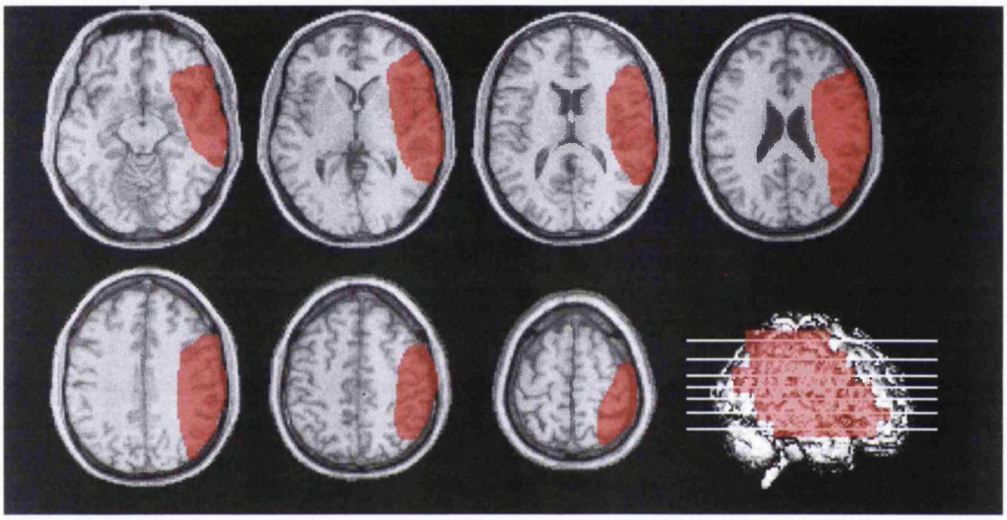


Fig 7.2. Anatomical location of SD's lesion in red. It involves the inferior, middle and superior temporal gyri, the supramarginal and angular gyri and the superior parietal lobule, the sensory, motor and dorsolateral prefrontal cortex. Early visual cortex and ventral projections to the temporal lobe are structurally spared.

SD was asked to perform two tasks on the same set of eye stimuli: a colour discrimination task and a gaze discrimination task. The stimuli comprised the presentation of either one unilateral eye (i.e. left visual field (LVF) or right visual field (RVF) eye) or both eyes (see also Chapter 6). In the colour task, when there was one eye she had to say the eye colour (i.e. green or brown), whereas when both eyes were presented on bilateral trials she had to report both colours, or (equivalently) say whether or not the two eyes were of the same or different colour. This first task aimed to test whether or not extinction occurred with gaze stimuli, and thus assess SD's degree of extinction for one vs. two eye stimuli (i.e. whether the LVF eye escaped her awareness on bilateral trials). In the gaze discrimination task, SD had to discriminate the direction of gaze (i.e. left, right or straight) regardless of eye colour, which was now irrelevant for the task. The stimuli were the same for both tasks, and were like those used for normal subjects in Experiment 14, Chapter 6. The gaze discrimination task was as for that normal study.

Method

Apparatus: The experiment was run on a PC laptop computer with an active matrix, colour VGA screen. The graphics mode was set to a 640 x 480 pixel resolution with 16 million colours using the Borland C++ and Genus Microprogramming Library software packages. The timing of the visual displays was synchronised with the vertical synchronisation of the computer monitors at 16 2/3 ms intervals (60 Hz). The verbal response from the patient was coded into the keyboard of the computer by the experimenter after each trial.

Stimuli and Procedures: All of the eye stimuli used in this experiment were like those used in Experiment 14 (see Chapter 6). As before, they were presented on a black background. The fixation point, a small white square measuring 0.1°, appeared at the start of each trial in the centre of the display monitor for 500 ms. Following this fixation interval, one eye or a pair of eyes, clipped from a digital image of a face, was presented (see Fig. 7.3). If only one eye was presented (unilateral stimulus conditions), it appeared in the left or right hemifield with equal probability. The other hemifield in the unilateral stimulus condition contained a grey square that was the same area (and average luminance) as the clipped half of the face. When a pair of eyes was presented (bilateral stimulus condition), one eye appeared to the left and one to the right of fixation. In all cases, the gaze stimulus was presented for 300 ms. The patient sat approximately 57 cm from the computer monitor.

Colour discrimination task. The colour of the stimuli was also manipulated (see also Experiment 14, Chapter 6) to assess the amount of extinction on bilateral trials. The colour of the unilateral eye was green on half of the unilateral trials, whereas the other half of the unilateral trials contained one brown eye. The colour of the bilateral stimuli was manipulated such that 1/3 of the stimuli contained both brown eyes, 1/3 contained a left brown eye and a right green eye, and the remaining 1/3 contained a left green eye and a right brown eye. In both the colour and gaze discrimination tasks, the total number of possible stimuli was 27. The patient was asked to report the colour of the eye or eyes in this task, specifying if they were same or different whenever she saw two eyes. She completed a total of 62 trials for this task where 27 of these trials were unilateral stimuli and the remaining 35 of the stimuli were bilateral. The uneven proportions of trials in these two conditions were due to time constraints. I expected the patient to miss the colour of the contralesional (LVF) eye on some bilateral trials. Such errors provide a measure of any extinction.

Gaze discrimination task. The same stimuli used in the colour discrimination task were also used in the gaze discrimination task. However, in this gaze discrimination task, the actual direction of gaze was important and the colour of the eyes was now task-irrelevant. Bilateral displays could have both eyes straight, or one eye straight and the other deviated to yield an "incongruent" display (see Fig. 7.3). Across all of the trials, each eye was deviated to the left or right, or was straight, an equal proportion of trials. In this task the patient was asked simply to tell where she thought the gaze was looking (either to her left, right or straight ahead). The patient first completed a practice block of 27 trials where all the possible stimuli each appeared once. Following this practice block, a total of 375 trials were collected. Of these 375 trials, 165 were unilateral stimulus trials and the remaining 210 trials were bilateral stimulus trials.

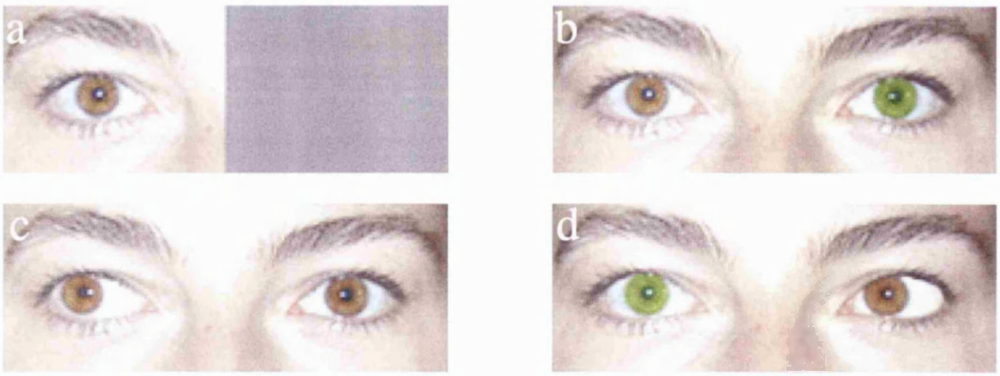


Fig. 7.3. Example of unilateral and bilateral stimuli used with the patient SD. (a) Unilateral left eye straight; (b) bilateral straight eyes (different colour). (c,d) Bilateral "incongruent" stimuli, (c) has same colour, with the RVF eye straight, (d) has different colour eyes with the LVF eye straight.

Results: To test the critical hypothesis concerning a possible "Ehrilch" effect (see Chapter 6), the analysis presented here focuses on the percentage of "straight" responses for displays with unilateral or bilateral straight gaze. Data for all the remaining conditions are presented in Appendix 2.

In the colour discrimination task, SD showed a high degree of extinction for bilateral stimuli, reporting most of the time only the colour of the RVF eye as if the LVF eye was not present, or occasionally claiming that the two eyes were the same colour even when they were not. Thus, her performance at the colour discrimination task for bilateral trials was poor (57.14% of correct response, with all errors concerning the LVF eye). By contrast, SD's performance for unilateral stimuli was at ceiling, as she always (100%) correctly reported the colour of the eye, even when presented in her left visual field (see Fig. 7.4).

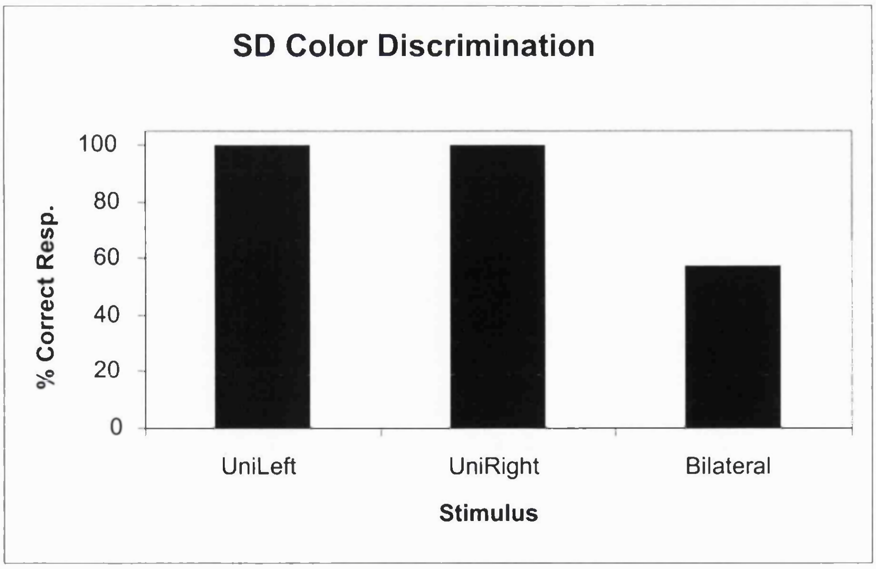


Fig. 7.4. SD's performance at the colour discrimination task. Percentages of correct response for bilateral trials (rightmost bar) and unilateral trials (left and centre bars).

Her good performance for unilateral trials differed significantly (X^2=15; p< .001, df=2) from her poor performance for bilateral trials. Both unilateral left and unilateral right trials were significantly different from bilateral trials (X^2=8.65, p<.0001, df=1; X^2=8.3, p<.0001, df=1, respectively). The fact that all the many errors on bilateral trials concerned the LVF eye, yet this same eye could be reported perfectly on unilateral trials, demonstrates clear extinction, with a loss of awareness for the LVF eye's colour only on bilateral trials. The colour task is, of course, trivially easy for normals.

In the gaze discrimination task, SD was not very accurate at reporting the direction of a unilateral straight eye, neither for the LVF eye nor for the RVF eye (37% and 39.28% straight responses, respectively; see also Appendix 2). However, her performance improved substantially and was almost at ceiling when both straight eyes were presented simultaneously in bilateral displays (92.86% correct responses; X^2=62.6, p<.0001, df=4; see Fig. 7.5). Crucially, SD's performance for both unilateral right only and unilateral left only trials was significantly different from bilateral trials (X^2=24, p<.0001, df=2; X^2=27, p<.0001, df=2, respectively). In other words, adding a LVF eye to a RVF eye, to change a unilateral display into a bilateral display, affected SD's gaze perception (producing an Ehrilch-like effect), even though on the colour task she always extinguished the LVF eye on bilateral trials.

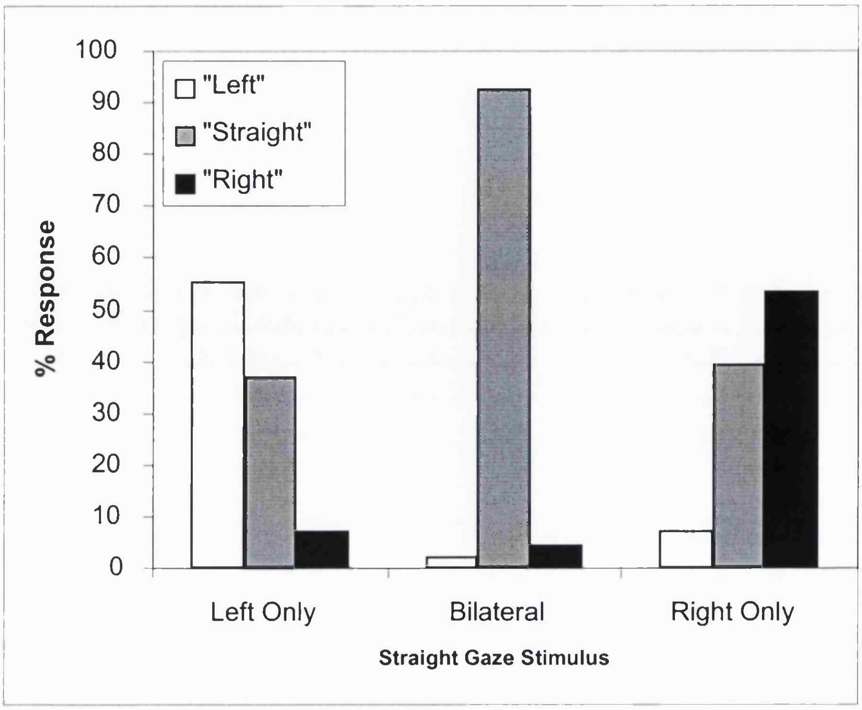


Fig 7.5. SD's performance in the gaze discrimination task plotted as function of response percentages (i.e. "left", "straight" and "right"), for left unilateral straight eyes (left bars in graph), bilateral straight eyes (middle bars in graph) and right unilateral straight eyes (right bars in graph).

General Discussion

The aim of the present study was to examine whether or not gaze perception can be preserved to any extent in neglect, and if there are any effects from the leftmost of two presented eyes upon gaze perception, despite a lack of awareness for the left eye on such bilateral trials. The performance of a unilateral right damaged patient (SD case) with left neglect and extinction was measured in two gaze perception tasks (i.e. colour vs. gaze direction discrimination). Like normals (Ehrlich & Field, 1993; see also Chapter 6), the patient showed better performance in judging straight gaze when presented with two eyes, one in each visual field, than when presented with just one straight eye unilaterally (see Fig. 7.5). This relatively preserved processing of the left eye in gaze judgements contrasted with her performance on the control task, involving judgements of the colour of two eyes or one eye in bilateral versus unilateral displays. In this colour task, SD was able to correctly report the colour of the right eye but not the left eye in bilateral displays. Yet, the very same left eye in bilateral displays increased her directional judgements in the gaze task.

The results from the colour task suggest that neglect can impair conscious awareness for the leftmost of two eye stimuli, as already shown with other types of stimuli (for a review Vallar, 1998). Nevertheless, a left eye whose colour cannot be seen may still exert some influence on judgements of where someone else is looking, particularly for straight gaze, suggesting a degree of unconscious residual processing for it. Comparing SD's performance for bilateral trials (92.86% of correct responses) to the drop of her performance in judging straight gaze for unilateral trials (37% and 39.28%, for LVF and RVF respectively), it clearly emerges that adding the left eye in the gaze stimulus does have some effect on her discrimination of gaze direction. In other words, a dissociation between processing different features of gaze (i.e. colour vs. gaze direction) for bilateral displays is apparent, possibly due to processing of gaze direction still taking place implicitly.

This may have some anatomical basis in recent reports of functional imaging data showing the involvement of temporal areas in gaze processing (e.g.

Hoffman & Haxby, 2000). These areas are likely to be spared in SD, as her lesion is higher and more anterior involving mainly parietal areas and dorsolateral prefrontal cortex. Driver & Vuilleumier (in press) proposed that unconscious processing in neglect may take place to some extent in areas along the ventral pathway projecting to the temporal lobe. Input to posterior occipital and inferior temporal areas may still be sufficient to support contralesional stimuli processing of some kind. If that is really the case, it might explain SD's apparent residual processing for the left eye in straight bilateral stimuli.

However, it should be noted that SD's overall performance was not very good, given her low rate of "straight" responses to straight unilateral stimuli (see Fig. 7.5). Similarly, she was not very accurate in judging the direction of gaze for the other unilateral conditions either (see Appendix 2). Finally, she showed no evidence for LVF dominance in gaze perception (see Appendix 2), unlike the young normal subjects of Chapter 6. Thus, while providing preliminary evidence for a degree of preserved gaze processing for neglected left eyes on bilateral trials, SD's gaze perception may nevertheless be far from normal, prompting several questions for future research. First, is there any particular brain structure responsible for SD's especially good performance with bilateral straight gaze? The role of amygdala responses to direct gaze, when comparing the brain response to direct versus averted gaze, has been suggested by recent functional imaging studies in normals (Kawashima et al., 1999). Second, SD's age and her large lesion may have contributed to the apparently abnormal aspects of her performance in the gaze perception task. It is unknown whether or not any decline in gaze perception occurs with age, as for other cognitive functions, such as memory. Moreover, it is also possible that other deficits commonly associated with neglect might interfere with the spatial nature of the gaze-direction discrimination task to some extent. For example, "spatial agnosia" (Warrington and James, 1967) is associated with parietal lesions, and its symptoms include an inability to precisely localise a dot within a frame, which is often present in neglect. This may have some analogy with localising the iris relative to the sclera in an eye stimulus.

Recently, it has been proposed that the inferior parietal lobe areas may be crucial for the integration of spatial information from the dorsal stream together with ventral shape properties (see for a review Driver & Vuilleumier, in press). The spatial properties of a stimulus would be processed by the dorsal pathway and then linked with the nonspatial (shape) properties of the same stimulus as processed by the ventral pathway (Watson et al, 1994; Driver, 1996). A very precise representation of the direction of gaze and its spatial code might thus depend on the good functioning of the inferior parietal cortex, so could be impaired in neglect after parietal lesion, at least at the conscious level. Such spatial information concerning gaze perception may automatically be generated by the normal visual system so as to allow an observer to shift attention in the same direction as the perceived gaze (see also Friesen & Kingstone et al., 1998; Driver et al., 1999). An intriguing issue is whether the formation of a spatial code to move the observer's own attention according to the perceived gaze can be damaged separately from explicit gaze judgements. For instance, it has been already shown that directing attention in the same direction as seen gaze seems to be an automatic and reflexive response in healthy neurological people (Driver et al., 1999). Therefore, monitoring the patient's own attention could be useful, to study whether or not neglect patients make corresponding shifts of attention in the same directions a somebody else's gaze, even when less accurate in reporting gaze direction explicitly. In sum, although some evidence for a relatively preserved effect of the left visual field eye in bilateral displays on gaze judgements can be found in SD, gaze perception may not be fully normal in neglect patients such as her, and their spatial deficit could be responsible for this.

In addition, the fact that no left visual field advantage in gaze processing was found in SD, as previously found in neurological intact people (see Chapter 6), shows that her gaze perception is not totally normal. A further possible reason for this is that her lesion does encroach to some extent into the superior temporal gyrus (see Fig. 7.2). Thus, the present initial foray into neuropsychological research raises almost as many questions as it answers. Nonetheless, the present study does illustrate that the topic can be fruitfully pursued with brain-damaged patients.

As noted above, one issue for the future would be to determine whether preserved aspects of gaze processing in such patients can influence where the patient attends and looks. This could even result in a rehabilitative improvement of neglect and/or extinction. Some preliminary evidence comes from a recent study (Vuilleumier, submitted) which reported less extinction in right-parietal patients for a left stimulus if a face on the right gazed towards it.

Chapter 8

CONCLUSIONS AND FUTURE RESEARCH

It may be appropriate at this point to stand back and consider what the studies reported in this thesis may contribute to the understanding of gaze perception and "social attention". In addition to summarising conclusions drawn in each chapter of the thesis, where possible I shall highlight more general implications of the present findings for models and theories of social attention, gaze and face perception. Finally, I shall try to outline possible directions for future research.

The main focus of this thesis was to examine mechanisms of gaze perception, which is an important trigger for social attention. Orienting our own attention towards the same direction or object as another person is an example of what social attention means in every-day life. Gaze direction and its perception offers one of the most effective way to signal or perceive someone's current interest, since our visual attention often moves with our eyes.

Past accounts of gaze perception emphasised purely <u>geometrical</u> cues from the seen eye. Human eyes have a unique morphology, with a large white surround (sclera) to the dark iris that may have evolved to enhance gaze processing. It has often been remarked that the high contrast of human irises and sclera may aid gaze perception, but the <u>polarity</u> of this contrast has not previously been considered explicitly. A series of new experiments (Experiments 1,2,3,5,6,7,8,9) showed that in fact the contrast polarity of seen eyes has a powerful influence on gaze perception. Adult observers are highly inaccurate in judging gaze direction for images of human eyes with negative contrast polarity (Exps. 1 and 2). This applies regardless of whether the surrounding face is in positive or negative polarity (Exp. 6). It holds across images of different people (Exp. 3), and applies even for eyes shown with bizarre colour schemes (Exp. 5), or when the light reflections on the visible part of the eyes (the "highlight") is removed (Exps. 7 and 8). A difficulty with negative eyes remains even with dynamic eye stimuli (Exp. 9), although motion in gaze stimuli does help somewhat in gaze perception.

The detrimental effect of negative contrast polarity is much greater for gaze perception than for other directional judgements (judging which way a head is turned; Exp. 4). Moreover, the mechanisms responsible for the contrast polarity effect seem also to play a role in the reflexive orienting of an observer's own attention in the direction of seen gaze, as cueing effects of this type are reduced for negative polarity eye stimuli (Exps. 10 and 11). Taken together, all these results suggest an "expert" system for gaze perception, which always treats the darker region of a seen eye as the part that does the looking. In this respect, the effect of polarity on gaze may have somewhat analogous implications to the face inversion effect (e.g. Yin, 1969). Just as inversion affects face processing more than for other classes of object, so negative contrast polarity may affect gaze-direction judgements more than other directional judgements (e.g. judgements of head orientation; Exp. 4).

Gaze perception can also be affected by seen head orientation, in a manner that depends on the time constraints given for gaze-direction judgements (Exps. 12 and 13). Head orientations were weighted more heavily for speeded gaze judgements. With less time pressure, more complex aspects of face configuration had an influence. Gaze judgements were not solely driven by the eye region.

New evidence was also brought for possible right-hemisphere specialisation in gaze perception, as normal observers are more influenced by the left visual field (LVF) eye than the right visual field (RVF) eye in a seen bilateral gaze stimulus (Exps. 14 and 15). Finally, an exploratory study of gaze perception in a right-parietal patient (SD) with neglect and extinction suggested that some aspects of gaze perception can be relatively preserved, even when awareness of the LVF eye is impaired, with other aspects apparently impaired. These results have potential implications for the neural substrate of gaze processing.

It may be worthwhile at this point to recall the main general questions that first led to my experimental work (see Chapter 1):

First, what are the exact cues used by the visual system to perceive gaze direction? Do they affect the use of gaze in social attention (e.g. the gaze cueing effect)? How do other cues from the head contribute? Do the factors found to influence face perception (e.g. negative contrast polarity) have related effects on gaze perception? Is the processing of gaze perception "qualitatively" different from face perception in any way, or is it not reduceable to the known mechanism of face perception? Finally, how might gaze perception be affected by the pathological disorder of attention and spatial representation that is seen in neglect patients? I hope it is clear to the reader that my experiments have shed at least some light on these issues. Below I discuss them in greater detail.

<u>Effect of contrast polarity on perceiving the direction of gaze</u>

Previous accounts of gaze perception emphasised the geometrical shape-cues to gaze direction that are available in seen eyes, in particular those form cues indicating the position of the iris (dark region around the pupil) relative to the sclera (white region of the eye). However, I hypothesised that eye contrast polarity may also be critical, since human irises are invariably darker than the sclera.

In Chapter 2, four experiments (Exps. 1,2,3,4) were carried out to examine people's ability to judge where computerised faces were looking. The role of contrast polarity for the eyes in the computerised images of real face was investigated. In particular, the crucial manipulation was that half the displays had reversed contrast polarity for the eye region (i.e. sclera darker than iris). Different head orientations and eye directions were also combined. For all the experiments, gaze-direction judgements were much less accurate for eyes shown in negative contrast than in positive contrast.

In Chapter 3, five follow-up experiments (Exps. 5,6,7,8,9) investigated further the effect of contrast polarity in several different conditions. Unusual colours for the sclera and the iris were used (while still always having one darker than the other); the polarity of the surrounding face context was reversed; and the reflection of light on the iris (highlight) was also removed, as it might have been used as a cue to gaze direction discrimination (and, possibly, misinterpreted as a dark "pupil" for negative polarity eyes). Dynamic gaze stimuli with motion cues were also used, to test whether motion might help to disambiguate gaze direction in negative polarity stimuli by helping the visual system to disambiguate which part of the eye is the iris and which is the sclera. In all conditions, an effect of the contrast polarity of the eye region was still found, with the direction of the negative polarity gaze extremely difficult to judge (although adding motion to the eyes slightly improved observers' performance with negative polarity stimuli). The results all show that to make an accurate discrimination of gaze direction, the seen iris must be darker than its surround. This effect remains even in observers with some insight into the phenomenon, and much experience with the stimuli, such as myself. It thus appears to be "cognitively impenetrable" (Fodor, 1983). Although negative contrast polarity disrupts recognition of familiar faces, as well as gaze perception, the latter effect cannot be reduced to the former, as was discussed in Chapter 3.

Attentional gaze cueing effect and contrast polarity

In Chapter 4, two experiments (Exps. 10 and 11) investigated whether or not the contrast polarity of the eyes may also affect orienting of the observer's own attention in the direction of perceived gaze. Recall that cueing visual attention to a specific location in space improves people's performance there; if any reflexive orienting of attention occurred in the same direction as the perceived gaze, and the polarity of gaze did not affect this, it should be shown in better and/or faster performance for targets appearing in the same direction as gaze, for both positive and negative polarity gaze. I therefore manipulated both the direction of gaze with respect to the subsequent target (congruent or incongruent), plus the contrast polarity of the eyes (positive and negative) using both static and dynamic gaze stimuli. Faster discrimination of peripheral targets on the side the computerised face gazed toward was found, suggesting reflexive covert and/or overt orienting in the direction of seen gaze. However, for the incongruent negative polarity stimuli, such an effect was significantly less and there was even a trend to reverse it for static gaze stimuli. Motion enhanced the gaze cueing effect though it could not completely override the disruptive effect of negative polarity to fully restore the advantage for valid trials with negative polarity stimuli. I concluded that the mechanisms responsible for the contrast polarity effect on gaze perception also play a role in social attention, given the reduced cueing effect for negative polarity stimuli.

<u>Effect of head orientation in gaze perception</u>

Several past studies had considered how perceived head orientation may be combined with perceived gaze direction in judging where someone else is attending. Intuitively, one might expect that turning the head in one direction would increase judgements that the person is attending in that direction (positive congruency effect), yet the opposite result has in fact sometimes been observed for gaze judgements (reverse congruency effect;

Anstis et al., 1969).

In Chapter 5, I tested the impact of different sources of information by examining the role of head orientation in gaze-direction judgements when presenting either a) the whole face, b) the face with the nose masked, c) just the eyes, removing of all other head orientation cues apart from some visible part of the nose and d) just the eyes, with all parts of the nose masked and no head orientation cues present other than those within the eyes themselves. In the first experiment (Exp. 12), subjects were asked to judge as quickly as possible (speeded task) the direction of gaze, while in the second experiment no emphasis was given to speed. The results obtained showed that under time pressure, the head angle of the whole face (when visible) is apparently weighted more highly, so that gaze in the same direction as the head becomes easiest to judge (positive congruency effect, as in Langton and Bruce, 2000). However, people's sensitivity to different sources of information varies with time pressure. Given sufficient time, the human visual system can work out a more precise solution by integrating gaze information with other sources of information about the angle of the head, as shown by a more complex pattern of interaction between head orientation cues and eye geometry in the second experiment (Exp. 13). In this latter experiment, unspeeded judgements showed gaze perception advantaged in the opposite direction of head orientation (reverse congruency effect). This progressively reduced when other facial cues become available. These results seem able to resolve many previous discrepancies in the literature.

Left visual field advantage in gaze perception

Much previous work has found a left visual field advantage for various judgements on faces, concerning identity or emotional expression. This has been related to possible right-hemisphere specialisation for face processing. In Chapter 6, I sought to determine whether a similar specialisation may exist for a more specific aspect of face processing; specifically, gaze perception.

Two experiments (Exps. 14 and 15) were carried out in which normal adult subjects were asked to make a forced judgement of gaze direction. Findings suggested the existence of a left visual field (LVF) advantage for gaze perception in normal people. Since in the present study only the eye region was visible, my results present problems for more general face perception accounts that attribute previous LVF advantage only to configural processing of the entire face.

Gaze perception and unilateral neglect

Right-hemisphere brain damage often leads to "unilateral neglect", in which the patient ignores information towards the contralesional side of space. The perception of gaze has not been previously investigated in such patients, despite its importance in everyday life. Previous work on normals shows that accurate gaze perception depends on seeing both eyes, rather than just one (Ehrlich & Field, 1993; see also Exps. 14 and 15). Since neglect patients might be expected to be unaware of the left eye in a seen face, their gaze perception might be abnormal; alternatively, some residual processing of the left eye might still take place unconsciously. In Chapter 7, I examined the performance of a right-parietal neglect patient (SD) in two tasks with eye stimuli. Like normals (see Chapter 6), the patient showed better performance in judging direct gaze when presented with two eyes, one in each visual field, than when presented with just one eye unilaterally. This relatively preserved processing of the left eye in gaze judgements contrasted with performance on a control task, involving judgements of eye colour. Although this control task is trivial for normals, it was impaired in the patient, who missed the colour of the LVF eye only on bilateral trials. I suggested that some aspects of gaze processing can be relatively preserved in neglect, even when awareness of the left eye is impaired. However, in other respects the patient's gaze judgements may not have been fully normal (see Appendix 2).

In the next section, I shall link the findings summarised above for each chapter to the general questions outlined earlier. As far as models and theories of social cognition are concerned, I shall also point out which of my findings fit naturally with existing models of social attention and face perception, and which are instead difficult to accommodate with existing models without some extension to them.

Chapters 2 and 3 answer part of my first question, by showing that contrast polarity is a powerful cue for gaze perception. The results suggest that the visual system follows a simple rule of treating the darker region of the seen eyes as the part that does the looking. Moreover, they offer some evidence to answer the second question concerning possible relations between face and gaze perception. Although at first glance the eye contrast polarity effect may appear reminiscent of the face negation effect on identification of individuals, the latter face effect cannot explain the eye contrast polarity effect for several reasons. First, all the faces used were unknown to the subject, and no face recognition was required by the gaze perception task. Furthermore, the eye contrast polarity effect is found regardless of the polarity of the surrounding face (see Exp. 6). Finally, the difficulty of recognising familiar faces when shown in negative polarity is commonly attributed to a disruptive effect on interpretation of shadow cues to the 3D structure of a face. This seems very unlikely to have played an important role in judging gaze direction in my studies. Therefore, the findings reported in Chapters 2 and 3 suggest an "expert" system specifically for gaze perception.

The classical model of face processing proposed by Bruce and Young (1986) does not accommodate the eye contrast polarity effect reported in this thesis as usually the model takes into account only face identity, face expression and face speech, otherwise neglecting eye gaze, or dealing with it only under the rag-bag of "other cues"! The results accord more naturally with the neurally inspired account of Haxby et al. (2000), which comprises a distributed neural system capable of dealing both with invariant and changeable aspects of faces (e.g. perception of face identity versus perception of eyes gaze, respectively). Interestingly, according to this model, distinct representations and neural systems underpin the different aspects of faces.

Chapter 4 directly addressed the third general question, regarding the link between gaze perception and orienting of social attention. It reported findings showing that gaze perception can trigger joint attention behaviour (i.e. gaze cueing effects for positive contrast polarity stimuli), but that this is reduced for negative contrast polarity stimuli. Moreover, the fact that reversing the contrast polarity in the eyes has specific effects on gaze perception, which also affects joint attention, illustrates the close coupling between these functions.

The results in Chapter 5 addressed the last part of my initial general questions, showing that gaze perception and seen head orientation can interact. As already discussed, the results provide the first behavioural findings indicating the importance of time pressure. They challenge both Anstis' et al. (1969) and Langton and Bruce's (2000) specific accounts for the relation of head orientation and gaze perception, while resolving the empirical conflict between their findings.

Chapter 6 further addressed possible similarities and differences between gaze and face perception. It showed a LVF advantage for gaze similar to that previously described by other researchers for faces, but with the important point that the gaze effect cannot be reduced to processing of other facial cues (since only the eye region was shown). Although these results cannot resolve whether or not the LVF dominance is specific to a system just for gaze processing, or more generally for processing of face components, they do challenge those accounts which attribute any LVF dominance solely to holistic processing of all face *components* together (e.g. Tanaka & Farah, 1993).

Finally, the case report (SD) in Chapter 7 provides an initial foray into the territory of the final question with which I set out; how gaze perception may be affected by pathological disorders of attention. It suggested that some aspects of gaze perception can be relatively preserved (e.g. better gaze judgements for bilateral straight gaze compared to a unilateral stimulus); these results may also can be reconciled with recent claims about specific distributed neural systems for gaze perception. In particular, the results appear consistent with a possible role of temporal regions as well as the amygdala in social perception (e.g. Haxby et al., 2000; Allison et al. 2000), since these brain areas remained largely intact in the patient.

In the next section, I shall propose some future directions for research. In particular, I will focus on further possible investigation of how gaze perception and joint attention could be related to development and even to some pathological syndromes. I shall also try to indicate possible ways to investigate their neural correlates by means of techniques different from the behavioural ones employed in this thesis.

<u>Future directions</u>

In the experimental work presented in the first part of the thesis, gaze perception was investigated following two main streams; explicit judgements of gaze direction, or gaze influences on orienting of social attention (i.e. the gaze cueing effect). The common line linking the two was the contrast polarity effect. One theoretical issue arising from the findings in Chapter 2 and 3 is the concept of "expert systems". A parallel with the face inversion effect (e.g. Yin, 1969) was drawn to propose that, just as inversion disrupts recognition more for faces than for other classes of object, so reversal of contrast polarity disrupts directional judgements more for eyes than for other classes of stimuli (e.g. judgements of head orientation are unaffected; Experiment 4). There has long been controversy over whether specialised processing of faces is pre-programmed genetically, or is the consequence of acquired "expertise" during extensive exposure to faces, or reflects some specific combination of nature and nurture (e.g. Diamond & Carey, 1986; Johnson & Morton, 1991; Gauthier et al., 2000). Similar issues arise for the contrast-polarity specificity uncovered here for gaze perception. Since even young babies are highly sensitive to gaze-direction (at least in "positive" stimuli; e.g. Maurer, 1985; Hood et al., 1998), developmental work with the stimuli introduced here could reveal whether the contrast-rule implied by the polarity effect reflects learned or innate expertise in gaze processing. The stimuli used here to study the contrast polarity effect could also be used to test whether contrast-specific expertise in gaze perception is lacking in individuals who exhibit (or go on to show) dysfunctional social attention, as in autism (e.g. Frith, 1989; Baron-Cohen, 1995).

However, while people with autism are reported as lacking in various social skills, some have also been described as being particularly good at other tasks such as maths, drawing and, particularly relevant for my argument, at visual spatial tests (e.g. Happe', 1999). In particular, the fact that people with autism can be characterised as having a specific cognitive style, biased towards local rather than global information processing (e.g. Frith, 1989), may make the study of the contrast polarity on gaze perception in people with autism even more interesting. The fact that people with autism can be extremely good at "disembodying configurations" could predict a better performance at judging gaze direction for negative polarity stimuli than that found with normal people. Note that it will be essential when testing the effect of contrast polarity on explicit gaze judgements in autism, to do so separately from testing the effect of contrast polarity on gaze cueing in the same subjects. It is possible that people with autism could show normal "expertise" for one aspect (e.g. explicit gaze judgements) but not for the other (e.g. gaze cueing).

From a general methodological standpoint, it would also be useful to avoid the ceiling effects that were present for positive-polarity stimuli in most of the experiments reported in Chapter 2 and 3 (with the exception of the head judgement study, Experiment 4).

As far as eye motion is concerned, the use of dynamic eye stimuli in gaze perception brought initial behavioural evidence for some role of motion in gaze perception, as dynamic eyes improved gaze judgements, for negative polarity stimuli. By using functional imaging techniques (e.g. fMRI) with dynamic and static contrast polarity stimuli, it would be interesting to see whether the same brain areas (e.g. STS) already shown to be selectively involved in the perception of moving faces (Puce et al. 1998) are also activated in the perception of dynamic gaze stimuli. Functional imaging could also be used to compare brain activation to positive and negative polarity stimuli.

In addition, a better understanding of the neural correlates underpinning the effect of head orientation described in Chapter 5 is certainly needed. Recall that, at least behaviourally, time pressure seem to be a key element for the emergence of both the positive head/eye congruency effect and the reverse congruency effect. I proposed that the time-course of processing for information coming from the head may be extracted quicker than that coming from the eyes. Electrophysiologically, one signal may carry both head and eye information, but at different processing times one may weighted more than the other (Saguse, 1999). To investigate such issues, the use of ERP techniques would be ideal; I would expect a stronger influence of head orientation over the eye direction in relatively early gaze-and-face-related ERPs components (e.g. N200), while the opposite should occur at later ERPs components.

Moreover, regarding the LVF dominance for gaze perception reported in Chapter 6, it would be interesting to carry out an fMRI study in which the incongruent gaze stimuli made of the straight LVF eye and the temporally deviated RVF eye are compared to the reverse incongruent gaze stimuli, or congruent stimuli in which now both eyes (i.e. LVF and RVF) are deviated temporally. In such a study, I would seek an asymmetric activation between the two hemispheres, to determine whether the LVF advantage does indeed relate to lateralised processing in the brain. In particular, I would expect to find more activation in the right-hemisphere, presumably, for the incongruent gaze stimuli with the LVF eye straight. Such a result would further support the behavioural findings in Chapter 6, as well as providing more information on the brain areas involved specifically in gaze processing.

Finally, having found that perception of gaze in neglect (patient SD) can in some respects be preserved, yet may not be fully normal (see Chapter 7), encourages further investigation of several issues. First, SD's relatively poor accuracy in discriminating the direction of gaze (especially with unilateral gaze stimuli) raises the question of whether or not the mechanisms thought to underlie the spatial deficit in neglect relate to those involved in gaze perception. It would be helpful to disentangle neglect patients' ability or inability to correctly localise an object in space or within a frame (e.g. as in many tests for "spatial agnosia"; Warrington and James, 1991) from their ability to discriminate the actual direction of more general spatial cues (e.g. arrows), with both being compared to their performance in gaze direction judgements. Moreover, regarding the quite well preserved perception of straight gaze in bilateral stimuli for SD, it would be interesting to conduct an fMRI study to determine whether in the patient's brain there is indeed any activation in areas such as the amygdala and/or in the STS for direct gaze. Those areas seem to play an important role in the perception of straight or diverted gaze in normals (e.g. Kawashima et al., 1999). Evidence of activation in those areas would not only strengthen the behavioural data reported in Chapter 7, but would also offer further empirical evidence for recent neurally inspired models of face processing (e.g. Haxby et al. 2000). Moreover, a systematic investigation of whether neglect patients can orient their attention in the same direction of a seen gaze, especially when the gaze is looking towards the contralesional side of the space (i.e. leftward for right-hemisphere patients), is also needed. In fact, the presence of any form of joint attention behaviour in neglect could carry important implications for rehabilitation, as care-givers could in principle help to improve the patients' attentional deficit by systematically gazing towards their bad side of space.

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Appendix 1

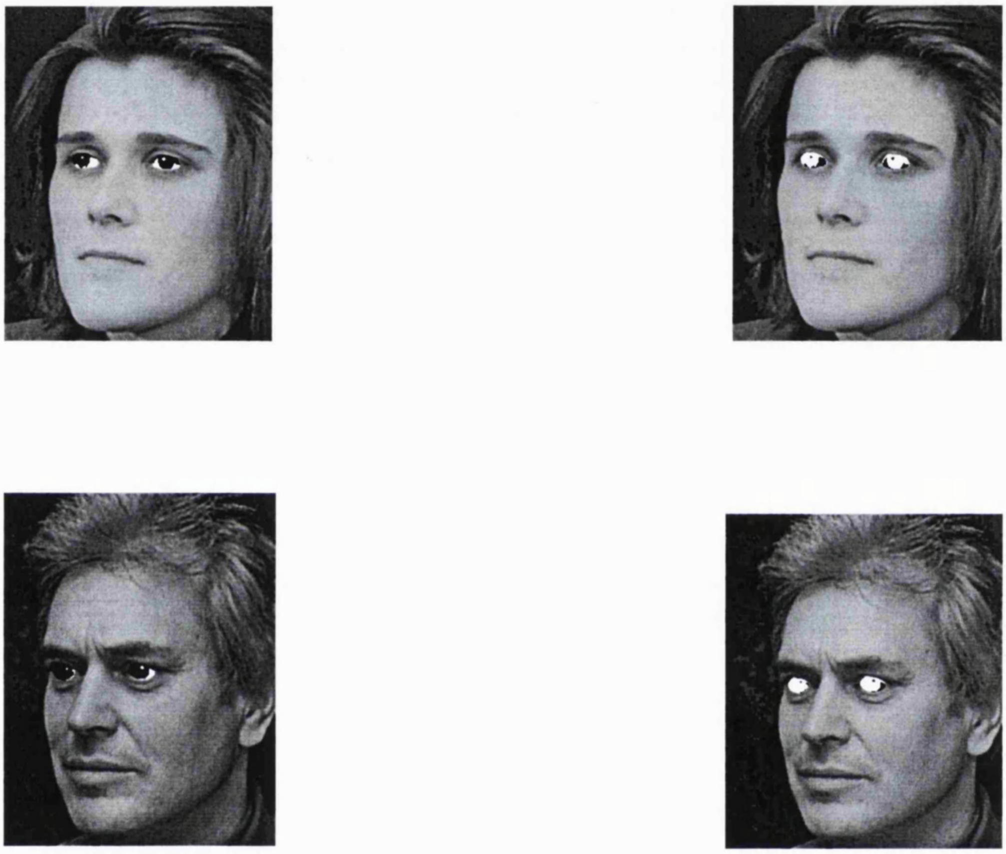

Fig. A1.1 (above). Examples of head left/eyes left stimuli used in Experiment 3. The eyes have positive polarity on the left, and negative on the right. Different people (i.e. both male and female) were photographed for all conditions; ten people in all.

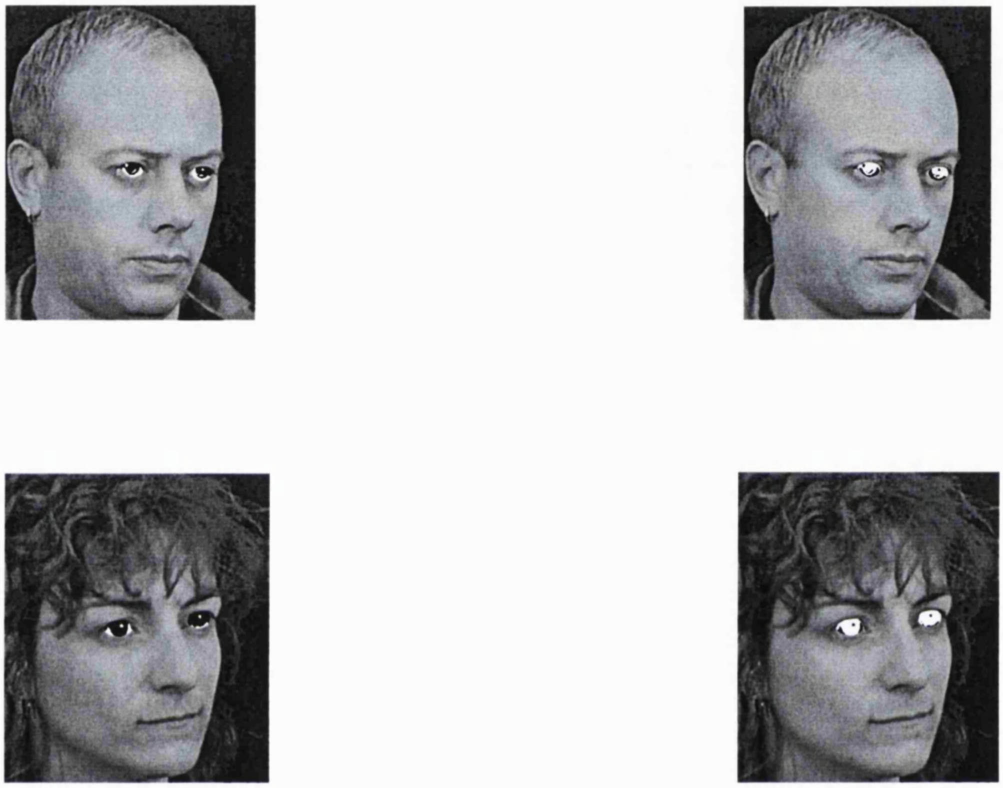

Fig. A1.2. Examples of head right/eyes right stimuli used in Experiment 3. The eyes have positive polarity on the left, and negative on the right. Different people (i.e. both male and female) were photographed for all conditions.

Appendix 2

UNILATERAL LEFT VISUAL FIELD EYE ONLY

EYE DEVIATION	*% RESPONSES*		
	% LEFT	% STRAIGHT	% RIGHT
TEMPORAL	**85.2**	11.1	3.7
STRAIGHT	55.6	**37**	7.4
NASAL	51.9	40.7	**7.4**

Tab. A2.1. Table of mean percentages of SD's responses for all the unilateral left stimulus conditions. In bold are the percentages of correct responses. Note that SD was not very accurate at reporting the direction of the unilateral left eye, except when it deviated temporally (i.e. leftwards). See also Fig. A2.1.

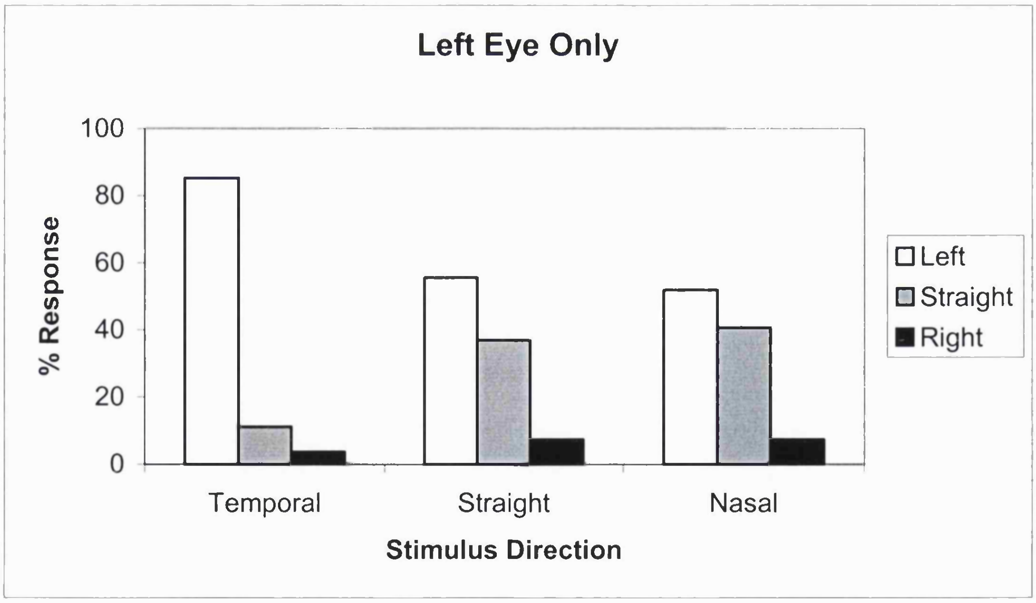

Fig. A2.1. SD's performance in the gaze discrimination task plotted as a function of response percentages (i.e. "left", "straight" and "right"), for the left unilateral eye.

UNILATERAL RIGHT VISUAL FIELD EYE ONLY

EYE DEVIATION	*% RESPONSES*		
	% LEFT	% STRAIGHT	% RIGHT
NASAL	**96.4**	0	3.6
STRAIGHT	7.1	**39.3**	53.6
TEMPORAL	7.1	32.1	**60.7**

Tab. A2.2. Table of means percentages of SD's responses for all the unilateral right stimulus conditions. In bold are the percentages of correct responses. Note that SD was not very accurate at reporting the direction of the unilateral right eye, except when deviating nasally (i.e. leftwards). See also Fig. A2.2.

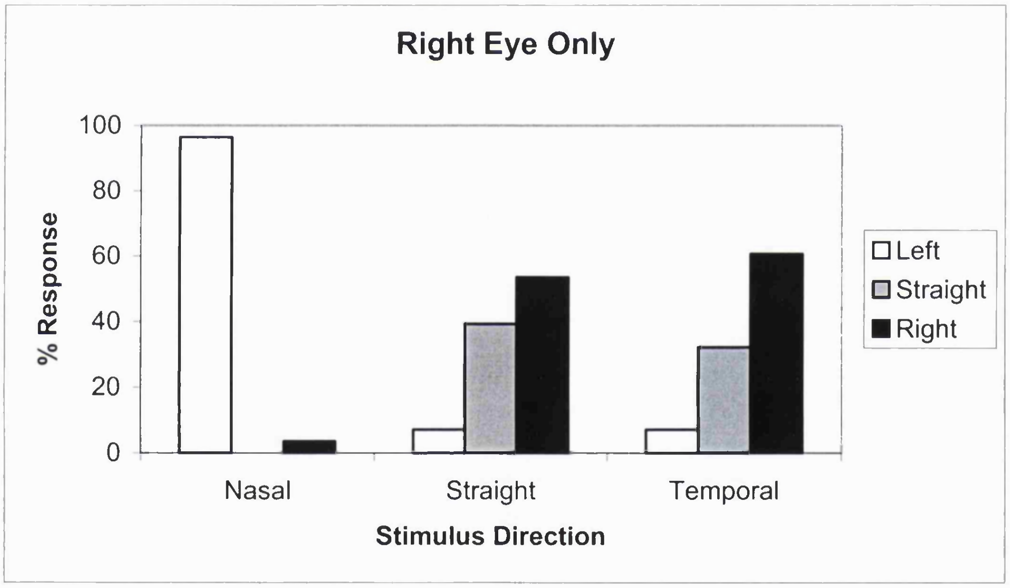

Fig. A2.2. SD's performance in the gaze discrimination task plotted as a function of response percentages (i.e. "left", "straight" and "right"), for the right unilateral eye.

BILATERAL STIMULUS CONDITIONS

DEVIATED EYE	*EYE DEVIATION*	*% RESPONSES*		
		% LEFT	% STRAIGHT	% RIGHT
LVF	TEMPORAL	9.5	81.0	9.5
	NASAL	2.4	92.9	4.8
RVF	TEMPORAL	4.8	81.0	14.3
	NASAL	80.5	14.6	4.9
BOTH STRAIGHT	BOTH STRAIGHT	2.4	92.9	4.8

Tab. A2.3. Table of means percentages of SD's responses for all the bilateral stimulus conditions. See also Fig. A2.4.

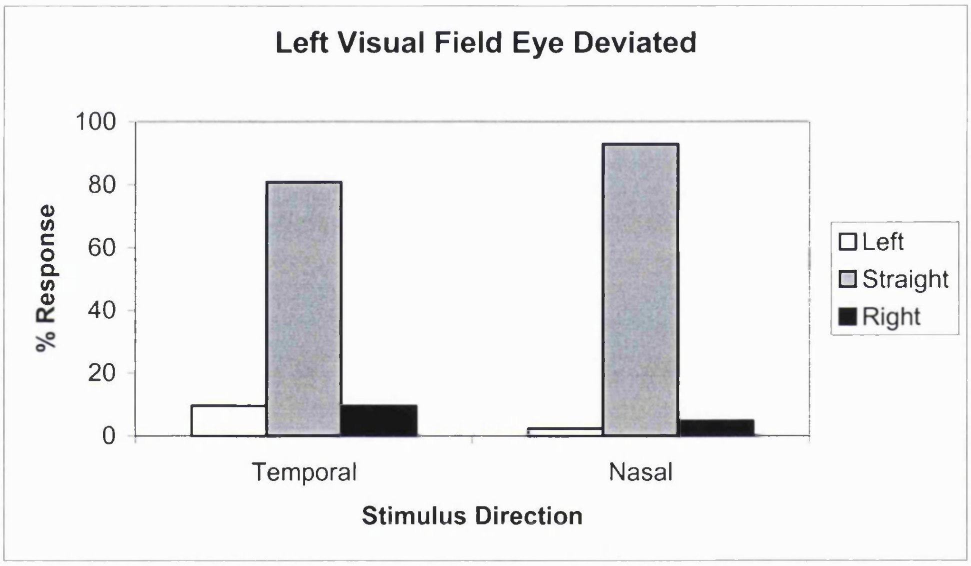

Fig. A2.4. SD's performance in the gaze discrimination task plotted as a function of response percentages (i.e. "left", "straight" and "right"), for bilateral incongruent eye conditions with LVF eye deviated. Note that the percentage of "STRAIGHT" responses is high, but decreases slightly when the LVF eye is deviated temporally compared to when both eyes are straight (81% vs. 92.9%, respectively, see in Tab. A2.3). Although this trend was not significant (X^2=2,08; p>.1, df=2), it suggests that adding a straight versus temporally deviated LVF eye (though often extinguished) affects gaze judgements.

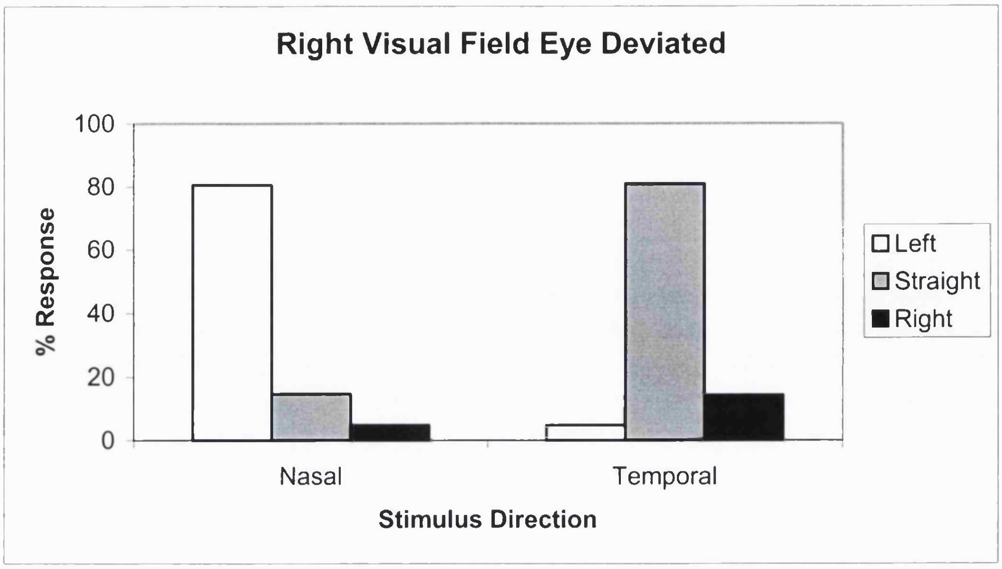

Fig. A2.5. SD's performance in the gaze discrimination task plotted as a function of response percentages (i.e. "left", "straight" and "right"), for bilateral incongruent eye conditions with RVF eye deviated. Note that the percentage of "STRAIGHT" responses is high, except when the RVF eye is deviated nasally (i.e. leftwards). This shows that, unlike normals (see Chapter 6), SD was strongly influenced by the RVF eye in incongruent bilateral displays, especially when it deviated leftward. There was no evidence that the LVF eye influenced her more than the RVF eye, for incongruent bilateral displays (compare Figs. A2.4 and A2.5), unlike normals (see Chapter 6).